PHD

Using Personalised Multidimensional Visual Feedback to Support a Change in Physical Activity Behaviour and Improve Health

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USING PERSONALISED MULTIDIMENSIONAL VISUAL FEEDBACK TO SUPPORT A CHANGE IN PHYSICAL ACTIVITY BEHAVIOUR AND IMPROVE HEALTH

Max James Western

A thesis submitted for the degree of Doctor of Philosophy

University of Bath
Department for Health

September 2016

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Signed on behalf of the Faculty/School of ..............................
I would like to dedicate this thesis to my wife Naomi, whose love and support has been instrumental in keeping me cheerful and sane throughout the PhD process, and our little bear, Ramona, whose imminent arrival could not have been more timely in giving me the final push towards completion. As one chapter closes and another one begins, may this be the gateway to a long and happy life for our family.

Adventures are waiting! 😊
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AUTHORS ORIGINAL CONTRIBUTION

The work presented in this thesis was undertaken as part of the MRC NPRI funded Mi-PACT project. Mi-PACT is a collaborative project to which the candidate made a significant contribution as part of their PhD research. Throughout the phases of design and delivery of Mi-PACT the candidate worked in close proximity with their primary and third supervisors, Principal Investigator Professor Dylan Thompson (University of Bath) and postdoctoral researcher Dr Oliver Peacock (University of Bath). Other co-applicants on the MiPACT project include Professor Martyn Standage (University of Bath), Dr Afroditi Stathi (University of Bath), Professor Alan Batterham (Teeside University) Professor Alan Tapp (University of the West of England), and Dr Paul Bennett (University of Bath). As such it is important to acknowledge that aspects of the empirical work described within the pages of this thesis were conducted in collaboration with the wider research team:

Chapter 3 – Validation study of multisensor physical activity monitors

The principle investigator, postdoctoral researcher and the candidate undertook conceptualisation and selection of methods. The candidate was present at every data collection session, 50% leading in isolation and 50% with support from postdoctoral researcher. All data handling from physical activity monitors, statistical analysis presented in chapter 3 represents the candidate’s own original work.

Chapter 4 – Graphic design of multidimensional feedback

The candidate was present at all conversations with the Graphic Design team and was a member of the core Concept team who discussed and suggested revisions for the visual feedback graphics. The candidate was also responsible for creating and refining working usable format using Microsoft software.

Chapter 5 – Patient preferences of personalised multidimensional feedback

The candidate took a lead role on the design and data collection for this study. The candidate developed the topic guides, recruited and coordinated meetings with patients and healthcare professionals and conducted and analysed all semi-
structured interviews. The written chapter reflects the contents of a published article (see publications list on page vi) for which the candidate was lead author.

**Chapter 6 – Cognitive-affective response to personalised feedback**

This chapter presents a second analysis of the data captured in chapter 5 which was principally analysed and interpreted by the candidate.

**Chapter 7 – Mi-PACT randomised controlled trial**

Wider research team and co-applicants made the general conceptualisation of the Mi-PACT study and its design. More specific details concerning the final delivered project were largely born out of discussions between the principal investigator the postdoctoral researcher (trial manager) and the candidate. Examples of these finer details include refinement of visual feedback and interactive features (in collaboration with commercial Information Communication Company) based on previous study, intervention design such as the number and timing of trainer sessions and the selection of assessment materials. The candidate also played a large role in the development of a 90-page protocol document and created the first draft of a training manual used to guide health trainers in delivering Mi-PACT to patients. The candidate was responsible for all DEXA scans and the retrieval and processing of physical activity monitors for the primary outcome data and conducted focus groups (not reported) and end of intervention feedback. A research nurse primarily collected other outcomes and patient screening. The methods section presented in Chapter 7 emulates a published protocol paper (see publications list on page vi) for which the candidate was a co-author. All statistical analysis and the interpretation of results represent the candidate’s own original work.

**Chapter 8 – Instant feedback randomised controlled trial**

The candidate took a lead role on the conceptualisation and implementation of this study and was responsible for all trial-related activity including ethics applications, recruitment of participants, data collection, intervention delivery, conducting semi-structured interviews and all quantitative and qualitative data analysis. The interpretation of results represent the candidate’s own original work.
PUBLICATIONS

JOURNAL ARTICLES


CONFERENCE PAPERS


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ABSTRACT

Health-harnessing physical activity has been traditionally been conceptualised in terms of moderate to vigorous intensity with a recommendation to undertake 150 minutes per week of moderate to vigorous activity forms the basis for many interventions or promotion efforts. Recent advancements in the measurement of physical activity however reveals that other dimensions can incur profound health benefits such as an increase in energy expenditure or a reduction in sedentary time. Excitingly, we now have the technology to capture and present personalised visual feedback across the multiple physical activity dimensions, which could theoretically help individuals change their behaviour by providing them with more options or solutions that can be aligned to the individual’s needs, barriers and preferences. The aim of this thesis was to develop a visual presentation of multidimensional physical activity behaviour and evaluate its efficacy as a tool to support behaviour change. Firstly, a laboratory validation concluded that the BodyMedia Mini was a valid and reliable option for capturing a presenting multidimensional physical activity. Secondly, a number of visual representations were developed from minute-by-minute physical activity data captured by this monitor. Step three was to pilot these graphical depictions to group of patients and health professionals during one-to-one, semi-structured interviews who provided evidence that the design and message was clear, informative and motivating. Secondary analysis of this data suggested this was particularly true of individuals with a low physical activity status for which the personalised multidimensional feedback served to evoke strong and persuasive cognitive and emotional responses. The final steps were to test the efficacy of this approach in two multicomponent, exploratory randomised controlled trials. Trial one was conducted on patients identified as at-risk (n=204) and showed that trainer led self-monitoring of multidimensional feedback had a minimal impact on behaviour. Trial two was conducted on individuals declaring themselves as inactive (n=51) and showed that using multidimensional feedback along with real-time self-monitoring appears an effective strategy for behaviour change.
The focus of this thesis is physical activity behaviour. In its simplest form, physical activity describes any bodily movement caused by the musculoskeletal system that exerts energy expenditure above that expended at rest (Caspersen et al., 1985). Energy expenditure is typically measured in kilocalories (Kcal) and comprises basal metabolic rate, i.e. the amount of kilocalories used by bodily systems; diet induced thermogenesis, i.e. the amount of energy used to digest and utilise food in the body; and physical activity thermogenesis (Westerterp, 2004). Although basal metabolic rate and diet induced thermogenesis can be subtly modified by factors such as body composition (Cunningham, 1980) and the volume and components of one’s diet (Westerterp et al., 1999), physical activity is the most adaptable constituent of energy expenditure (Rising et al., 1994). It is important to distinguish the concept of physical activity from that of ‘exercise’, which describes the premeditated and structured set of actions undertaken to achieve a goal of improved fitness or skill, as this is only one sub-domain of physical activity behaviour i.e. leisure (Caspersen et al., 1985). In fact with the exception of sleep there are a number of domains in which people can be physically active over the course of a day such as those propagated by the ‘SLOTH’ model of sleep, leisure, occupational, transport and housework (Pratt et al., 2004). Leisure physical activity also includes sport participation and play, but even combined only typically represent a fraction of ones total physical activity (Ng and Popkin, 2012). Activities undertaken at work, household chores such as cleaning and cooking, active travel be it walking or cycling and even passive movements brought on by reactive interactions with the environment are also constituents of ones total physical activity (Gabriel et al., 2012). Thus, physical activity is not only highly strenuous exertion but an encompassment of all behavioural actions undertaken by an individual be it light-, moderate- or vigorous-intensity in nature (Powell et al., 2011). It is therefore important to consider that within every domain an individual can be physically active they can also be physically inactive, otherwise known as sedentary behaviour (Owen et al., 2010).
An understanding of the health benefits of physical activity is not new to science and medicine with earliest reported prescriptions of exercise to reduce the burden of disease dating back nearly two millennia (Tipton, 2014). For our earliest and most primitive ancestors physical activity served a fundamental purpose in that it enabled them to hunt, gather, escape danger and ultimately interact with and survive their environment (Eaton et al., 1988). The evolution of humans has over time been sculpted by necessity-driven functional activity such as farming, nurturing, forging tools and shelters and fighting (Cordain et al., 1998). Completing these tasks required persistent practice and likely contributed to the development of the modern man and woman. Since the industrial revolution of the 1800’s, where technological advancements continually supplant the need for manual housework, physical occupations and even active social leisure time, the requirement to undergo constant physical activity has diminished and nowadays it is only a relatively select few motivated individuals who lead highly active lifestyles (Hallal et al., 2012a). This disparity between human behaviour and their genetic makeup creates a major problem in that the biochemistry and physiology of the human body is designed to optimally function in conditions where the body is regularly undergoing daily physical activity (Eaton and Eaton ii, 2003).

It is thought that at least a third of all adults are not reaching the levels of physical activity required to prevent the onset of major non-communicable diseases and avoid premature death (Kohl et al., 2012). Recent estimates suggest that low levels of physical inactivity is thought to be directly responsible for 3.2 million deaths per year worldwide and indirectly, along with other important modifiable lifestyle factors such as tobacco use and an unhealthy diet, associated with many non-communicable physiological and psychological diseases that account for 60% of deaths worldwide (Lee et al., 2012; Waxman, 2005; Lim et al., 2012). For example, low physical activity is thought to be a fundamental factor in cardiovascular disease, diabetes mellitus, cancer and depression (Warburton et al., 2006). A synthesis of existing evidence suggests that comparisons between individuals of high and low physical activity
levels indicate a reduction in the risk of 30% for all-cause mortality, 20-35% for cardiovascular disease, 30-40% for type two diabetes and 20-30% for breast and colon cancer (Department of Health, 2011). Moreover, the link between physical activity and these conditions is graded, meaning that those with the highest activity levels have the lowest risk of contracting these conditions (Lee and Skerrett, 2001; Powell et al., 2011). There are a number of mechanisms by which increased physical activity levels can help prevent non-communicable diseases including an improvement in body composition by reducing visceral adiposity and overall body mass, greater lipid profile for instance reductions in triglyceride and total cholesterol levels, reduced blood pressure, and improved regulation of blood glucose levels and insulin sensitivity (Booth et al., 2008; Warburton et al., 2001). In the UK alone the health burden of low physical activity levels is thought to incur a monetary cost of £1billion for direct healthcare and could have a wider societal cost of up to £6.5billion (Scarborough et al., 2011). Consequently physical inactivity is presently considered to be amongst the greatest public health problems of our time, and finding ways to increase the activity levels of the population remains a high priority (Blair, 2009; Trost et al., 2014).

It is clear that innovative strategies are needed to help individuals combat an environment that continues to thwart active lifestyles. Attempts to improve physical activity have been met with limited success and typically small improvements are not maintained for very long (Orrow et al., 2012). New cost-effective approaches that stimulate meaningful long-term changes in physical activity are required. Technology is featuring evermore prominently in many aspects of one’s occupational, recreational and social life and whilst this may be a fundamental cultural antecedent to the inactivity pandemic it may also help present a promising solution (Pratt et al., 2012). In the past 5-10 years, there has been an explosion in the availability of technologies for the general public to monitor and receive feedback on their physical activity. As these devices become more advanced, more affordable, and indeed more popular there is a unique opportunity to use them in public health (Piwek et al., 2016; Thompson, 2015; Chiauzzi et al., 2015). Practically speaking, wearable technology has...
the potential to reach many individuals who are most inactive or at risk, particularly when considering trends in computer and smartphone ownership in the UK, which extends to even the most vulnerable sections of society (Ofcom, 2015). Thus, we are entering an era where the capture of free-living physical activity energy expenditure will become more-and-more accessible and commonplace. Nevertheless, in reality physical activity monitors are generally marketed and used by motivated, affluent, healthy young adults who already have a handle of their behaviour and are focused on tracking specific exercises or training for sports (Patel et al., 2015).

The successful application of technology-derived feedback for promoting a change in behaviour in inactive individuals relies on a clear, persuasive message that encapsulates the important health-harnessing components of physical activity (Patel et al., 2015). One strategy that has seldom been considered for the development of current technological applications or even interventions is to anchor the feedback a user receives to evidence-informed public health recommendations (Knight et al., 2015). To date, physical activity has been promoted and marketed in unidimensional terms, often encapsulated in a single message (e.g., five x 30 min of moderate intensity activity per week) (Department of Health, 2011). Physical activity is however a much more heterogeneous behaviour than this with various dimensions known to have clear health benefits. Early physical activity recommendations were (inevitably) conceptually narrow given the evidence base and technological options available for data capture but this can weaken the message about physical activity (Thompson et al., 2009). For weight loss or maintenance, physical activity energy expenditure is the most important consideration and the nature of the physical activity is not important (Levine, 2004). However, in addition to thermogenesis, certain forms of physical activity generate independent benefits. For example, short bouts of intense exercise generate significant metabolic gains without a major impact on total energy expenditure (Burgomaster et al., 2008; Rakobowchuk et al., 2008). Bed rest studies show that brief bouts of daily activity have the capacity to prevent the unravelling of metabolic homeostasis to sustained inactivity (Lee et al., 2010). Epidemiological studies show that gaps in activity and sedentary time are independently important
(Healy et al., 2008; Helmerhorst et al., 2009). In summary, there is not just one acceptable physical activity strategy and it is unlikely that there will be a single outcome measure that captures all information. Instead, one can represent or capture an integrated picture and offer multiple physical activity options so that information on physical activity can be used to develop personalised strategies that befit an individual's specific personal, social and environmental demands.

To this end the overarching research question for the present thesis is to develop and determine the efficacy of using technology-enabled multidimensional physical activity feedback for an improvement in physical activity behaviour and health.
Chapter 2 REVIEW OF LITERATURE

The aim of this review is to introduce the notion that multidimensional physical activity feedback might be a useful tool for helping people change their physical activity behaviour. Firstly, the evidence linking physical activity behaviour and health will be explored with a particular focus on public health recommendations around moderate to vigorous physical activity and the idea that other classifications of physical activity may also benefit health. Secondly, there will be a brief overview of current assessment methods for physical activity to highlight the most appropriate and useful way to accurately capture the multiple health-harnessing dimensions. The third section of this review will discuss what is currently known about feedback as a strategy can support behaviour and other techniques and setting might be required to support its application. The final section will then make a case for why personalised multidimensional physical activity feedback could be a useful strategy for supporting individuals to increase their activity levels in accordance with psychosocial mediators purported by behaviour change theory.

2.1 PHYSICAL ACTIVITY IS MULTIDIMENSIONAL

Physical activity is thought to be the fourth leading risk factor for premature mortality worldwide (WHO, 2010). Indeed, there is now compelling evidence that physical activity can prevent the onset of a number of chronic diseases including cardiovascular disease, type 2 diabetes, colon and breast cancer, osteoporosis and arthritis, depression and anxiety and premature death (Booth et al., 2008; Booth et al., 2012; Warburton et al., 2006). With this in mind, physical activity is considered an integral preventive strategy to eliminate the burden of non-communicable chronic diseases (Sallis, 2009; Trost et al., 2014). Pioneered by the work of Jeremy Morris in the 1950’s who found physically active workers had significantly fewer instances of chronic heart disease compared to sedentary contemporaries (Morris et al., 1953; Morris and Crawford, 1958), countless epidemiological and physiological studies have attempted to establish the links between physical activity and a number
of increasingly prevalent non-communicable chronic diseases such as cardiovascular disease and type two diabetes (Epstein, 1965; Taylor et al., 1962; Paffenbarger et al., 1978; Efroelicher, 1987; Helmrich et al., 1991; Lee and Paffenbarger, 2000; LaMonte et al., 2005; Ford and Caspersen, 2012). As the number of studies exploring the relationship between physical activity and health increases so too does our understanding of the quantities required to reduce the burden of disease (Powell et al., 2011). Given the rising pandemic of physical inactivity (Moore et al., 2012; Kohl et al., 2012) public health institutes have produced and disseminate recommendations that aim to guide people towards the minimum healthful levels of physical activity (Blair et al., 2004).

2.1.1 Confusion in Traditional One-Size-Fits-All Physical Activity Recommendations

To combat the prevalence of inactivity, the first of these guidelines was produced in 1995 by the USA’s Centre for Disease Control and Prevention and the American College of Sports Medicine and stated that “every adult should aim to undertake a minimum of 30 minutes of moderate intensity activity on most, if not every, day of the week” (Pate et al., 1995). Twenty years later these recommendations were updated by the American College of Sports Medicine and American Heart Association to include an option of vigorous-intensity activity such that individuals were advised to undertake at least 30-minutes of moderate-intensity aerobic activity on 5 days per week, or 20-minutes of vigorous intensity activity on 3 a week (Haskell et al., 2007). Most recently, the US Department of Health and Human Services (DHHS, 2008), and subsequently World Health Organisation (WHO, 2010) and the UK’s British Association of Sports and Exercise Sciences (O’Donovan et al., 2010) and Chief Medical Officer (Department of Health, 2011) have presented guidelines that suggesting 150 minutes of moderate intensity activity or 75 minutes of vigorous-intensity activity or an equivalent combination of both should be achieved. Almost ubiquitous throughout these evolved guidelines is the need to accumulate the recommended minimum activity time in sustained bouts of at least 10-minute in duration. Additional guidance within the most recent recommendations advises on
the need to do muscle strengthening exercise on 2 days per week for functional benefits such as mobility and bone health (Department of Health, 2011).

Condensing physical activity guidelines to a simple one-size-fits all message clearly has its benefits. The recommendations in this format are, in theory, very straightforward to comprehend for individuals who want to know how much physical activity they should be doing to improve their health. A simple, blanket recommendation also makes for easier dissemination as there is no requirement to adapt ones advice to a given population or setting, with the notable exception of children and older adults (Department for Health, 2011). Accordingly, these guidelines form the basis for numerous promotion efforts in clinical settings such as the NHS (NHS Choices, 2015) and from researchers or practitioners designing public health interventions. Careful consideration must however go into which particular recommendation is selected for use in trials as even subtle differences in the definition of what constitutes healthful moderate to vigorous physical activity such as the frequency, intensity threshold, duration or need for sustained bouts can dramatically distort the message an individual receives about their behaviour as is illustrated below (Thompson et al., 2009). This is particular important in an era where the measurement of physical activity is becoming less reliant on self-reported recall and more objective and accurate and sophisticate devices are being used to assess the appropriateness of physical activity behaviour (Freedson et al., 2013)

In principle therefore it should be easy for individuals involved in such to use technology to track their activity levels and answer what appears a simple question “Am I doing enough of the right kind of physical activity for health?”. Yet, research using sophisticated measurement instruments shows that providing an unambiguous answer to this question is far from straightforward (Scheers et al., 2013a; Thompson and Batterham, 2013). Thompson et al. (2009), using a validated physical activity monitor, sought to determine whether a given individual met the recommended levels of physical activity so they could provide a clear message about the appropriateness of their behaviour from a health perspective. In this study the
Authors looked at several variations in guidelines from different public health agencies as described above and found that up to 90% of men could be described as either active or insufficiently active based on the same physical activity energy expenditure data (Figure 2-a). This means that, in response to the simple question, nine out of every ten people would get an answer that was something like ‘yes’, ‘no’, or ‘it depends’. The discrepancy is highlighted in Figure 2-a is based on a post hoc analysis of the same raw data and thus this disagreement and inconsistency is unrelated to errors at the data capture stage. It is also not due to an unrepresentative study sample – the observed group of middle-aged men had an energy expenditure from physical activity which was similar to the median reported in the UK (SACN, 2011). Instead, it appears that the required dose of physical activity and/or the way in which it is expressed has a powerful effect on apparent physical activity status.

**Figure 2-a. Examples of discrepancies between variants of a moderate to vigorous physical activity guideline within a group of 100 middle aged men.** The bars represent the proportion of individuals who met (black) a given physical activity recommendation as set by the American College of Sports Medicine (ACSM), Centre for Disease Control (CDC), American Heart Association (AHA), UK Department of Health (DOH), Institute of Medicine (IOM) and US Department of Health and Human Services (USDHHS).
2.1.2 HETEROGENEOUS NATURE OF PHYSICAL ACTIVITY

It is therefore easy to see that with multiple physical activity recommendations stemming from several reputable health organisations how understanding physical activity can be confusing to researchers, practitioners and the public alike. Another problem with a focus on traditional approach however is that it is conceptually narrow in that it fails to capture other important aspects of physical activity behaviour that have been shown to be important for health (Esliger and Tremblay, 2007; Thompson et al., 2009). The traditional focus on moderate-to-vigorous-intensity was inevitable given the level of evidence and historic methods of assessing physical activity, namely associations between risk of major non-communicable disease or mortality and individuals grouped by self-reported activity levels (Powell et al., 2011). Recalling structured moderate to vigorous bouts of leisure time activity is much easier than accurately gauging and reporting on sporadic light to moderate habitual daily activities (Shephard, 2003; Prince et al., 2008).

However, there are clearly other ways that physical activity can impact health. For example the moderate to vigorous physical activity recommendations are not necessarily sufficient to prevent unhealthy weight gain (Blair, 2004). With this in mind additional guidelines have been set to combat the rising obesity epidemic that anchor to energy expenditure in the context of typical nutritional habits rather than activity intensity (Brooks et al., 2004; FAO, 2004; Saris et al., 2003). To account for discrepancies in individual’s sex, weight and height guidelines have tended to focus on physical activity level (PAL) which expresses ones total energy expenditure in multiples of their basal metabolic rate with a typical guideline of >1.6. Figure 2-b shows normalised physical activity energy expenditure (PAL) and a recommendation that uses time engaged in moderate to vigorous intensity physical activity. As demonstrated in Figure 2-b, some people can accumulate considerable energy expenditure through physical activity without also meeting the time/intensity-based recommendation. Other individuals on the other hand can accumulate the required amount of moderate to vigorous intensity activity but have a very low PAL.
Figure 2-b. The relationship between participants from a sample of 100 men who hit a guideline on moderate to vigorous physical activity and physical activity level (PAL) This figure displays a rank order of individuals by physical activity level (PAL) with the IOM guideline of 1.6 indicated by the horizontal line. The shaded bars represent the individuals within the sample who also met the ACSM/AHA recommendation for moderate activity on 5 days and/or vigorous activity on 3 days. Reproduced with permission (Thompson et al., 2009).

That is not to say that the evidence around moderate-to-vigorous physical is not convincing, particularly for reducing the burden and risk factors associated with the most prevalent non-communicable diseases including cardiovascular disease and type two diabetes (Alwan et al., 2010; Lim et al., 2012; Waxman, 2005; Lee and Paffenbarger, 2000). Indeed, the evidence that helped the various aforementioned consortiums arrive at their respective guidelines arose from expert panels synthesising a good body of epidemiological evidence and continue to be supported by large prospective cohort studies (e.g. Pate et al., 1995; Haskell et al., 2007; Department for Health, 2011). In their recent analysis of 204,542 45-75 year old adults who were followed for of 6.25(1.23) years, Gebel et al., (2015) found that compared to those who reported zero minutes, each additional 150 minutes per week of moderate-to-vigorous activity reduced the chance of all-cause mortality by approximately 10%, with the most pronounced impact occurring in the first 150 minutes (adjusted hazard ratio of 0.66 (95% CI, 0.61-0.71)). Interestingly, the authors
also found that in active individuals, the proportion of vigorous activity is potentially important, where compared to those who reported no vigorous activity, people reporting 0-30% or more than 30% of their activity of vigorous saw reduction in mortality rate of 9% and 13% (Gebel et al., 2015). Acute human and animal models have supported these findings in showing that strenuous forms of physical activity or exercise can lead to adaptive biological responses in cardiorespiratory fitness and metabolic control (Booth et al., 2008; Neufer et al., 2015). Exercise capacity, in particular, has been shown to provide substantial reductions in cardiovascular and all-cause mortality for both men and women and is only likely to be improved by continuous bouts of more strenuous activity (Myers et al., 2002; Gulati et al., 2003). Equally, objective monitoring methods which measure physical activity in small epochs have started to deter the view that sustained bouts of activity are essential for reaping these health benefits (Glazer et al., 2013; Murphy et al., 2009; Macfarlane et al., 2006).

For other risk factors such as increased adiposity and weight, moderate-to-vigorous-intensity physical activity isn’t the only aspect that can incur important health benefits. As previously mentioned one key dimension is overall physical activity energy expenditure (PAL) which is naturally the most important consideration for weight loss or maintenance (Levine et al., 2006; Levine, 2007). Albeit limited due to the complexities in accurately measuring energy expenditure (see section 2.2) certain epidemiological studies have also provided evidence for the role of energy expenditure in reducing mortality rate regardless of whether it is achieved by strenuous activity or not. In a 7-year follow-study of 6,620 females, Weller and Corey (1998) demonstrated that adults with the highest energy expenditure has reduced risk of 29% compared to the lowest physical activity and almost 50% reduction in cardiovascular related deaths, with non-leisure time energy expenditure contributing 82% of the total physical activity. Similar findings were observed in a prospective cohort of 67,143 women in the Shanghai Women’s Health Study followed for an average of 5.7 years where compared to those with low (less than 10 MET hours) nonexercise physical activity those who reported relatively medium (10-13.6 MET
hours) or high (13.7-18 MET hours) saw a respective 19% and 33% reduced risk of premature mortality (Matthews et al., 2007). It should be noted that these surveys were conducted in females only and relied on self-reported data for assessing non-leisure time or nonexercise ‘energy expenditure’, which is potentially more prone to systematic recall bias than the recall of more structured activities (Adams et al., 2005). Further epidemiological evidence should look to use more precise measures of energy expenditure and overall physical activity level, independent of reported levels of moderate for clarifying the impact it has on longevity in a more diverse sample of adults (Manini et al., 2006).

One dimension of physical activity behaviour that has seen an surge of evidence in recent years that distinguish its protective properties from moderate-to-vigorous activity sedentary time (Healy et al., 2008; Owen et al., 2010; Hamilton et al., 2007). Even when controlling for the amount of moderate-to-vigorous physical activity one undertakes reducing sedentary time can lead to profound reductions in the risk for overall mortality (Katzmarzyk et al., 2009; Koster et al., 2012; Matthews et al., 2012). For example, in a sample of 240,819 US adults from the NIH-AARP study tracked over 8.5 years sedentary behaviours found that in adults who reported high levels of moderate-to-vigorous-intensity activity, 7 hours of television viewing was associated with an increased risk of all-cause and cardiovascular mortality with hazard ratios of 1.47 and 2.0 respectively compared to adults who spent less than 1 hour watching television (Matthews et al., 2012). Katzmarzyk et al., (2009) surveyed 17,013 adults over 12 years and found a dose-response association between categories of the proportion of time spent sitting (almost none-, a quarter-, half-, three quarters- and almost all-of the time) and all-cause mortality with respective hazard ratios of 1.0, 1.11, 1.36 and 1.54 when adjusted for leisure time physical activity and other potential confounders. A similar pattern is observed when using an objective rather than self-report method for assessing sedentary time and physical activity as evidenced by Koster et al., (2012) in their study of adults aged 50 years older from the NHANES cohort. Over a 2.8 year follow up adults who spent over 70% of their day sedentary had a five times greater risk of death compared to their least sedentary
counter parts, again independently of how much moderate to vigorous physical activity they undertook. Other epidemiological and physiological evidence has also found independent associations between sedentary time and risks of metabolic syndrome (Bankoski et al., 2011; Kim et al., 2013; Duvivier et al., 2013), diabetes (Wilmot et al., 2012; Henson et al., 2013), and cardiovascular disease (Ford and Caspersen, 2012; Chomistek et al., 2013).

2.1.3 IMPLICATIONS OF MULTIDIMENSIONAL PHYSICAL ACTIVITY PROFILING

There is therefore convincing that certain classifications of physical activity behaviour can have independent association on health. To explore the extent of this heterogeneity within a given person, Thompson and Batterham (2013) showed that individuals who ostensibly appear similar for one physical activity measure (e.g., time engaged in moderate intensity physical activity) can score very differently for other metrics (e.g., overall physical activity energy expenditure) with only a very few people score consistently across all physical activity dimensions. It is thus quite reasonable to carve up physical activity energy expenditure in different ways depending on a given perspective or paradigm. However, it is also reasonable to anticipate that this could impact upon the message that an individual receives. To illustrate this point data from two 24-hour physical activity traces is presented in Figure 2-c and the activity that would count towards these multiple dimensions of physical activity behaviour. In this example, both participants have a similar physical activity level, Bill undertakes a lot more moderate and vigorous activity than Ben, whereas Ben is much less sedentary than Bill. Clearly, if an individual is provided with only one physical activity score then they would form an incomplete or inaccurate picture of their overall physical activity. It is unlikely that there is a single outcome or descriptor that reflects all the relevant information about physical activity and therefore to avoid misclassification need to capture physical activity ‘profiles’ across the physiologically important dimensions.
Figure 2-c. Physical activity energy expenditure analysed and dissected according to a few selected potentially important physical activity characteristics and dimensions.

In this example, two individuals have similar scores for overall physical activity energy expenditure but they have accumulated their physical activity in very different ways.

One of the most useful upshots of providing individuals with a multidimensional approach to physical activity is that it provides a much more comprehensive and holistic representation of this important health behaviour which could help avoid misclassification of physical activity behaviour (Thompson and Batterham, 2013).
Part of the problem is that people sometimes focus on just certain physical activity behaviours without taking into account other dimensions. For example, many forms of structured physical activity have only a small thermogenic effect so that total energy expenditure is minimally affected by participation (Turner et al., 2010). This might not be so important for some specific metabolic and health benefits – but it is important for the individual to know why they are not losing (or possibly even gaining) weight even if they are meeting guidelines on moderate to vigorous physical activity; and weight loss will be critically important for some health outcomes and personal goals (Wing et al., 2011). Rather than receiving a single physical activity score, the provision of a multidimensional profile will demonstrate how some people are failing to make use of any of multiple ways in which physical activity can impact upon health. If an individual in this situation chooses to undertake moderate to vigorous intensity physical activity then this should be applauded – but it might have only a modest impact on sedentary time or overall energy expenditure. Similarly, if they choose to reduce their sedentary time then this is unlikely to impact upon some of the other dimensions. Clearly, the capture and provision of feedback across these physical activity dimensions will be more useful and revealing than the reliance on a single outcome or continuum.

Physical activity is therefore a much more interesting and complex behaviour than the simple message of ‘high versus low’ communicated in traditional public health guidelines (Gabriel et al., 2012). What this novel approach to physical activity allows however is an opportunity to better inform individuals of the appropriateness of their physical activity behaviour which may in turn help motivate them to increase their levels and reduce their risk of chronic disease (as will be discussed in Sections 2.3 and 2.4). The success of any efforts towards a change in behaviour will ultimately depend on the net-change across these independent dimensions. In the case of energy expenditure, the introduction of ‘new’ physical activity will (inevitably) substitute for some other activity (probably of a lower intensity) so that the net effect is smaller than the effect predicted from the novel activity alone (Turner et al., 2010; Thompson et al., 2014). There is also the possibility that some people compensate for an
increase in one type of physical activity behaviour by decreasing another (Goran and Poehlman, 1992). These factors can mean that in spite of the introduction of a novel behaviour there is no net effect on total energy expenditure. Of course, providing a clear multidimensional picture will help people to understand how even a substantial change in one physical activity dimension might not have much of an effect on other dimensions and allows an understanding of what has been realised, what is achievable and in what timescale. Before this novel understanding can be successfully deployed as a strategy it is important to discuss the most appropriate way to capture all the health harnessing components of physical activity so that this message can be suitably communicated to individuals in need of a behaviour change.

### 2.2 Multidimensional Physical Activity Assessment

To capture and present a multidimensional physical activity profile a sophisticated measuring tool is required. Measuring physical activity is pivotal to our understanding of its protective effects, the specific dose, mode, intensity and frequency needed to reap these benefits and for enabling individuals to assess whether or not they are doing enough (Strath et al., 2013). To fully and objectively capture all of the biologically important aspects of physical activity behaviour the most useful outcome is energy expenditure per unit of time (LaPorte et al., 1985). From this information the relative intensity (sedentary, light, moderate or vigorous) of any given activity or period of time can be calculated (Ainsworth et al., 2011). There are several key elements to consider when evaluating the appropriateness of physical activity measurement. The first, and perhaps the most important feature for any monitoring method are the accuracy and precision of its measurement (Butte et al., 2012; Kelly et al., 2016). Accuracy (or validity) refers to how true a measure of what is really happening it is whereas precision, or reliability, refers to how consistent that measure is at accurately monitoring the component of interest (Bassett Jr, 2000). Accuracy, in the context of physical activity assessment, would refer to the appropriate measurement of energy expenditure at a given moment in time while
precision would describe whether the estimated energy expenditure of a given activity on one day would be scored the same on another. It is important to note that the constructs of accuracy and precision are not synonymous and should not be automatically assumed as a measure can be reliable but not valid and vice versa (Bassett et al., 2012). For example, consistently measuring an incorrect magnitude of energy expenditure may be appropriate for assessing relative changes but could have implications on an individual’s assessment of their own energy balance and lead to misguided appraisal of their attainment of a given physical activity recommendation (Ainsworth et al., 2015; Strath et al., 2013).

A second consideration that is particularly pertinent to the measurement of multidimensional physical activity is the qualitative resolution of the measurement (Trost and O'Neil, 2014). Physical activity is a complex behaviour and when evaluating its relationship to health across independent dimensions such as sedentary time and moderate-to-vigorous activity the qualitative component is just as important as the quantity performed (Esliger and Tremblay, 2007). Even when considering a single outcome there is a temporal component, i.e. ‘150-minutes’, and an intensity component, i.e. ‘moderate to vigorous’ that both need to be accurately captured (Haskell, 2009). Furthermore, individuals from different demographic backgrounds are likely to retrieve their physical activity from different sources (Macniven et al., 2012) For example, adults in the UK of different ages are likely to accumulate moderate-to-vigorous-intensity activity in different ways (Strain et al., 2016). Accordingly, an instrument that consistently captures all physical activities from all domains and across the full range of activity intensity is pivotal (Celis-Morales et al., 2012). A third and final consideration relates to the application of such measurements for use as a method of assessment and an intervention tool itself (i.e. to provide feedback). When implementing measures to capture multidimensional physical activity in large epidemiological or intervention studies set it is imperative to consider the practicality and cost of the instrument otherwise dissemination into practice is invariably unfeasible (Melanson Jr et al., 1996; Dishman et al., 2001). For the individuals using the measure one should also consider the comfort, wearability
and ease of administration and operation where applicable (Sylvia et al., 2014). In summary, the most appropriate method for capturing and assessing physical activity would be a measurement tool is highly accurate and precise, has a good qualitative resolution and is of low cost and practical burden as indicated in Figure 2-d.

![Figure 2-d. Factors integral to the assessment of physical activity for the presentation of multidimensional feedback](image)

### 2.2.1 Direct Physiological Measurement

In essence there are three distinct instrument classifications with which to measure physical activity. The first, and most accurate method for measuring energy expenditure is by assessing the body’s oxygen utilisation and carbon dioxide production, otherwise referred to as indirect calorimetry (Levine, 2005). This method can be achieved in controlled settings using a metabolic cart or chamber (Haugen et al., 2007) or in free-living setting using doubly labelled water (Ainslie et al., 2003). In brief, doubly labelled water involves an individual consuming water in which the hydrogen and oxygen elements have been replaced with traceable isotopic forms.
such as deuterium oxide. The rate of deuterium and $^{18}$O elimination over a period of time is then measured in the blood and directly relates to the carbon dioxide production giving an accurate average metabolic rate (Schoeller, 1999; Coward et al., 1994). The indirect calorimetry method on the other hand uses a more direct assessment of metabolic rate by measuring the fraction of inspired and expired oxygen and carbon dioxide in a given time period (da Rocha et al., 2006). The chamber, as its name dictates allows an individual to undertake activity in a small room whilst the cart offers a more portable version. These direct physiological methods are often referred to as the ‘gold standard’ for assessing physical activity although they are highly expensive and not without their practical limitations (Westerterp, 2009). Metabolic chambers and, to some extent, carts are excellent in laboratory settings and can be used for measuring almost any type of activity but are impractical to use in free-living settings (Strath et al., 2013). Doubly labelled water can be used in free-living conditions however one cannot breakdown the subcomponents or intensity of physical activity using this method at a finite resolution so for capturing any dimension of physical activity other than total energy expenditure it is impractical (Colbert and Schoeller, 2011). Therefore physiological methods are unfeasible for the capture of multidimensional physical activity behaviour in free-living settings but provide essential criterion methods against which to judge the accuracy and precision of cheaper, practical and more refined instruments.

2.2.2 Self report measures

At the opposite end of the spectrum in terms of expense and ease of implementation are self-report questionnaires (Prince et al., 2008; Besson et al., 2010). The number and popularity of self-report questionnaires has been increasing over the past couple of decades as they provide cost-effective, logistically feasible methods for collecting physical activity data across the multiple domains of physical activity (Jacobs et al., 1993; Dishman et al., 2001). As such a vast number of epidemiology and randomised controlled trials that utilise self-report physical activity measures have been conducted in recent years and many of the traditional recommendations described
in Section 2.1 are born out of this data (Bull et al., 2009; Powell et al., 2011). Self-report questionnaires range from very short single item surveys that measure the past day or weeks activity patterns (Matthews et al., 2005; Sallis et al., 1985) to those more global in nature that attempt to classify ‘typical’ activity levels (Godin and Shephard, 1985; Wareham et al., 2002). Many of these self-report questionnaires would be inappropriate in the present context as they focus on general activity scores defined in terms of frequency and duration in a single domain such as leisure time or the perceived acquisition of traditional guidelines (Sallis and Saelens, 2000; Colbert and Schoeller, 2011). There are however one two instruments developed that do attempt to make a more comprehensive assessment across domains and dimensions of physical activity including energy expenditure such as the World Health Organisations Global Physical Activity Questionnaire (Armstrong and Bull, 2006) and the commonly used the International Physical Activity Questionnaire (Booth et al., 2003).

The draw back to self-report measures however is in their validity when it comes to determining behaviour at lower ends of the physical activity intensity spectrum or accurately estimating total energy expenditure making them inappropriate for any of the dimensions that aren’t moderate-to-vigorous-intensity activity (Prince et al., 2008; Helmerhorst et al., 2012). For example, the International Physical Activity Questionnaire has been found to underestimate free-living energy expenditure by nearly 30% relative to a criterion method of doubly labelled water (Maddison et al., 2007). Similarly, a systematic review of multiple validation studies of this instrument suggests an average overestimation of physical activity level of 84% relative to objective criterion measure (Lee et al., 2011). Moreover, these measures are likely to be inadequate for accurately classifying changes in sedentary behaviour due to the nuances and sheer amount of time involved (Healy et al., 2011; Cleland et al., 2014; Strath et al., 2004). Additionally, subjective self-report assessments also come in for criticism in that they invite social-desirability bias, particularly in research settings where individuals are aware of or perceive external judgement (Adams et al., 2005; Lagerros and Lagiou, 2007; Sallis and Saelens, 2000). Even if recall or bias errors are
nullified there is also the potential for misinterpretation of the questions in hand (e.g. what constitutes a typical or normal week? does it count if it wasn’t for exercise? and was that walk to work occupational or leisure activity?) making the reliable quantification of physical activity virtually impossible (Silsbury et al., 2015; van Poppel et al., 2010). Consequently, while they may ultimately useful for mass surveillance of multidimensional physical activity in the future there is currently no validated self-report instrument suitable for the present investigation, which relies on the accurate assessment in accordance with various recommendations. Alternative subjective methods worthy of mention are direct observation (McKenzie, 2002) and activity diaries (van der Ploeg et al., 2010), which can help overcome some of the limitations around bias to self-report questionnaires they lose marks for feasibility as they require a large amount of time from an invasive external observer (Strath et al., 2013).

2.2.3 Wearable activity monitors

To account for shortcomings in the practicality and expense of physiological measures and the loss of precision and rigor associated with self-report questionnaires for detecting long term changes, objective wearable devices have been presented as an optimal solution for the measurement of physical activity (Plasqui et al., 2013; Butte et al., 2012; Westerterp, 2009; Bonomi et al., 2009; Plasqui and Westerterp, 2007). Over the past couple of decades movement sensing monitors, namely pedometers and accelerometers, have been used to quantify physical activity (Holbrook et al., 2009; Bassett Jr, 2000; Crouter et al., 2003; Ryan et al., 2006) Pedometers are small devices that measure the number of steps one takes by recording the times a small pendulum arm swings within the unit (Melanson et al., 2004; Corder et al., 2007). Accelerometers are slightly more sophisticated in that they measure body movements in up to three planes (vertical, mediolateral and anterior-posterior) typically converting raw acceleration into activity counts per unit of time (Chen and Bassett, 2005). Traditionally, pedometers work best when mounted on the waist with certain devices showing excellent validity, reliability and repeatability for the measurement of ambulatory activities such as walking and
running (Schneider et al., 2004; Graser et al., 2007). However, for the purpose of capturing information across all dimensions of physical activity, such as energy expenditure and time engaged at specific activity intensities, pedometer are not a suitable measure as they cannot reliably capture almost all other movement patterns (Bassett Jr and John, 2010; Corder et al., 2007).

Accelerometers on the other hand are capable of providing temporal information about the specific variables mentioned previously, such as the total amount, frequency, intensity and duration of physical activity and are thus more suited for the capturing of multidimensional physical activity (Troiano et al., 2014; Freedson et al., 2012). Problems arise however in the translation of activity counts to energy expenditure, which commonly uses linear regression models that are based on the premise that energy expenditure increases linearly with vertical acceleration in locomotion activities (Freedson et al., 2012). Although robust in the measurement of moderate-to-vigorous activity, this method is thought to be less accurate for non-locomotive activities that are representative of daily living and for estimating energy expenditure during low-to-moderate intensity physical activity thermogenesis (Bassett Jr and John, 2010; Van Remoortel et al., 2012; Chen et al., 2007). Indeed, validation studies of commercial devices that rely on accelerometers or step counters for their estimation of activity intensity and energy expenditure invariably show high levels of error when compared to gold-standard physiological measures (Hendelman et al., 2000; Bonomi et al., 2009; Plasqui and Westerterp, 2007).

A promising solution to the pitfalls of these other methods is the use of multisensor physical activity monitors that combine motion sensors with physiological responses to provide a more comprehensive and direct estimation of behaviour (Van Remoortel et al., 2012; Yang and Hsu, 2010; Intille et al., 2012). Integrating multiple sensors permits the use of sophisticated algorithms that combines contextual input such as the pattern, intensity and physiological demand of a specific movement providing the necessary qualitative information (Strath et al., 2013). As such, these devices can seemingly predict energy expenditure across the physical activity spectrum as they
can account for the relative effort and an individual is undertaking beyond that of accelerometers whose highly variable estimates are dependent on the type of movement, body placement or body composition of the wearer (Yang and Hsu, 2010; Plasqui and Westerterp, 2007; Westerterp, 1999). In their comprehensive meta-regression of the laboratory-based validation studies of physical activity monitors Van Remoortel et al. (2012) found that multisensor devices were on-the-whole significantly more accurate for estimating total energy expenditure when compared to uniaxial and triaxial accelerometers showing an average (95% CI) underestimation of just -3.6 (-9.0-1.7) % compared to a respective -12.1 (-18.3, -5.6) % and -6.9 (-18.2, 4.5) %.

At the time of planning there are relatively few examples of multisensor devices that have been validated for the capture of free-living physical activity. The IDEEA device (Zhang et al., 2004; Zhang et al., 2003), which uses five biaxial accelerometers in a variety of body locations to make a more comprehensive energy expenditure estimation, and the Actiheart™ (Brage et al., 2006; Brage et al., 2004), which combines a uniaxial accelerometer with heart rate signal are two of the more prominently used. Whilst these monitors have been shown to be very reliable and accurate in laboratory and free-living conditions they remain expensive to use and would therefore almost certainly not be adopted into wider practice (Andre and Wolf, 2007; Strath et al., 2013). There is however an increasing trend to use multisensor technology in commercially available activity trackers although at present, many commercially-available devices might not capture information with sufficient resolution to reflect the different physical activity dimensions (Lee et al., 2014). That said, there is one commercially-available instruments, the Bodymedia armband (Andre et al., 2006), with excellent reported validity in certain settings (Johannsen et al., 2010b; Welk et al., 2007). An initial aim of the present thesis will be to explore the validity, reliability of this ‘best-available’ device in both free-living and laboratory conditions and will be described in more detail in Chapter 3. A summary of the relative strengths and weaknesses of all reported methods is
described in Figure 2-e as a justification for using a sophisticated multisensor in the present body of work.

Figure 2-e. Summary of the respective strengths and limitations of different methods for the capturing of multidimensional physical activity behaviour.

The Venn diagram classifies different devices or instruments that can be used to measure physical activity behaviour according to their high accuracy, low cost and burden and the qualitative resolution of the device.

2.3 IMPLEMENTATION OF MULTIDIMENSIONAL PHYSICAL ACTIVITY FEEDBACK AS A BEHAVIOUR CHANGE STRATEGY

The ability to capture and distinguish the multiple key domains of physical activity behaviour using sophisticated monitoring devices affords an opportunity to provide rich personalised feedback. At this point however it should be stressed that simply
setting and making individuals aware of physical activity recommendations as a strategy in itself is unlikely to be sufficient drivers of behaviour change. Instead, they are useful points of reference that can guide policy makers, intervention designers and individuals towards an intended behavioural target. To actualise the potential of sophisticated monitors in capturing and presenting multidimensional physical activity feedback as a facilitator of behaviour change careful thought must go into the design and development of an intervention seeking to use this approach. As such, a useful starting point would be to consider the types of informational feedback and existing evidence as to the effectiveness of behavioural feedback as a behaviour change strategy in the context of physical activity.

According to the taxonomy of DiClemente et al. (2001), feedback can be generic (i.e. general information relevant to a whole population), targeted (i.e. adapted feedback for particular characteristics such as demographics or health risk) or personalised (i.e. providing feedback based on an individual assessment in relation to themselves or normative data). Personalised or tailored feedback can involve information about risk, current status and/or change options and has the benefit over the other formats in being much easier for the recipient to engage with or see as personally salient and meaningful (Krueter et al., 2000, 2003). In their taxonomy DiClemente et al. (2001) also introduce seven potential mechanisms of action as to how feedback can impact upon an individual to promote a change in behaviour. These include 1) education about the behaviour or outcome, 2) motivation or inspiration to change, 3) a change in attitude or belief about the problem and ability to overcome it, 4) provision of support to change, 5) the offering of social norms or standards that promote change, 6) increasing engagement with the information, and 7) the provision of critical risk or protective factor information.

Since the turn of the century the number of physical activity interventions in which behavioural feedback is provided has been steadily rising and has made use of a number of platforms including the internet (van den berg et al., 2007), text, multimedia messaging or personal desktop assistants (PDAs) (Burke et al., 2010) and
smartphones (Bort Roig et al., 2014). Differences and complexities in the design of these multi-component intervention trials makes it difficult to completely tease out the processes and features that lead to some being more effective than others for supporting changes in behaviour. An emerging focus in the field of health psychology is the need for better classifications of the various functions and techniques adopted by intervention programmes so as to inform the development and implementation of future programmes (Michie et al., 2011b). On one level there sit a selection of policy seven policy categories such as the setting of guidelines, marketing or communication, environmental planning, fiscal, regulatory and legislative policy, and service provision (Michie et al., 2011b). This particular level of influence goes beyond the remit of the current thesis, however should the approach be efficacious there is certainly scope to advance this strategy multidimensional feedback as an affordable policy strategy through updated guidelines and effective communicative marketing.

On the second level, and more pertinent to the present body of work are the general intervention functions that comprise the overall methods used to change behaviour. The most relevant and inherent of these evidence-based functions in the present context are education, i.e. raising awareness of physical activity behaviour, persuasion, i.e. the use of personalised visual feedback to motivate users, and enablement, i.e. providing more opportunities for behavioural strategies (the others being coercion, incentivisation, environment restructuring, restriction and modelling). Finally, the active ingredients that are selected to deliver a given intervention function are termed behaviour change techniques (Michie et al., 2011a; Abraham and Michie, 2008). Specifically, these are distinctive, intricate procedures that are chosen to support an intervention in translating theory into practice, which can be used in isolation or in conjunction with one another (Michie et al., 2013a). In recent years Michie and colleagues have put forward a catalogue of behaviour change techniques to serve as a framework for intervention development (Abraham and Michie, 2008; Michie et al., 2009; Michie et al., 2011a; Michie and Johnston, 2012; Michie et al., 2013a).
2.3.1 Self-regulatory behaviour change techniques

The utility of certain behaviour change techniques has been particularly emphasised in overcoming the intention-behaviour gap, a phenomenon that has long puzzled behavioural scientists in the field of physical activity and exercise (Sheeran, 2002; Webb and Sheeran, 2006; De Bruijn and Rhodes, 2011). In other words, physical activity interventions are often good at predicting people’s described willingness to enact a change their behaviour (intention), but not meaningful changes in physical activity itself (Rhodes and Dickau, 2012). For example, in their recent meta-analysis of experimental studies measuring intention and behaviour discordance, Rhodes and Bruijn (2013) found that 46% of people failed to actually fulfil their intended levels of physical activity.

A number of behavioural theorists have developed frameworks for post motivational processes with a view to help individuals self-regulate their behaviour (Maes and Karoly, 2005; Karoly, 1993). Notable examples include Goal setting theory (Locke, 1996; Locke and Latham, 1990), which postulates setting of specific, challenging goals over general, easily-accessible ones; Implementation Intentions theory (Gollwitzer, 1999; Gollwitzer and Brandstätter, 1997), which describes the process of specifying an if-then plan on where, when and how one is going to act in order to achieve a goal; Action control (Kuhl, 1987, 1985), which comprises awareness of standards, self-monitoring and self-regulatory effort; and Control Theory (Carver and Scheier, 1982), which involves using feedback to self-monitor and review discrepancies between behavioural goals and behaviour. Action planning and coping planning are also discussed as core facilitators of behavioural adoption once intention is formed in the Health Action Process Approach (Schwarzer, 1999). Indeed, there are promising signs that these self-regulatory processes can help harness ones motivation and translate positive physical activity intentions into behaviour as they help maintain ones focus on the target behaviour and incur cyclical positive reinforcement that facilitates its continued practice (Sniehotta et al., 2006, 2005; Webb and Sheeran, 2008; Scholz et al., 2008). It is no surprise then that the most effective behaviour change techniques derive from the processes outlined by these frameworks.
A number of systematic reviews and meta-analyses have attempted to determine the most appropriate behaviour change techniques for enabling changes in physical activity using Michie et al.’s (2011b) taxonomy. Almost ubiquitous in these studies is the use of behavioural self-monitoring, referring to the process by which individuals are prompted to constantly observe and note their physical activity levels (Abraham and Michie, 2008). In a Meta-regression analysis of experimental studies Michie et al. (2009a) found that self-monitoring explained the highest proportion of variance in changes in physical activity. Furthermore, the authors found that interventions that used self-monitoring plus any number of four other self-regulatory techniques taken from the Control Theory (Carver and Scheier, 1982) showed an effect size (95% CI) of 0.38 (0.27-0.49) compared to 0.27 (0.21-0.34) in those that didn’t. These additional self-regulatory techniques include the prompting of intention formation, goal setting, providing feedback on performance and prompt the review of behavioural goals in light of feedback.

A number of more recent analyses have supported this finding. For example, Greaves et al. (2011) looked specifically individuals who were at heightened risk of type 2 diabetes and found interventions that utilise self-regulatory techniques such as self-monitoring, goal setting and the prompting of practice were most effective for encouraging physical activity behaviour. Williams and French (2011) and Olander et al. (2013) looked the techniques associated with changes to physical activity and self-efficacy in healthy and obese adult populations respectively. In healthy Adults, the techniques for providing information on the consequences of behaviour in general, time management, facilitation of social comparison, the provision of instructions on behaviour, action planning and reinforcing effort towards behaviour were most effective for behaviour with the latter three also positively impacting self-efficacy (Williams and French, 2011). For obese individuals, action planning and time management were also effective for physical activity however self-monitoring of behavioural outcome and plan social support/social change were the only two techniques associated with changes to both self-efficacy and behaviour (Olander et al., 2013). These findings confirm those of Dombrowski et al. (2012) whose meta-
regression analysis also showed self-monitoring, prompting practice, providing instructions and relapse prevention were all strategies linked to more successful interventions. In their review of implementation intentions on physical activity behaviour, Bélanger-Gravel et al. (2013) found that small to moderate changes in physical activity behaviour were observed at the end of an intervention and at follow-up, but were strengthened when used in conjunction with barrier management. Finally, a recent meta-analysis has shown that for longer-term physical activity behaviour changes in older adults, feedback itself is the most promising behaviour change technique (O'Brien et al., 2015).

2.3.1 Effectiveness of feedback in eHealth interventions

A contemporary platform within which researchers have attempted to apply these behaviour change techniques has been termed ‘eHealth’ (Eysenbach, 2001; Neuhauser and Kreps, 2003). ‘eHealth’ refers to all domains of persuasive information and communication technology that such as text messaging, email, websites smartphone apps or wearable electronic devices to deliver behaviour change interventions (Kay et al., 2011; Chatterjee and Price, 2009). The appeal for utilising technological platforms for delivering physical activity interventions is growing as they can reach large numbers of individuals at one time, are becoming much more affordable to develop and disseminate and can be used to communicate large volumes of personalised content that maps on to health behaviour theory (Schweitzer and Synowiec, 2012; van Gemert-Pijnen et al., 2011; Lintonen et al., 2008). In terms of the efficacy and effectiveness of eHealth technologies for changing physical activity behaviour is still in its infancy although there are promising early signs of small to moderate effect sizes in interventions that tailor their content to the individuals receiving the treatment (Foster et al., 2013; Neville et al., 2009; Davies et al., 2012; Webb et al., 2010). The fact that eHealth tends to incur costs at the development phase rather than on an individual person-by person basis as with traditional face-to-face treatment, there remains the potential to have an impact on large numbers of people and thus be significant for patient or population health (Webb et al., 2010).
Many of these early interventions tended to focus on providing tailored feedback following an internet based physical activity survey which was then interpreted by a clinician or researcher and returned as personalised messages delivered via email with information, support and opportunities for goal setting provided on a website (McKay et al., 2003; Marshall et al., 2003; Revnoviak et al., 2005). The findings from these studies however is inconclusive as to the effectiveness of the feedback in changing behaviour based on the timing, frequency specific content written, personalised feedback derived from behaviour that the participant is already aware of (van den berg et al., 2007). Wearable technology on the other hand can not only be used to capture multidimensional physical activity behaviour (as described in Section 2.2), but also provide automatic feedback to the user so that the user can set personalised goals and self-monitor their behaviour overtime. By syncing data from wearable physical activity trackers to an interface that displays the key characteristics across the multiple health-harnessing dimensions one can provide personalised objective feedback with which to self-regulate behaviour (Burke et al., 2011).

A number of experimental research programmes have shown the provision of continuous step count feedback has helped motivate individuals in a number of clinical settings (Kang et al., 2009b; Ogilvie et al., 2007; Bravata et al., 2007). In their comprehensive meta-analysis of self-monitoring interventions using pedometers, Kang et al. (2009b) found an overall effect size (95% confidence interval) of 0.68 (0.55 to 0.81), whilst their moderator analysis showed that interventions using a standardised step goal of 10,000 or a personalised step goal improved the effect sizes to 0.84 (0.43 – 1.24) and 0.72 (0.47 – 0.97) respectively. The authors also noted that there was a negligible difference in the effectiveness of intervention length as studies of less than 8 week, between 8 and 15 weeks and greater than 15 weeks had effect sizes of 0.68, 0.65, and 0.76. In an earlier review by Bravata et al. (2007) the effectiveness of randomised controlled trials using pedometers for feedback translated into a significant increase in steps of 2491 (1098-3885) per day, approximately 30% from baseline, which again was found to be heavily moderated
by the use of a step goal. However, as previously described in Section 2.2, the use of pedometers is not without its limitations. Whilst they may have positive behavioural effects these are invariably a short-term strategy whose effects on behaviour and health are rarely maintained when measure at follow-up (Bravata et al., 2007; Ogilvie et al., 2007). Pedometer steps themselves only serve to capture one domain of physical activity behaviour (i.e. walking) and are perhaps less accurate at capturing sedentary and light activities meaning they neglect the biologically important multiple dimensions of physical activity behaviour described earlier in this chapter (Bassett Jr and John, 2010; Tudor-Locke and Lutes, 2009).

Albeit in its infancy, the findings of studies providing feedback on other physical activity metrics derived from sophisticated monitoring devices are somewhat mixed (Hurling et al., 2007, Koizumi et al., 2009; Slootmaker et al., 2009; Greene et al., 2012; Shrestha et al., 2013; Godino et al., 2013). In their randomised controlled trial Godino et al. (2013) found that feedback, regardless of whether it was simple (standard messages about health benefits and physical activity, guidelines and the participants average PAL), visual (simple feedback + line graphs of accelerometer and heart rate for each 24-hour period the participant was monitored) or contextualised (simple and visual feedback + provision of the PAL values for familiar activities such as walking and cycling to assist participants with goal setting), had no impact on adults physical activity behaviour when measured over an 8 week period. Slootmaker and colleagues (2009) also observed no effect on changing physical activity behaviour when comparing the provision of accelerometer feedback in the form of an activity score on a website along with tailored feedback and motivational tips versus simple generic physical activity advice in a sample of overweight, sedentary office workers for a 3-month period. It should be noted that the lack of effectiveness observed in these studies might be due to the fact that both studies recruited individuals who were fairly active at baseline or because the information provided was in a format less meaningful to individuals requiring to change their behaviour (according to a process evaluation by Slootmaker et al. (2009) only a small proportion found the feedback appealing).
A handful of studies have however shown that providing feedback in a more meaningful format and supporting self-monitoring and goal setting and planning can be an effective strategy. For example, Hurling et al. (2007) found that a 10-week website-based intervention delivered to that showed individuals a daily breakdown of light, moderate and vigorous activity as recorded by an Bluetooth transmitting accelerometer helped individuals in their intervention group improve their physical activity by over 2-hours a week compared to a control group who received just verbal advice. A similar approach was adopted by Wijsman et al. (2013), who found that inactive older adults who used a Philips DirectLife accelerometer and web-based digital coach improved their objectively measured physical activity by 11-minutes per day relative to a waiting list control group who received no advice. Neither of these studies reported long-term follow up data meaning the impact of feedback on behaviour once the intervention has stopped is unknown. Moreover the web-based systems used in these studies included several different processes such as an exercise planner, motivational and barrier reduction messages and an interactive chat-board so teasing out the absolute impact of feedback alone is difficult, although Hurling et al. (2007) found that the visual feedback was the most popular feature according to their intervention participants.

To date there has yet to be an explicit attempt at providing feedback on all of the multiple dimensions outlined in Section 2.1 as an intervention strategy, however lessons can certainly be learned from previous feedback based interventions as to how to best apply thus novel format of feedback. A number of experimental studies that have utilised wearable monitoring technology to provide feedback suggest that the integration of graphical displays in accordance with other self-regulatory behaviour change techniques and the use of real-time feedback (such as found in pedometer interventions) appear promising strategies for behaviour change.

2.3.3 IMPLEMENTING PHYSICAL ACTIVITY INTERVENTIONS WITH FACE TO FACE SUPPORT

With a new and potentially challenging approach to the conceptualisation of physical activity behaviour on must be cautious when disseminating this in a real-world
setting (Thompson and Batterham, 2013). To overcome potential challenges with interpretation and unlock other behaviour change techniques or theoretical mechanisms that aren’t inherently activated by the monitoring and presentation of multidimensional physical activity feedback, the role of a health trainer should also be considered (Richards et al., 2013). Several eHealth interventions that have had the most pronounced impact on changing physical activity behaviour have supported their technology-enabled feedback and self-monitoring programmes with expert or clinical trainers (Hurling et al., 2007; Van Hoye et al., 2015). There is currently a paucity of evidence comparing the effectiveness of internet delivered interventions with face-to-face delivery in the physical activity domain however it is clear that their conjunctive use may be an effective strategy for physical activity as both approaches hold advantages for the user (Foster et al., 2013; Richards et al., 2013). On one hand, persuasive technology that helps individual’s self-monitor physical activity behaviour through the automatic provision of feedback and can present a more objective and holistic picture of behaviour that captures habitual as well as volitional physical activity and provide a more consistent presence compared to a practitioner (Fogg, 2002). On the other hand, technological platforms, even those with tailored health messages, lack the empathetic, personal qualities are thus easier to ignore or disengage with (Richards et al., 2013). Of particular relevance to the present context, where the aim is to engage individuals in more physical activity to improve their health, interpersonal contact with a health trainer could help contextualise different components regard to the strategizing of personalised action plans or implementation intentions needed to achieve their chosen behavioural goals (Maes and Karoly, 2005).

Moreover, a health trainer can tailor their advice specifically to a given individual (i.e., context-specific guidance such as physical activity for weight loss) making it more likely to be perceived as personally relevant and meaningful. This is important as dynamic, individual tailoring of intervention content has been consistently shown to augment positive outcomes in eHealth physical activity interventions (Webb et al., 2010; Krebs et al., 2010; Morrison et al., 2012; Foster et al., 2013) but will not
intrinsically be available in a technological system that presents multidimensional physical activity feedback alone. Tailored trainer support might also help foster heightened self-efficacy and self-determination for physical activity by creating a meaningful rationale, reinforcing effort, providing instruction to help make personal goals more realistic and achievable, and help strategize against new barriers (Williams and French, 2011; Fortier et al., 2012). Thus it might be the case that a combination of persuasive technology and external support from a practitioner may be essential for actualising the potential of multidimensional physical activity so it can have the necessary impact on behaviour change.

2.4 Theoretical basis for using multidimensional physical activity to support behaviour change

In order to optimise the delivery and evaluate the efficacy of this approach careful thought must also go to understanding and target the theoretical mechanisms of action that support behaviour change (Moore et al., 2015). For decades public health and health psychology research has attempted to classify general antecedents to health behaviours such as physical activity (Dishman et al., 1985; King et al., 1992; Trost et al., 2002; Bauman et al., 2012). In recent years there has been a particular focus on the social-ecological model (Sallis et al., 2008; Giles-Corti et al., 2005; Golden and Earp, 2012), which acknowledges that to change a complex behaviour such as physical activity there are multiple levels of influencing factors from those personal to an individual (e.g. knowledge and attitude), interpersonal factors (e.g. social support from friends and family), environmental level factors (e.g. available space and resources) and policy level factors (e.g. legislation). This model is particularly comprehensive as it accounts for many, if not all, proximal and distal determinants of a given health behaviour (Bauman et al., 2012). It’s practical utility is however compromised as it serves more as a menu of influencing factors rather than provide a framework for understanding the interactions and mechanism of influence that may explain why one individual is physically active but someone else isn’t. Furthermore, there are inevitably many factors that within a social-ecological
framework that serve to moderate behaviour but are much less amenable to change such as the implementing of expensive policies, restructuring of the environment or modifying individual demographics (Armitage and Conner, 2000). Similarly, with physical activity, which by definition is an active rather than passive pursuit, the personal level influences are most likely to hold the largest influence particularly when considering that, in the High Income Countries at least, many environmental determinants are already in place (Biddle and Fuchs, 2009). Unsurprisingly then, theoretical frameworks of behaviour have tended to focus on specific psychological processes that can support a change in behaviour in the context of their social and built environment.

The most widely used psychological theories to explain physical activity behaviour stem from social-cognitive models that present the modifiable factors that help individuals develop the intentions to undertake a [new] behaviour (Armitage and Conner, 2000). The most widely used theories, of which there are thought to be over 80 (Davis et al., 2015), in the physical activity domain include the Social Cognitive Theory (Bandura, 1998; Bandura, 1986), the Theory of Planned Behaviour (Ajzen, 1991, 1985), the Health Belief Model (Janz and Becker, 1984) and Protection Motivation Theory (Rogers, 1975). In an extension of these cross-sectional theories that explain behaviour at one point in time a number of health psychologists have also put forward multi-stage models in an attempt to explain the dynamic process of behaviour change and organise the key influential interpersonal factors taken from the social cognitive models that are important at different stages. Such models deployed in the physical activity domain include the Transtheoretical (or Stage of Change) Model (Prochaska and Velicer, 1997; Prochaska and Marcus, 1994; Prochaska and DiClemente, 1982), and the Health Action Process Approach (Schwarzer, 1999; Lippke et al., 2005).

All of these frameworks are attractive to intervention developers as they provide logical, linear models of behaviour whose constructs are easy to translate into a practical programme (French et al., 2012). That said, the effectiveness of using a
single theoretical framework to develop and apply a behaviour change intervention remains ambiguous (Hardeman et al., 2002; Noar and Zimmerman, 2005). Nonetheless, it is widely considered that to successfully change behaviour it is important to understand the key antecedents of behaviour that have been empirically tested and foster these in the development of interventions (Michie et al., 2005; Michie and Abraham, 2004). To date pooled effect sizes of theory-based interventions are relatively small across a number of populations and even the most promising interventions rarely see long lasting benefits when physical activity and/or health is measured sometime after the intervention has ended (Michie et al., 2008a; Prestwich et al., 2014; Gourlan et al., 2016). Some authors have suggested that this may be due to poor application of theory in intervention design (Prestwich et al., 2015; Michie and Prestwich, 2010; Eccles et al., 2012). Others have levelled rational criticisms at particular theories themselves creating confusion amongst behavioural scientists as to which is the most appropriate framework to adopt for their intervention (Ogden, 2003; Sniehotta et al., 2014; Adams and White, 2005; Weinstein et al., 1998). Part of the problem in the evaluation and application of theories is that their constructs tend to overlap (Michie et al., 2005; Lippke and Ziegelmann, 2008; Hagger, 2009). To overcome some of the criticisms of single theories and unite the multiple, yet similar constructs and processes some authors have proposed integrated theories of behaviour change (Hagger and Chatzisarantis, 2014).

In an effort to summarise and guide the key proximal and distal underpinnings of health behaviour derived from psychosocial theories and social-ecological frameworks and subsequently inform appropriate intervention development Michie et al. (2011c) have proposed the “COM-B” model. The COM-B behavioural system, as described by the authors, explains the causal interactions between three overarching components necessary for initiating health behaviours, Capability, Opportunity and Motivation. The capability component describes the physical (e.g. functional ability and motor skills) and psychological (e.g. knowledge, comprehension, rational) capacity to participate in the activity of interest. Opportunity, on the other hand, defines the external factors that enables the enactment of the behaviour and covers
the physical and social contexts that prompt the target activity. The final component, motivation, encompasses all the cognitive-affective processes that stimulates an individual and directs their energy towards the desired behaviour. In the COM-B system, motivation covers automatic processes such as emotional responding, habits and innate dispositions, and reflective processes that incorporate the analytical decision-making and evaluation of goals and plans (Michie et al., 2011c). In this behavioural model, the three components can each influence and be influenced by enactment of the target behaviour whilst the capability and opportunity components can also influence motivation. The COM-B model doesn’t place any priority on the proximal or distal personal, social or environmental determinants of behaviour, but rather directs efforts to change a given behaviour by directing decisions around the key components appropriate to a particular context. Importantly the model can be used to explain the utility of multidimensional physical activity feedback (Figure 2-e) as it relates to different key constructs from most pertinent theoretical frameworks used in physical activity behaviour change (Buchan et al., 2012).

2.4.1 Capability: Improving awareness of physical activity behaviour

An enhanced knowledge of the nature of physical activity and its relationship to health is likely to be fundamental in guiding people towards appropriate levels of this important health behaviour (Bandura, 1998; Nutbeam, 2000). Several key social-cognitive theories champion the role of attitudes towards a health behaviour regarding its importance as a key precursors to the formation of behavioural intentions and ultimately behaviour itself (Armitage and Conner, 2000; Lippke and Ziegelmann, 2008). For example, the Health Belief Model, Theory of Planned Behaviour, the Health Action Process Approach, Social Cognitive Theory and the Transtheoretical Model all postulate that the likelihood of adopting a new health behaviour (i.e. physical activity) is enhanced if an individual perceives it as a means to avoiding a health threat (i.e. to reduce the presence of obesity or diabetes) (Ajzen, 1985; Schwarzer, 1999; Rosenstock, 1974; Prochaska and DiClemente, 1982; Bandura, 1986). Humans tend to need to vindicate their actions and for a volitional pursuit such as physical activity there needs to be an appropriate degree of
meaningful rational driving them towards behaviour (Schwarzer, 2008; Bandura, 2004).

Another important psychosocial construct related to ones capability to undergo physical activity that features in all of the aforementioned social-cognitive models of behaviour change is self-efficacy (Bandura, 1977). Self-efficacy describes ones belief in their capability to undertake behaviour in a given situation (Bandura, 1997). In the Theory of Planned Behaviour self-efficacy is conceptualised as ‘perceived behavioural control’ (Ajzen, 1985; de Vries et al., 1988). Systematic reviews have consistently shown self-efficacy to be strongly associated with the initiation and regular engagement of physical activity behaviour (Bauman et al., 2012; Trost et al., 2002; Rovniak et al., 2002; Kaewthummanukul and Brown, 2006; Sherwood and Jeffery, 2000). Randomised controlled trials using objectively measured physical activity outcomes have also shown that a change in self-efficacy is fundamental in determining the successful adoption of physical activity behaviour following a behavioural intervention (Dutton et al., 2009; Burke et al., 2008; Darker et al., 2010; Armitage, 2005). The key sources of self-efficacy as described by Bandura (1977) are vicarious experiences and observing others, past behaviour or performance accomplishments, cognitive-affective states and social persuasion and interventions that focus on these constructs have been shown to evoke positive physical activity outcomes (Ashford et al., 2010).

It is in relation to some of these sources of self-efficacy that multidimensional can prove to be a useful resource. With a holistic multidimensional profile, an individual who is not confident to engage in one format of physical activity (for example strenuous exercise) may become buoyed by the sudden presence of alternative options. As far as past performance is concerned in cases where an individual recognise that they are already on the path to achieving certain guidelines and simply require ‘more of the same’ rather than the adoption of new behaviours that they are not confident undertaking. In terms of persuasion, positive feedback in one dimension of physical activity could even offset the detrimental impact of negative
evaluations on self-efficacy in another dimension. A heightened awareness of multiple behavioural strategies for achieving good health through physical activity may also serve to present inactive individuals with more opportunities to observe other people achieving certain recommendations and find social support for achieving more. Finally, the ability assess physical activity behaviour against personalised, achievable and realistic goals from a previously unthought-of health-harnessing dimension may also serve to enhance ones self-efficacy as they feel more physically capable of doing so.

2.4.2 Opportunity: Changing Perceptions of Physical Activity Options

Not only does information about multiple dimensions of physical activity help individuals better gauge the appropriate levels, and reinforce its presence as a health risk it can also be used to offer the most inactive individuals a platter of behaviour change options and strategies. The key role of the opportunity component of the COM-B system is the need to break down common external barriers as purported by the social-ecological models and enable suitable performance of the target behaviour (Michie et al., 2011c). Barriers, either perceived or literal, are pivotal in explaining discordance between an individual’s understanding, intentions towards healthful physical activity and the undertaking of behaviour itself (Amireault et al., 2008; Sallis et al., 2008). Barriers to regular physical activity engagement will most likely differ depending on the domain of physical activity and the demographics of individuals (Bauman et al., 2012). Commonly barriers to walking for example may be more environmental such as the attractiveness of the area, the convenience and accessibility of green spaces or walking trails, and the perception of neighbourhood traffic and safety (Owen et al., 2004; Humpel et al., 2002). For structured exercise on the other hand time and cost are often cited as reasons for not being able to attend classes or leisure centres along with alternative preferences or priorities such as childcare, a dislike of exercise or lack of social support (Withall et al., 2011; Reichert et al., 2007; Salmon et al., 2003). Moreover, older adults are more likely to report different and more barriers when compared to their younger counterparts including things such as a perceived physical frailty, health problems, fear of resultant injury or
falling (Brawley et al., 2003; Chen, 2010; Schutzer and Graves, 2004). Individuals with specific disease states may also incur additional barriers such as physical discomfort for exercising or anxiety towards sweating or exacerbating their condition (Korkiakangas et al., 2009; Wanko et al., 2004; Conraads et al., 2012), while gender differences may also exist in relation to barriers in the compliance to physical activity rehabilitation programs (Marzolini et al., 2008).

As the traditional approach to healthful physical activity was the regular engagement in daily or weekly moderate-to-vigorous-intensity there was an inevitable these barriers are often surveyed in relation to exercise or leisure time physical activity rather and ignore other dimensions (Sallis and Owen 1999:). As far as environmental opportunities are concerned, the provision of multidimensional physical activity feedback will not change ones social or physical environment directly however may serve to breakdown these barriers to exercise as it presents other important behavioural strategies. For example, should an individual who currently undertakes very little physical activity do so because of a lack of interest in sports or even recreational exercise, then informing them that they can reap health benefits by reducing sedentary time or increasing their overall calorie burn through non-exercise-activity-thermogenesis may be an attractive solution (Owen et al., 2010; Levine et al., 2006). For Individuals who see time and cost as a barrier guiding them on opportunities to fit accumulate single minutes of just moderate activity or focusing on one or two vigorous bouts per week may also prove efficacious.

Inadvertently, the physical environment may open-itself up to people who previously felt that provision or the cost of leisure facilities made them inaccessible, but who now recognise that there are other forms of healthful physical activity. Multidimensional physical activity in this context then can therefore offer tailored solutions and that align to the needs and preferences of a given individual. It is important to note that many individuals with have quite distinct barriers for physical activity participation and for this the presence of more options for achieving good health may help individuals find bespoke solutions that work for them (Booth et al.,
The specific confidence to overcome certain aforementioned internal or external barriers and sustain desired levels of physical activity has been termed barrier self-efficacy (McAuley and Blissmer, 2000; McAuley, 1992). Increasing physical activity in general, such as through focusing on decreasing sedentary time may in fact raise one’s confidence to undertake more vigorous exercise and help individuals hit more targets in time (Kowal and Fortier, 2007). Through flexible and dynamic behavioural strategies that provide people with an opportunity to target different dimensions at different times, barrier self-efficacy may increase.

2.4.3 Motivation: self-determination and the internalisation of physical activity

Perhaps the most exciting prospect afforded by this novel understanding of physical activity behaviour is the ability to use it as a persuasive tool that encourages increases in activity levels. Motivation, in the COM-B system, incorporates and describes the most proximal factors that energise a change in behaviour such as intentions and emotions (Michie et al., 2011c) and can be influenced by increases to the other core components of capability and opportunity. Based on the previous discussion it is certainly apparent that a raised awareness and understanding of the various dimensions of physical activity can help individuals break their personal barriers and feel more adept to accomplish an increase in healthful physical activity. Likewise, the role of emotion in directing the formation of coping and action plans has already been discussed in the context of Leventhal et al. (2003) Common Sense Model of Illness Regulation in Section 2.3.1. A useful and widely applied framework for understanding the nature of motivation itself is the Self-Determination Theory (Ryan and Deci, 2000; Deci and Ryan, 2000).

Self-Determination Theory intimates that conditions in which three innate psychological needs are fostered rather than thwarted will encourage higher quality motivation, positive behavioural outcomes and improved health and wellbeing (Deci and Ryan, 2008). These three basic needs are autonomy, which describes the need to feel in full volitional control of one’s actions; competence, which describes one’s need to feel effective at dealing with their environment; and relatedness, which
describes one's need to feel engaged and close to others (Ryan and Deci, 2000). Motivation within the self-determination framework is described on an internalisation continuum that distinguishes amotivation, extrinsic and intrinsic motivation. Amotivation reflects complete disengagement or lack of intention and control with a particular activity or behaviour. Extrinsic motivation comes in a variety of forms that vary in their degree of external or internal regulations from compliance and external rewards or punishment, to approval from others, valuing an activity and the endorsement of goals or congruence and synthesis with oneself. Intrinsic motivation is the most self-determined form of motivation and describes the inherent internal interest and enjoyment and satisfaction that comes from undertaking the activity or behaviour in question (Ryan et al., 2009). A final sub-theory of Self-Determination Theory is goal content theory, which makes an intrinsic-extrinsic distinction between one's life aspirations or the reasons for engaging in a particular activity (Deci and Ryan, 2000). Examples of extrinsic goals might be to look good, financial success, or social recognition whereas intrinsic goals would include items such as the development of personal or community relationships, self-acceptance or physical health (Kasser and Ryan, 1996). Intrinsic goal pursuit has been positively associated with need-support and self-determined motivation and greater well-being, whereas extrinsic goal pursuit is predictive of more controlling forms of motivation, need-thwarting and adverse functioning (Sheldon and Kasser, 2008; Sheldon et al., 2004; Kasser and Ryan, 1996).

Importantly, within Self-Determination Theory the interaction between goal content, need-support and development of more internalised forms of motivation can occur at a global life level and at a more contextual, domain specific level such as that of physical activity (Vallerand, 1997; Vallerand and Lalande, 2011). Indeed, there is an emerging body of evidence supporting the core tenets of self-determination theory in the physical activity domain where relative intrinsic goal content, need supportive climates and internalised motivation lead to greater adoption and maintenance of physical activity behaviour (Fortier et al., 2012; Teixeira et al., 2012a; Silva et al., 2010; Fortier et al., 2007). There are a number of foreseeable ways in which the
provision of multidimensional physical activity feedback may facilitate one's self-determination for physical activity. Starting with goal content, the provision of feedback in line with empirically derived physical activity recommendations may help encourage people to adopt certain types of behaviour for health reasons where they were previously disengaged or had more extrinsic exercise specific goal content. This in turn could lead to increased adoption of the behaviour itself (Sebire et al., 2011, 2009). In terms of the three basic needs, autonomy may be supported by a greater sense of choice inherently afforded by observing several independent recommendations that serve as a menu of behavioural strategies (Standage and Ryan, 2012; Kilpatrick et al., 2002; Fortier et al., 2012). Encouragingly, a multidimensional profile in this context would provide the greatest support for autonomy for the most inactive individuals who do not currently achieve any of the health-harnessing recommendations but would be most in need of a change in behaviour. In a similar vein to the facilitation of self-efficacy described in Section 2.3.1, the needs for competence and relatedness may also be fostered by the presence of more behavioural options as individuals can find personalised solutions for achieving healthful physical activity in which to feel more accomplished and seek greater social support. Competence can also be supported as users identify behaviour change options that minimally disrupt their present routine so that continued, long term self-regulation isn't necessarily required (Yardley et al., 2015). As far as motivation itself is concerned one could argue that the direct effect of personalised objective feedback may initially serve as a more controlling form of motivation (Standage and Ryan, 2012; Vallerand, 2007). Overtime, however, if the hypothesised impact on goal selection and psychological need support is realised, then should this result in more internalised engagement and maintenance of behaviour once the behaviour change has taken place (Ng et al., 2012; Teixeira et al., 2012a). The internalisation of motivation may also lead to more habitual enactment of physical activity (Gardner and Lally, 2013), which is important when considering that objective monitoring and feedback would capture all domains and dimensions of one's behaviour. Thus, one might expect that as behaviour becomes more internalised and enjoyable for a participant, the reciprocal impact on volitional and
Habitual behaviour change may improve and enhance the positive nature of multidimensional feedback that will reinforce one's intrinsic motivation over time.

Figure 2-f provides an overview of the intended process and behaviour change techniques hypothetical mechanisms as outlined within the context of the COM-B framework and the behaviour change techniques discussed in Section 2.3. In summary, to target the proposed theoretical mechanisms the provision of multidimensional physical activity feedback and accompanying face-to-face support will help educate recipients about the appropriateness of their behaviour by presenting a more complete picture of their physical activity, enable them to set goals and action plans that align to their individual preferences and needs and help persuade them to increase their physical activity through the provision of visual behavioural feedback and self-monitoring. Key aspects of this model will be evaluated in the ensuing empirical research within this thesis through qualitative interviews and appropriate validated quantitative questionnaires in accordance with Medical Research Council guidance for process evaluations (Moore et al., 2015).
<table>
<thead>
<tr>
<th>Intervention function</th>
<th>Behaviour change techniques</th>
<th>Psychosocial mediators</th>
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<tbody>
<tr>
<td><strong>CAPABILITY</strong></td>
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<tr>
<td>Education: <em>increase knowledge and understanding of healthful physical activity</em></td>
<td>Framing of message about physical activity behaviour</td>
<td>Creation of meaningful rationale&lt;br&gt;Increased Self-efficacy</td>
</tr>
<tr>
<td><strong>OPPORTUNITY</strong></td>
<td></td>
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<tr>
<td>Enablement: <em>increased awareness of different means by which to be physically active and reduce barriers to other dimensions</em></td>
<td>Goal setting in relation to achievable dimensions of physical activity and personal preferences&lt;br&gt;Action planning</td>
<td>Increase barrier self-efficacy&lt;br&gt;Raise implementation intentions</td>
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<tr>
<td><strong>MOTIVATION</strong></td>
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<td>Persuasion: <em>frame existing behaviour relative to several health targets and reinforce with continuous feedback</em></td>
<td>Present discrepancy between current behaviour and health target&lt;br&gt;Provide continuous feedback on behaviour&lt;br&gt;Self-monitoring of behaviour using visual data</td>
<td>Improved autonomy and competence&lt;br&gt;More self-determined motivation&lt;br&gt;Evoke cognitive/emotional response</td>
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Figure 2-f. Proposed intervention design in terms of intervention functions, behaviour change techniques and hypothesised psychosocial mechanisms that are potentially activated by the provision of multidimensional physical activity feedback.
2.5 Next steps and aim of thesis

On face value then there is a sound theoretical rational for the use of visual multidimensional physical activity information as a tool to entice and support positive behaviour change. The information alone that physical activity is a heterogeneous behaviour within which there are multiple ways to harness health benefits can increase the capability, opportunity and motivation to change. To test the efficacy and actualise the potential of this instrument however it is necessary to consider how best to apply such a tool in a practice. Both the design and implementation will need careful planning to enhance the efficacy of this approach and the likelihood of its subsequent adoption into research and clinical practice.

2.5.1 Considerations for the visual design of multidimensional physical activity feedback

For many individuals, gauging the significance of scores in terms of health from conceptually abstract parameters and then translating this knowledge into an appropriate action is challenging (Consolvo et al., 2012). Accordingly, one danger with the provision of sophisticated multidimensional physical activity feedback for a health benefit is that users will find it confusing or difficult to interpret its significance. Ultimately the success of the proposed approach will be the communication of multidimensional physical activity data in a way that is readily understandable, engages the user, is easy to use and communicates the correct level of information (Kreps and Neuhauser, 2010). The appropriate design of personalised feedback will be essential for activating its potential mechanisms of action discussed in Section 2.4 such as making the use of this data more informative, motivational and communicating the standards against normative data (DiClemente et al., 2001). One risk is that people could find such sophisticated personalised information to be complicated and difficult to comprehend. Many people tend to overestimate their own physical activity and are thus less likely to intend to change, or even have an awareness of the need to change, their behaviour (van Sluijs et al., 2007). It would therefore be important to provide a clear and complete picture of physical activity
behaviour so that individuals will be able to better understand how different components or domains independently effect specific health goals (such as weight loss). For example, should an individual undertake structured exercise as a means to lose weight but every time they do so they also increase the amount of sedentary time, having a multidimensional profile will reveal that this additional exercise is having a negligible effect on their total energy expenditure (Thompson et al., 2014).

There is also the possibility that some people compensate for an increase in one type of physical activity behaviour by decreasing another (Goran and Poehlman, 1992). These factors can mean that in spite of the introduction of a novel behaviour there is no net effect on total energy expenditure. In this context, when data is potentially complex or intangible, visualisations have a fundamental role in helping to foster understanding (Evanko, 2010; McInerny et al., 2014). Approaches to communicating multidimensional physical activity information could use graphics and exploratory web-based applications linking data and visualisations with an interactive platform (Fox and Hendler, 2011). A detailed discussion of the important design considerations for technologically driven physical activity feedback interventions has been presented by Consolvo and colleagues (Consolvo et al., 2012; Consolvo et al., 2009b). Particularly relevant to the application of multidimensional feedback is that that visuals should be sufficiently abstract and reflective (e.g. aggregated graphical representations of behaviour and activity patterns rather than raw data to help the conceptualisation of goal progress); comprehensive (e.g. include all important aspects of behaviour); positive (e.g. use visual cues to reinforce successful behaviour) and aesthetics (e.g. the visual feedback should be pleasing on the eye). It is unlikely that there will be a definitive design solution to meet the needs of everyone and, given the diversity of the potential audience, user-centred and participatory approaches that involve stakeholders in the design process will be required to ensure that the diversity of user needs are met (Consolvo et al., 2008; Consolvo et al., 2006).

2.5.1 Considerations for the development and evaluation of multidimensional physical activity feedback
User-centred design involves end-users throughout the development processes involved in the design and testing of technological interventions in an effort to optimise its functionality, usability and subsequent engagement to increase the likelihood of facilitating positive behavioural outcomes (De Vito Dabbs et al., 2009). Involving users in this design process is also likely to enhance adherence to eHealth interventions and ensure that systems are not abandoned by dissatisfied users rendering the tools as a costly waste of economic and human resource (Johnson et al., 2005; van Gemert-Pijnen et al., 2011; Kelders et al., 2012). Using qualitative methodologies to inform the design of visual intervention tools and processes can also help refine the content to overcome individual cultural differences and levels of health literacy (Rowsell et al., 2015). This is particularly important as practically speaking, wearable technology has the potential to reach many individuals who are most inactive or at risk, particularly when considering trends in computer and smartphone ownership in the UK, which extends to even the most vulnerable sections of society (Ofcom, 2015).

Nevertheless, in reality physical activity monitors are generally marketed and used by motivated, affluent, healthy young adults who already have a handle of their behaviour and are focused on tracking specific exercises or training for sports making the need to involve potentially unmotivated individuals in the design phase essential (Patel et al., 2015; Consolvo et al., 2012). A recent paper by Yardley et al. (2015) documents the importance of a person based approach to designing eHealth interventions to supporting theory and evidence-based approaches described throughout this chapter to ensure that the technology is persuasive and functional enough to activate these mechanisms and techniques. The authors describe that in depth qualitative research should be used to not only design and evaluate technological interventions, but also to develop an understanding of the psychosocial context of the people who will use them. A useful example would be to use qualitative research in the development phase of the intervention to understand how comfortable users are in self-monitoring with multidimensional physical activity
on their own and when clear directives or examples to follow are needed to best foster the autonomy and competence of the target users (Yardley et al., 2015).

With potential end-user design preferences established it would then be important to the efficacy in a randomised controlled trial, the gold standard and most commonly used experimental design in healthcare evaluations (Kumar et al., 2013). Given the infancy and potential complexity of the present concept it would be important to understand not only the immediate impact for behaviour change, but also the long term impact on behaviour and the extent to which individuals actively use the self-monitoring tool (Klasnja et al., 2011). In this early developmental phase the focus of this investigation will therefore be to establish the efficacy of the provision of multidimensional physical activity (can it work?), rather than its effectiveness (does it work?) (Khan and Tunaiji, 2011).

2.5.3 Aim of Thesis

Despite renowned health benefits of regular physical activity, efforts to increase the activity levels of people have shown to only be modestly effective and short lived. Recommendations for physical activity disseminated at a population level do not appear to be too effective in encouraging sustained changes suggesting that a narrow-focused ‘one-size-fits-all’ approach may not be the most suitable strategy as it neglects other important aspects of ones behaviour. The heterogeneity of physical activity is emphasised by the fact that individuals can be misclassified as being inactive or active depending on the parameter of interest, be it total energy expenditure, sedentary time or variations of moderate to vigorous intensity activity. With technological advancements we can capture more detailed and accurate information about physical activity behaviour than ever before and this data can be used to create integrated pictures of the independently important health-harnessing dimensions. This novel approach has clear benefits to researchers and practitioners in that it enables a more holistic assessment by which to understand the relationship between physical activity and health. Excitingly, a multidimensional approach to physical activity also lends itself to a number of key techniques and theoretical
underpinnings of health behaviour change. Using portable activity monitors individuals have the capacity to self-regulate their physical activity through personalised visual feedback. If the feedback takes a multidimensional form it may provide individuals the necessary capability, opportunity and motivation required to increase their activity levels.

The programme of work carried out within this thesis will therefore seek to undertake an iterative process to develop appropriate multidimensional self-monitoring tool and test its efficacy in an intervention setting (Figure 2-f). Due account will be taken of the need to consider the views of potential end users in the design and evaluation of this tool to optimise its effectiveness and make future recommendations for its application. In the development phase of the present programme of work there is a need to firstly identify an appropriate, cost-effective tool that has the necessary accuracy and precision to capture the multiple health-harnessing dimensions of physical activity. Secondly, the data that the chosen devise captures will need to be transformed into visually evocative feedback that portrays a given individual’s multidimensional physical activity profile and includes the necessary context and interactive features to make it a functioning persuasive recourse. A final feature of the development phase will be to involve members of the target user populations in the refinement of it to ensure it is conceptually comprehensible and informative. Using qualitative methodologies it will also be important to establish whether the multidimensional feedback is engaging and motivating and whether target users have any reservations pertaining to its practical application for supporting any changes to their behaviour. The final phase of the present thesis will be to explore the efficacy of self-monitoring with technology enabled personalised multidimensional feedback for both behaviour and health.
Figure 2-f. Summary of the framework and research questions to be addressed in the present thesis.
Chapter 3 VALIDITY AND RELIABILITY OF MULTISENSOR PHYSICAL ACTIVITY MONITORS

1. What is the validity and reliability of the leading multsensor wearable monitors for measuring multidimensional physical activity?

2. Can data from wearable monitors be turned into visual multidimensional physical activity feedback?

3. Do end-users find personalised multidimensional feedback meaningful and useful?

4. Does personalised multidimensional visual feedback initiate a meaningful change in physical activity behaviour?
3.1 BACKGROUND

Physical activity is widely regarded as a modifiable lifestyle behaviour that can give rise to numerous health benefits and have a preventive effect on several prevalent non-communicable diseases such as cardiovascular disease and type 2 diabetes mellitus (Lee et al., 2012; Warburton et al., 2006; WHO, 2010). Evidence based recommendations for physical activity are typically framed in a unidimensional format and are largely derived from epidemiological data that relies predominantly on self-reported measures (Thompson et al., 2009). Advancements in the battery life and memory capacity of monitoring technology allow us to capture more data than ever before, which permits a greater understanding of the heterogeneous nature of physical activity behaviour with regards to health. For example, there is growing evidence for causal associations with markers of health for total daily energy expenditure or physical activity level (Manini et al., 2006; Saris et al., 2003), reduced volume and breaks in sedentary time (Tremblay et al., 2010; Owen et al., 2010; Healy et al., 2008) and independent influences of moderate and vigorous-intensity physical activity, which can be accumulated in single minutes or bouts (Powell et al., 2011; Strath et al., 2008; Loprinzi and Cardinal, 2013). This wider knowledge has led to calls for more holistic approaches that provide individuals with a more appropriate behavioural picture incorporating all health-harnessing dimensions of physical activity (Esliger and Tremblay, 2007; Scheers et al., 2013b; Thompson and Batterham, 2013).

To successfully capture physical activity behaviour in a multidimensional format presents a number of potential advantages. Firstly, it would help overcome confusion for individuals who are confronted with different recommendations for physical activity, which might classify them as both inactive and active at the same time (Thompson et al., 2009). An example might be an individual who is comfortably achieving the widely reported guideline of moderate-intensity physical activity of 150 minutes per week or 75 minutes per week of vigorous-intensity activity (Department of Health, 2011) but would be considered insufficiently active based on their overall
physical activity level (FAO, 2004). Secondly, there would be a unique opportunity to provide sophisticated feedback to individuals or patients who would benefit from raising their physical activity that would provide them with multiple strategies for change (Thompson and Batterham, 2013). This approach would particularly benefit individuals with specific goals (e.g. informing them that total energy expenditure is likely to have a much greater impact than vigorous activity on weight loss), preferences (e.g. providing alternative solutions for individuals who dislike exercise and gyms) and needs (e.g. for people who are restricted in the time or opportunities to engage in certain aspects of physical activity behaviour). The provision of personalised feedback that clearly distinguishes these key, health-harnessing, dimensions does however rely on the accurate capturing of physical activity (Matthews et al., 2012; Powell et al., 2011).

As discussed in Chapter 2, to measure multidimensional physical activity in a way that is reliable, informative and useable as a tool for supporting behaviour change, the instrument needs to have certain specific characteristics and properties. It should be accurate and precise enough to measure movement at varying intensities repeatedly over time and should have the necessary qualitative resolution to differentiate between activity intensities that contribute to each of the recommendations (Heil et al., 2012). Finally, it should be cost-effective and functional so as to be usefully applied in research, clinical intervention or real-world settings (Andre and Wolf, 2007; Strath et al., 2013). With this in mind, wearable multisensory monitors have the potential to be the most appropriate method for assessing physical activity in free-living conditions as they overcome the commonly purported issues associated with traditional instruments such as the accurate but impractical criterion methods of doubly labelled water and indirect calorimetry, the lack of precision and rigor associated with self-report questionnaires, and the absence of detail required for certain health outcomes associated with pedometers and accelerometers (Berntsen et al., 2010; Plasqui et al., 2013; Butte et al., 2012; van Poppel et al., 2010; Colbert and Schoeller, 2011; Van Remoortel et al., 2012; Chen et al., 2007).
At the time of planning two research-grade multisensor monitors were deemed the best available and most appropriate devices for use in the present programme of work: the Actiheart™ (CamnTech, Cambridge, UK) and the Bodymedia armband (Bodymedia Inc., Pittsburgh, USA). The Actiheart™ uses novel branches chain equation modelling to estimate energy expenditure from uniaxial accelerometry counts and heart rate (Brage et al., 2005), whereas the Bodymedia Armband use pattern recognition or “machine learning” approaches that identify specific activities by applying different types of pattern recognition algorithms to accelerometer data using body heat and sweat response sensors and a bi-axial accelerometer (Fruin and Rankin, 2004). Previous research has shown that the Actiheart™ (Brage et al., 2006; Thompson et al., 2006; Crouter et al., 2007) and Bodymedia armband (St-Onge et al., 2007; Johannsen et al., 2010a; Berntsen et al., 2010) provide reasonable accuracy relative to a criterion method of doubly labelled water or indirect calorimetry. In 2012 Bodymedia released a newer smaller model with a theoretically more sensitive tri-axial accelerometer and updated energy expenditure estimation algorithms. This device remains to be validated and will be the focus of the present investigation.

Importantly, both of these lightweight, portable devices could be effectively utilised in a self-monitoring intervention setting as they provide raw minute-by-minute physical activity data that can be transformed into personalised visual feedback. Thus, the Bodymedia device maybe a more attractive option as a functional instrument for everyday use by a large number of participants. There are however a number of ‘best practice’ considerations that previous validation studies have yet to address, that could be integral to its application as a successful intervention tool (Heil et al., 2012). Kelly et al. (2016) highlight the importance of considering different types of validity and reliability when selecting a physical activity measurement in the Edinburgh Framework. Examples include experimental validity such as examining internal and external sources of bias, the test validity such as the feasibility of using the device in practice and its accuracy relative to criterion measures, and the absolute reliability of the device in performing consistently and stable over time. In the context of capturing and presentation of multidimensional physical activity...
outcomes, it is vital that the content validity is considered over a wide range of activities at varying intensities that typify those of the target population and include measurements for determining sedentary behaviours such as lying, sitting and standing as these account for large proportions of typical free-living day (Bassett et al., 2012). It is also important for trials that intend to monitor physical activity behaviour long-term that the device is precise (test-retest reliability) as well as accurate, that is, they are robust enough to capture the same information over time within the varying intensity thresholds (Brazeau et al., 2011). Finally, previous validation work has tended to focus on a single group such as normal or overweight males or females, however for optimal utility all of these subgroups should be tested within one study (Welk et al., 2012). Previous versions of the Bodymedia have been shown to be less accurate for obese individuals (Papazoglou et al., 2006) although this has yet to be validated in the new model. Therefore the present research will assess the accuracy and precision of both the Actiheart™ and the new Bodymedia Mini for measuring physical activity behaviour in healthy and overweight male and females.

3.2 METHODS

The present study sought to answer the following research questions:

- What is the validity of the Bodymedia Mini and Actiheart™ wearable monitors for measuring energy expenditure across a range of activity intensities and movement patterns?
- How reliable are these devices at measuring physical activity over time?
- How do users feel about the wearability of these devices after a week’s wear?

3.2.1 STUDY DESIGN

The present study took place over three phases. The first stage involved an assessment of the criterion validity of the Bodymedia and Actiheart™ monitors against indirect calorimetry during sedentary, moderate and vigorous activities in a
laboratory setting. The second phase was to examine the test-retest reliability of these estimates were over a series of ten trials. The final phase explored the convergent validity between the two devices for capturing relevant behavioural information in free-living conditions. Ethical approval for the study was provided by the University of Bath Research Ethics Approval Committee for Health (REACH reference number: EP 12/13 3, Appendix A).

3.2.2 PARTICIPANTS

A convenience, quota sampling method was used to recruit thirty two adult male and female participants who were selected to obtain an even split of sex and weight status (normal weight = BMI <25 kg/m² and overweight = BMI ≥25 kg/m²). Invitation for the study was carried out by local advertisement within the university and word of mouth. Sample size estimates were based on previous studies that have compared the accuracy of energy expenditure estimates of the Actiheart™ (Brage et al., 2005; Thompson et al., 2006) and the Bodymedia (Johannsen et al., 2010a; Brazeau et al., 2011) with indirect calorimetry. All volunteers were required to complete the physical activity readiness questionnaire (PAR-Q) and provide written informed consent prior to participation.

3.2.3 MULTISENSOR PHYSICAL ACTIVITY MONITORS

*Actiheart™*: The Actiheart™ (Cambridge Neurotechnology Ltd, Papworth, UK), which integrates an omni-directional accelerometer and heart rate signals and has been described in detail previously (Brage et al., 2005). The unit weighs approximately 8g and is fitted to each adult’s chest midway between and below V1 and V2 (Figure 3-a ‘A’), with the medial electrode located at V5 using two standard ECG electrodes (Telectrode T815, Bio-Protech Inc., Exeter, UK). Data from the Actiheart™ unit collected during the laboratory protocol and free-living were downloaded using associated software. Participant’s descriptive characteristics (i.e. gender, age, mass and height) and sleeping heart rate (as measured by the device in the 7-day trial) were entered into the software (V2.171) for each individual. This information,
accelerometer counts and heart rate was then used to estimate energy expenditure using the most recent branch equation model (Brage et al., 2007).

**BodyMedia Armband:** The Bodymedia Armband (present model referred to as the SenseWear Mini) is a wireless multisensory monitor that integrates motion data from a tri-axial accelerometer along with other physiological responses (*heat flux*: measuring the rate that heat dissipates from the body; *skin temperature*: measuring the surface temperature of the body; *galvanic skin response*: measuring skin impedance or sweat content and constriction or dilation of peripheral vascular system). The device weighs approximately 80g and is worn on the upper arm over the triceps brachii muscle (Figure 3-a ‘B’). Data was processed using the most recent software V.8.0 and algorithms V.5.2. The software calculates the energy expenditure of each minute of data using complex pattern recognition algorithms, composed of “activity classification” and “energy expenditure estimation”. A Naïve Bays classifier is used to match the armband data to the activity class that best describes the current minute. Each activity class has a linear regression model, mapping the sensor values and body parameters to energy expenditure. The specific assumptions and steps relating to these algorithms are not currently made available by the manufacturer.

![Figure 3-a. The Actiheart™ (A) and Bodymedia (B) devices and their respective body placements.](image)

Wear instructions that were provided to participants are displayed in Appendix C for the Actiheart™ and Appendix D for the Bodymedia.
**Indirect calorimetry**: The criterion measure for energy expenditure in the laboratory conditions was acquired using indirect calorimetry. Douglas bags were used to collect expired gas during each activity with the fractions of expired O\textsubscript{2} and CO\textsubscript{2} assessed using paramagnetic and infra-red gas analysers, respectively (Servomex 1440, UK). These analysers were calibrated prior to each test with gases of known composition and volume within the physiological range, as certified by prior gravimetric analysis. A dry gas meter (Harvard Apparatus, UK) was used to measure total expired volume and the temperatures of expired gases measured with a digital thermometer. Energy expenditure for each activity was subsequently calculated using equations determined using Weir (1949) and Frayn (1983) equations for activity and rest.

3.2.4 Procedure

During their laboratory visit, participant height was measured barefoot to the nearest millimetre using a Seca Stadiometer, and weight to the nearest 100g using a set of Waylux 424 Adult Scales. Waist circumference measurements were taken to the nearest millimetre using a Hoechstmass tape measure placed parallel to the floor at the mid-point between the iliac crest and the lowest palpable rib after a gentle exhalation.

**Main laboratory trial**: Participants were asked to come into the exercise physiology research laboratory following a five-hour fast to undergo a series of self-paced and structured physical activities of varying intensity and modality as suggested by best practice guidelines (Welk et al., 2012). The laboratory protocol consisted of three periods of measurement (Table 3-a). Every participant underwent an initial measurement of resting metabolic rate and subsequently a block of self-paced activities and a block of fixed paced activities. To mitigate against fatigue and any adaptive physiological responses participants were randomly assigned to take these blocks in reverse order. Participants were also instructed to take a measured period of rest at the end of both the self- and fixed-paced blocks of activity.
Table 3-a. Description of activities used within the lab validation protocol

<table>
<thead>
<tr>
<th>Task</th>
<th>Description</th>
<th>Activity duration (minutes)</th>
<th>Sample duration (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Resting metabolic rate</td>
<td>Participants were instructed to lie in a supine position on a bed and not talk or move. After 15 minutes the participant was provided with the mouthpiece to allow for a 5-minute habituation period prior to sampling. A total of 4 Douglas bags were taken of 5 minutes each with a minute in between to allow for the changeover.*</td>
<td>45</td>
<td>20</td>
</tr>
<tr>
<td>2. Sitting</td>
<td>Participants were asked to sit in a natural position and again not move their arms or talk for the duration of the task.</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>3. Standing</td>
<td>Participants were instructed to stand upright and still for the duration of the task.</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>4. Folding and stacking</td>
<td>Using their own preferred but uniform speed, participants were instructed to pick up t-shirts one at a time from a pile, fold them as they might their own clothes and stack them on top of each other.</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>5. Box walking</td>
<td>Participants were asked walk back and forth for 4 meters whilst carrying a 6kg box. Participants were instructed to place the box on a flat surface at each end of the walk and pause before picking it up.</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>6. Stationary cycling</td>
<td>Participants were asked to cycle at a comfortable and continuous cadence between 60 and 100 revolutions per minute, keeping their arms fixed to the handlebars.</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>7. Rest</td>
<td>As with the sitting task participants were asked to sit comfortably without talking or moving for the duration of the task.</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>8. Walk</td>
<td>Participants were asked to walk on a treadmill running at 4.8 km/h flat and minimise any variation in their arm swing.</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>9. Incline walk</td>
<td>Participants were again asked to walk at 4.8 km/h on the treadmill set to a 3% gradient.</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>10. Jog</td>
<td>With the treadmill set to a speed of 8 km/h flat participants were asked to jog.</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>11. Rest</td>
<td>Once again participants were asked to sit comfortably without talking or moving for the duration of the task.</td>
<td>8</td>
<td>4</td>
</tr>
</tbody>
</table>

* This conforms to best practice guidelines for resting metabolic rate assessment (Compher et al., 2006).
**Repeatability trial:** Further to the inter-device comparison, one participant underwent a shortened version of the laboratory procedure on 10 occasions to assess the intra-device precision of energy expenditure estimation. Each trial occurred at the same time of the day following a 5 hour fast. An initial familiarisation was taken to ensure that the participant could practice a self-paced technique for each activity that they believed would be maintainable in terms of movement pattern and speed of execution across all 10 trials. The activities were chosen to incorporate multiple levels of intensity and variable movement patterns and included the following tasks as described in table 3-a: sitting (8 minutes total, 4 minutes gas collection), folding and stacking of clothes (8, 3), box walking (8, 2), treadmill walking (8, 2) and treadmill jogging at 8 km/h (6, 1). The participant took 2 minutes seated rest between each activity.

**Free-living physical activity monitoring:** All participants were required to undergo 24-hour monitoring for a seven-day period. Participants were instructed to wear both multisensor monitors for as much of the week as possible removing the devices solely for water based activities including bathing and showering. Participants were also provided with a short survey (Appendix E) with which to judge the comfort and harm of both devices and state their overall preference at the end of the monitored week.

### 3.2.5 Statistical analysis

All data was cleaned and processed in Microsoft Excel. Predicted energy expenditure data from the Actiheart™ and Bodymedia was compared to corresponding criterion energy expenditure data for each activity. Statistical significance was set *a priori* at $\alpha < 0.05$. Analyses of agreement were conducted by comparing indirect calorimetry and predicted energy expenditure from each device using Bland and Altman (1986) plots to calculate absolute bias and 95% limits of agreement. Other comparison statistics were also calculated including mean absolute error for each activity. As it is likely the absolute error of estimation will increase with exercise intensity (Staudenmayer *et al.*, 2012) and to allow comparison between activities, error of estimate data is presented as a percentage (absolute kcal/min is presented in Table
Paired samples t-tests with a Holm-Bonferonni stepwise adjustment to prevent inflation of type 1 error (Ludbrook, 1998) were conducted on lab activities and free-living energy expenditure estimates from the two devices and time spent in each of the six intensity thresholds (sedentary, \(<1.5\) METs; light, \(\geq 1.5\), \(<3.0\) METs; moderate, \(\geq 3.0\), \(<6.0\) METs; vigorous, \(\geq 6.0\), \(<10.2\) METs; and very vigorous \(\geq 10.2\) METs). Independent t-tests were used on both devices to determine whether there were any significant differences in the accuracy of energy expenditure estimation between males and females or lean (\(<25\) Kg/m\(^2\)) and overweight (\(\geq 25\) Kg/m\(^2\)) participants. These analyses were conducted on the overall mean absolute percentage error across the full lab validation trial.

### 3.3 Results

A total of 16 females and 16 males completed both the laboratory protocol and the 7 days free-living PA monitoring. The mean ±SD age of the group was 37 ±13 years who had an average body mass of 78.5 ±16.2 kg, height of 1.73 ±0.10 metres, a BMI of 26.07 ±4.77 kg/m\(^2\) and waist circumference of 88 ±14 cm. The participant who undertook the repeatability trial was a 25 year old male with a body mass of 73.0 kg, a height of 1.78 meters and a BMI of 22.78 kg/m\(^2\). All participants fulfilled the necessary free-living wear time of \(>95\%\) per day on all 7-days, with the mean on body time for the group being 98.6 ±1.2 %. Three participants were excluded from any comparisons involving the Actiheart™ on the basis of having inflated energy expenditure estimations due to extreme low sleeping heart rate (see appendix B for an illustration and discussion of this issue).

#### 3.3.1 Lab Validation Trial for Accuracy

Table 3-b displays the energy expenditure for indirect calorimetry, Actiheart™ and Bodymedia and mean absolute percentage error for the two devices relative to criterion indirect calorimetry for each activity. The energy expenditure estimations
for both devices were close for the sitting and standing activities and for the uniform movements of treadmill walking and jogging. There are indications that the Bodymedia device tended to slightly over-predict energy expenditure for the self-paced activities of box walking and folding and stacking and underestimated energy expenditure for cycling and incline walk. The Actiheart™ also under-predicted the incline walk and cycling and over-predicted the rest periods after a block of activity. Looking at groupings of activities by intensity, the respective mean ±SD energy expenditure (kcal/min) for indirect calorimetry, Actiheart™ and Bodymedia were for sedentary: 1.19 ±0.22, 1.20 ±0.22 and 1.30 ±0.26; moderate: 3.55 ±0.63, 3.33 ±0.84 and 3.82 ±1.07; and vigorous: 7.42 ±1.20, 6.55 ±1.69 and 6.17 ±1.56 (Figure 3-d). When looking at the whole battery of activities together there were no significant differences in the accuracy of the energy expenditure assessment from either device between males and females, nor between lean and overweight individuals.

Bland and Altman plots (Figure 3-b) illustrate the agreement between criterion and predicted energy expenditure for each device by displaying the mean difference and 95% limits of agreement for every activity undertaken in the laboratory trial. For the Actiheart™, the absolute bias ± 95% limits of agreement values was -0.05 ± 3.39 kcal/min, and for the Bodymedia -0.37 ± 2.64 kcal/min. There was evidence of more heteroscedasticity for the Actiheart™ device as shown by raised error as the intensity of activity increased. Visual inspection of the plots for the two devices highlights some tendency for over-prediction of higher-intensity activity relative to more frequent under-prediction of lower-intensity activities. Modified box and whisker plots (Figure 3-c, panel A and B) present the overall and activity specific percentage error of estimate ±95% limits of agreement for all devices and the variability within and between the two devices for each of the activities. Figure 3-c (panel C and D) also displays the percentage error of estimate ± 95% limits of agreement for those activities classified as sedentary, moderate and vigorous in nature. For Actiheart™ this was 2.3 ±13.9 %, -6.2 ±15.6 % and -12.0 ±16.4% and for Bodymedia this was 6.4 ±11.7%, 6.1 ±27.4%, and -19.7 ±14.8% respectively.
Figure 3-b. Bland and Altman plots displaying the absolute bias ± 95% limits of agreement for the Actiheart™ and Bodymedia devices relative to indirect calorimetry in the lab trial for all analysed participants (n=29)

Figure 3-c. Modified box and whisker plots displaying the percentage error for the Actiheart™ and Bodymedia devices across activities and for those grouped according to activity intensity.
Table 3-b. Mean (±SD) energy expenditure and mean (±SD) absolute percentage error for all activities undertaken in the lab trial.

<table>
<thead>
<tr>
<th>Activity</th>
<th>RMR</th>
<th>Sit (kcal/min)</th>
<th>Stand (kcal/min)</th>
<th>Fold (kcal/min)</th>
<th>Box (kcal/min)</th>
<th>Cycle (kcal/min)</th>
<th>Rest (kcal/min)</th>
<th>Walk (kcal/min)</th>
<th>Incline (kcal/min)</th>
<th>Jog (kcal/min)</th>
<th>Rest (kcal/min)</th>
<th>All (kcal/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IC</td>
<td></td>
<td>1.09 ± 0.20</td>
<td>1.21 ± 0.24</td>
<td>1.27 ± 0.27</td>
<td>2.34 ± 0.55</td>
<td>3.96 ± 0.88</td>
<td>6.11 ± 0.23</td>
<td>4.40 ± 0.78</td>
<td>6.33 ± 1.28</td>
<td>1.32 ± 0.30</td>
<td>1.99 ± 0.60</td>
<td>1.46 ± 3.55</td>
</tr>
<tr>
<td>AH</td>
<td>1.16*± 0.17</td>
<td>1.16 ± 0.20</td>
<td>1.29 ± 0.35</td>
<td>1.94 ± 0.80</td>
<td>3.60 ± 1.11</td>
<td>4.34* ± 2.05</td>
<td>1.54 ± 0.63</td>
<td>4.47 ± 1.00</td>
<td>5.40* ± 1.37</td>
<td>10.78 ± 1.72</td>
<td>2.24 ± 0.69</td>
<td>0.74 ± 3.29</td>
</tr>
<tr>
<td>BM</td>
<td>1.16 ± 0.22</td>
<td>1.37* ± 0.29</td>
<td>1.38 ± 0.30</td>
<td>3.70* ± 2.02</td>
<td>1.05 ± 0.29</td>
<td>1.05 ± 0.29</td>
<td>1.32 ± 0.29</td>
<td>1.01 ± 0.21</td>
<td>1.24 ± 0.35</td>
<td>3.55 ± 0.75</td>
<td>1.52 ± 3.34</td>
<td>0.40 ± 0.75</td>
</tr>
</tbody>
</table>

IC = Indirect calorimetry; AH = Actiheart™; BM = Bodymedia; RMR = resting metabolic rate; EE = energy expenditure; MAPE = mean absolute percentage error

* = p < 0.05 for difference between monitor estimation and indirect calorimetry with Holm-Bonferroni stepwise correction

Table 3-c. Mean (±SD) and coefficient of variation (CV) for each measurement device across five activities of varying movement patterns and intensity in the raw and relative format.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Sitting</th>
<th>Fold/Stack</th>
<th>Box Walk</th>
<th>Walk</th>
<th>Jog</th>
<th>Mean of full block</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kcal/min</td>
<td>IC</td>
<td>AH</td>
<td>BM</td>
<td>IC</td>
<td>AH</td>
<td>BM</td>
</tr>
<tr>
<td>Mean</td>
<td>1.44</td>
<td>1.24</td>
<td>1.43</td>
<td>2.23</td>
<td>1.26</td>
<td>2.43</td>
</tr>
<tr>
<td>SD</td>
<td>± 0.09</td>
<td>± 0.00</td>
<td>± 0.05</td>
<td>± 0.15</td>
<td>± 0.05</td>
<td>± 0.38</td>
</tr>
<tr>
<td>CV (%)</td>
<td>5.9</td>
<td>0.0</td>
<td>3.8</td>
<td>6.8</td>
<td>3.6</td>
<td>15.7</td>
</tr>
</tbody>
</table>

IC = Indirect calorimetry; AH = Actiheart™; BM = Bodymedia; † = Trial 5 Jog was subject to gas analysis measurement error during IC and so has been excluded from mean data.

To account for variation in the movement itself the relative scores for each trial were calculated by dividing the mean energy expenditure by the corresponding IC score.
3.3.2 Repeatability trial for precision

The coefficients of variation for all five activities included in the repeatability trial are shown in Table 3-c. The raw, unadjusted values show that across all activities there was 11.4% variation in the Actiheart™ energy expenditure estimates and 5.4% variation in the Bodymedia armband. The Actiheart™ showed good repeatability for sitting (CV = 0%) and folding and stacking (CV = 3.6%) despite underestimating the energy expenditure relative to indirect calorimetry but showed more variation in scores for the box walk, fixed speed walking and running. The Bodymedia showed good repeatability in the fixed speed walk and jog (CV = 5.2% and 6.4% respectively) but provided more variable energy expenditure estimates in the fold and stack and box walk tasks. Relative scores are also shown in table 3-c and figure 3-d, which account for the variation in the movement type itself as indicated by fluctuating CVs in the indirect calorimetry measures. Overall, this marginally improves the variability observed in both devices where coefficient of variance for the Bodymedia falls to 4.8% and the Actiheart™ 8.5%.

3.3.3 Free living assessment

Data for estimated 24-hour energy expenditure is displayed in Figure 3-e. The Actiheart™ predicted mean ±SD daily energy expenditure from all participants to be 2889 ±570 kcal/day whereas the BodyMedia predicted 2707 ±561 kcal/day. Pairwise comparisons indicated that there were no significant differences between the estimates for mean daily or total energy expenditure nor for time engaged in sedentary, light, moderate or vigorous activity or moderate to vigorous-intensity activity accumulated in 10 minute bouts (Figure 3-f). A total of 24 participants completed the wearability evaluation (Appendix E). Of these, 12 stated preference for BodyMedia, 11 Actiheart and 1 stated no preference. In general participants felt more self-conscious wearing the BodyMedia, felt it moved around more and felt slightly more awkward compared to wearing the Actiheart™. More participants felt the Actiheart caused some degree of pain or discomfort compared to the BodyMedia. Raw data for all user feedback can be found in appendix E.
Figure 3-d. Energy expenditure estimates from the Actiheart™ and Bodymedia devices for activities in the repeatability trial.

Each graph represents the five distinct activities: A) sitting, B) fold and stack, C) box walk, D) treadmill walk at 4.8 km.hr⁻¹ and E) treadmill jog at 8 km.hr⁻¹. Panel F shows the relative mean energy expenditure (EE) across all repeats for activities A-E and the combined repeatability when summing the scores for all activities. Raw estimates including the between trial variability for indirect calorimetry is shown in Table 3-c.
Figure 3-e. Mean daily energy expenditure (kcal/day) as estimated by the Actiheart™ and Bodymedia monitors.

Figure 3-f. Mean time spent (minutes per week) and total energy expenditure estimated in each intensity threshold as measured by the Actiheart™ and Bodymedia for all participants.
3.4 Discussion

This investigation sought to determine which of two leading, research-grade multisensor activity monitors would be most accurate and precise and thus suitable for the purpose of capturing and providing feedback on multidimensional physical activity behaviour. Specifically, the present study looked at the validity of physical activity measurement across a number of movement patterns of varying intensity, the reliability of measurement over a number of trials for these activities and the equivalence of these two devices in free-living conditions when measured over 7-days. Overall, both the Actiheart™ and Bodymedia monitors provided similar estimates of energy expenditure across the lab and free-living conditions, and were within 10% of the indirect calorimetry criterion measure. The Bodymedia armband showed marginally improved repeatable than the Actiheart™ across the five tested movement patterns and had tighter limits of agreement relative to indirect calorimetry in the lab trial. However, the Bodymedia did demonstrate more error than the Actiheart™ in its estimation for activities involving either stationary or sporadic arm movements.

A strength of the present study was the comprehensive and stringent lab validation protocol that included a wide range of activities that varied by intensity, movement type and also included a selection of activities that were self-paced and fixed. The Bodymedia device modestly outperformed the Actiheart™ across the full battery of activities as evidenced by its tighter limits of agreement and more homoscedastic energy expenditure estimation across the full range of activities relative to the criterion measure of indirect calorimetry demonstrating less random error in its measurement (Bland and Altman, 1986). Overall the new Bodymedia device showed a mean absolute percentage error of under 9% across the whole battery of activities, which demonstrate improved accuracy relative to validation studies of previous Bodymedia models and software algorithms (Johannsen et al., 2010; Mackey et al., 2011; Berntsen et al., 2010). This said, there appears to be some issues with arm movements that are either highly variable (overestimate) such as that with the self-paced folding and stacking of clothes or activities where the arms in a fixed position
such as the stationary cycling (underestimate). Again, this error in energy expenditure of certain activities has been observed for previous Bodymedia validations (Dudley et al., 2013) and could present a problem for assessments in people who do large amounts of these types of movements.

It is important nevertheless when making judgements about either of the monitors to incorporate all components of the validation study together (Heil et al., 2012; Bassett et al., 2012; Matthews et al., 2012). One could look at the large mean absolute percentage error observed for Bodymedia in self-paced activities such as folding and stacking clothes and box walking and dismiss this device as inaccurate. Looking at the free-living data in the present study however suggests that the error observed in these discrete, self-paced, activities is absorbed when a full 24-hour, 7-day week is measured. In particular, both the Bodymedia and Actiheart™ devices expressed similar estimations of total energy expenditure and time engaged in the discrete intensity thresholds. This suggests that the between device differences observed for folding and stacking and box walking movement patterns represent a negligible period of an individual’s week. In the laboratory the Bodymedia demonstrated the lowest error in activities that would conceivably be considered more representative of a typical weeks’ behaviour such as sitting, standing and walking. Another strength of the Bodymedia device observed in the present study was within the repeatability trial, which one might argue is the most critical factor when selecting a device for use as a self-monitoring tool (Strath et al., 2013). Users who monitor their behaviour overtime would require precise re-measurement of the same activity to be measured at the same rate day-on-day to appropriately track their progress. The overall variance between 10 trials performed on different days was excellent, less than 5% variability for the Bodymedia device, which performed particularly well for the more uniform sedentary, moderate and vigorous movements of sitting, walking and jogging. The Actiheart™ showed overall variability of 8.5% and only outperformed the Bodymedia in terms of its coefficient of variation in the folding and stacking task.
Accounting for all aspects of the validity and reliability tests, it would seem that both the Actiheart™ and Bodymedia present viable options for capturing physical activity across a range of activity intensities over time and could be used to provide information pertaining to the multiple health-harnessing dimensions. Thus, to choose between these two multisensor devices for use in a pragmatic research setting there are other practical factors that should be considered (Powell et al., 2011). It is important, for example, to think about the cost, wearability, and ease of use for the researchers and participants to download and interpret the data (Broderick et al., 2014). Interestingly, there were mixed perceptions regarding the two devices from those who provided feedback with almost the same amount of users stating a preference for each respective device. Both devices scored relatively low when asked about the stability of the device and their influence on behaviour or the user feeling self-conscious or awkward with a slight overall preference for Actiheart™ perhaps because of its more discrete body placement. The Actiheart™ did however come across as more painful or uncomfortable compared with the Bodymedia device due in part to the requirement of adhesive electrodes. It should be considered that a number of alternative consumer multisensor monitors are appearing on the market that may indeed meet some of these practical requirements they have yet to show as good accuracy as the devices observed in the present study (Lee et al., 2014). Furthermore, as these commercial trackers all come with their own software and in-built feedback presentations they are inappropriate for use in the present research setting due to restricted access to raw, manipulable data. Neither the Actiheart™ or Bodymedia Mini device has this issue, but it is noteworthy when choosing between the two devices that the Actiheart™ (at ~£1000 per unit) currently costs significantly more than the price of the Bodymedia armband (<£100 per unit).

There are several notes of caution that should be considered when interpreting the present findings. Firstly, the activities chosen in the current laboratory validation were selected to represent a range of activity intensities and movement types. This however is by no means all the activities that could have been examined and so caution should be exercised when presenting the devices as accurate in other, more
specific settings (Welk et al., 2012). Furthermore the repeatability study conducted as part of the present investigation included just one adult male participant. Based upon the finding that sex or BMI did not significantly impact the error estimates in the current study this was considered appropriate as a test of the device rather than the participant in question. That said, it may be the case that the devices perform differently for people of different body types or in special populations (e.g. extreme obese) and further studies may be advised to clarify this (Matthews et al., 2012). It should be also be acknowledged that the Actiheart™, which itself performed very similarly to the Bodymedia device across all three investigations, would probably have been improved by individual calibration (for a full description of this technique see Brage et al. (2004)). Whilst this method would have most likely improved the accuracy of energy expenditure estimation, it would be an impractical step when delivering large-scale interventions given the requirement for every participant to undergo time-consuming and potentially arduous submaximal exercise testing. Finally, the present study doesn’t evaluate other important components of validity and reliability, which should be considered when selecting these devices for a specific context including the experimental validity (such as potential bias including reactivity or how to handle missing data) and the intra-instrument reliability (Kelly et al., 2016)

In an era where technological advancements are driving an abundance of commercial physical activity monitors to market, there is an opportunity to use these sophisticated devices for presenting richer feedback than has ever been possible. To capture and portray all the important dimensions of physical activity behaviour to a number of individuals it is essential that the instrument used is highly accurate and precise, has the necessary resolution to distinguish variable behaviours and be of low practical and financial burden. The present study shows that of the existing leading research grade monitors, the Bodymedia Mini Armband has improved relative to previous versions and performs very well across all of these criteria. Although similar in accuracy and precision, given the superior practical elements when compared to the Actiheart™, the Bodymedia device offers a viable tool for capturing and self-monitoring multidimensional physical activity behaviour.
Chapter 4 Development of Multidimensional Feedback

1. What is the validity and reliability of the leading multisensor wearable monitors for measuring multidimensional physical activity?

2. Can data from wearable monitors be turned into visual multidimensional physical activity feedback?

3. Do end-users find personalised multidimensional feedback meaningful and useful?

4. Does personalised multidimensional visual feedback initiate a meaningful change in physical activity behaviour?
4.1 Background

Rapid advancements in physical activity monitoring has opened up a number of opportunities for helping individuals self-monitor their behaviour and health (Bonato, 2005; Freedson et al., 2012; Yang and Hsu, 2010). It is well documented that physical activity is integral in the prevention and management of many highly prevalent, non-communicable diseases including heart disease, diabetes and certain cancers (Lee et al., 2012; Warburton et al., 2006; Booth et al., 2008). Through improvements in technology we now not only better understand the health-harnessing properties of physical activity but can also capture and present highly sophisticated information that individuals can use to monitor and potentially change their behaviour (Morrison et al., 2012; Trost and O'Neil, 2014). Given the movement towards a world abounded by mobile Internet and smartphones, the potential to reach a lot of individuals with these devices is extremely large (Pratt et al., 2012). It would seem an invaluable opportunity to not only monitor ones performance as is increasingly present in the fitness consumer industry, but to also use technology to provide widespread personalised health messages and feedback to reduce the risk of chronic disease (Lyons and Lewis, 2014).

In recent years an appreciation for the multiple ways in which physical activity can benefit an individual’s health has developed (Esliger and Tremblay, 2007; Thompson and Batterham, 2013). Elements such as the intensity of activity, the duration of moderate and vigorous physical activity, the amount of sedentary time one undertakes independent of their structured physical activity, and even ones total energy expenditure have all been shown to associate with reduced disease risk (Lee and Paffenbarger, 2000; Haskell, 2009; Powell et al., 2011; Gibbs et al., 2014; Duvivier et al., 2013; Hamilton et al., 2007). Importantly, it is clear that individuals can score highly in one health-harnessing dimension of physical activity but low in another suggesting that these components can be independently modified (Thompson et al., 2009; Scheers et al., 2013a). There are a number of foreseeable advantages to treating physical activity as a multidimensional behaviour that integrates all of these
key behavioural components. For one, it would help individuals draw more appropriate and informed conclusions about their physical activity data from a wearable device by clearing up the confusion that might arise when being described as high active by one definition, but insufficiently active by another (Thompson and Batterham, 2013). Moreover, it may enhance an individual’s autonomous motivation towards physical activity behaviour (Teixeira et al., 2012a) through presenting people with a menu of options from which to set personal goals or targets. If appropriately presented, personalised multidimensional feedback could enable individuals to focus on aspects of their behaviour that aligns to their interests, needs and preferences and thus encourage sustained commitment to both the use of this persuasive technology and any ensuing behavioural changes.

One risk of this approach is that in the absence of well designed, intuitive feedback people could find multidimensional physical activity to be complicated and difficult to comprehend. When data is potentially complex or intangible, visualisations play a fundamental role in supporting understanding and can help contextualise quantitative data in a way that makes it meaningful in terms of the health impact of their behaviour (Consolvo et al., 2012; McInerny et al., 2014). Although seldom explored in the physical activity domain itself, there are certain factors pertaining to the components of visual information that improve comprehension and risk communication of other health behaviours (Suggs, 2006; Bennett, 2010; Lipkus and Hollands, 1999). A notable example would be the simple yet effective use of traffic light colours on nutrition labels for promoting healthier food selection (Hawley et al., 2013). Several studies from a number of countries deploying a traffic light system on front of food packaging have shown this method to encourage consumers to make healthier choices (Borgmeier and Westenhoefer, 2009; Campos et al., 2011; Jones and Richardson, 2007; Roberto et al., 2012). This is one of a number of approaches that could quite conceivably be used for depicting performance in relation to the various health-harnessing aspects of physical activity behaviour in a visually evocative way.
Although multidimensional feedback could be used as part of a one-off assessment to show people how active they currently are, potentially the most useful application would be to apply it on a personalised basis over time. The ability to self-monitor physical activity for a sustained period has been championed as one of the most effective techniques used to engender a positive change in behaviour in adults (Greaves et al., 2011; Dombrowski et al., 2012; Michie et al., 2009). Furthermore, continuous feedback on a health behaviour that is personalised or tailored to an individual could more effectively resonate with the recipient and thus would have a better chance of initiating a positive behaviour change (Noar et al., 2010; Krebs et al., 2010; Hobbs et al., 2013). In this context, whilst the guidelines towards sufficient activity levels are fairly ubiquitous for adults, visual presentations that help individuals identify with their own activity patterns and its implications across the key health-harnessing dimensions could be very effective. If this personalised message is sufficiently evocative, it may even drive people to install lasting changes, a feature missing from prior interventions (Vandelanotte et al., 2007). Moreover, carefully designed feedback could be applied alongside other self-regulatory techniques to help a user plan and track their progress such as goal setting and action planning (Consolvo et al., 2012; Carter et al., 2013). Given the trend towards web and mobile health applications, it would also be important for the visualisations to be in a format that can be successfully integrated with an interactive platform (Fox and Hendler, 2011).

The aim of the present investigation was to examine the possible ways that minute-by-minute physical activity data could be presented to effectively highlight the meaningful domains of physical activity, distinguish clearly the multiple aspects of physical activity important to health and could be integrated as an interactive Internet-based personalised feedback resource.
4.2 METHODS

The present study sought to address the following research questions:

- How can minute-by-minute energy expenditure data be transformed into graphical presentations of physical activity that clearly define the multiple dimensions of physical activity?
- Can the feedback take a format that is considered informative, motivational and functional in the context of self-regulatory behaviour change techniques?

4.2.1 STUDY DESIGN

The present study adopted an iterative design process where by a ‘Concept Team’ of academics and health professionals (research team) and ‘Design Team’ of graphic designers (Information is Beautiful, London, UK) collaborated to develop and refine a selection of visuals (Van Velsen et al., 2013). Initially, the Concept Team identified 3 essential and 3 desirable information needs for the graphics, which were provided in a briefing document provided to the Design Team. The Design Team then created several visual options using a raw minute-by-minute 24/7 physical activity data file.

4.2.2 ORIGINAL BRIEF

The Concept Team, composed of several multidisciplinary academics from exercise physiology, health psychology and social marketing and a GP, reviewed existing health communication sources including graphic design theses, infographics and visuals developed by other health initiatives to communicate risks and guidelines, and existing commercial based activity monitoring apps and websites. As championed in the requirements development approach (Van Velsen et al., 2013) discussions were also made around the technological application of the visual feedback and the needs and characteristics of the end users (e.g. inactive/‘at-risk’ patients). From this review the concept team developed and identified the following three essential ‘design needs’ that were considered integral to the portrayal of personalised multidimensional physical activity feedback:
Need 1 – Multidimensional physical activity: the feedback should include designs that capture five independent health harnessing portrayals of physical activity behaviour and incorporate them into a single profile that highlights the strengths and shortcomings of a given individual and helps them to focus on particular areas of interest.

Need 2 – Daily activity patterns: to help individuals better understand their behaviour and be able to identify the source of their multidimensional target attainment clear, high resolution 24-hour activity patterns graphs should also be displayed. These graphs would ideally display both time and energy expenditure and break down the intensity of activity.

Need 3 – Activity summary: a final distinct element of the feedback should be lucid summary statistics that provide average or summative graphs of their weekly behaviour in terms of both the time spent and calories burned within specific intensity thresholds. This should help them to understand the relationship between time and energy expenditure.

In terms of the requirement for the feedback to be motivating and integrative of key self-regulatory behaviour change techniques the following desirable design needs were also presented as part of the briefing:

Need 4 – Targets and goals: this involves the provision of visual incentives that enables users to use their personalised multidimensional physical feedback to develop individual targets or goals that would help them achieve the recommended physical activity levels.

Need 5 – Normative information: another desirable aspect for the designs was for the visual feedback to incorporate comparison with other people of the same characteristics as the individual (i.e. sex and age) with particular reference to summary activity (time and calories).
**Need 6 – Historical data:** the final desirable aspect of the feedback was to have clear visual graphs that would help users track their progression of the multidimensional health target attainment over time and where possible include added incentives such as ‘personal bests’.

A final facet of the original design brief was a reiteration of the requisite for the feedback to be intelligible, comprehensive and, where permitting, motivational. Emphasis was therefore placed in the need to be mindful of the target audience, which in the present context was to be largely inactive members of the general public, and the omission of technical language. A final request was for the designs to be in a format compatible with web-based or mobile platforms so that they could be automatically generated from raw physical activity data.

**4.2.3 Physical activity data handling**

To further enable the graphic designer to identify with and understand the final graphical displays they were asked to wear an activity monitor for a week and use their own data. Minute-by-minute energy expenditure was captured using a Bodymedia armband [Sensewear Professional 8.0 Pittsburgh, US] for seven complete days. Once the device was returned and downloaded Microsoft Excel files containing columns with date-time and minute-by-minute energy expenditure was provided back to the design team. This file was cleaned so that 7-days of 1440 minutes per day (10080 data points in total for the week) comprised the raw data. Thresholds for determining the intensity of a given minute of activity were based on metabolic equivalents (MET) of the individuals basal metabolic rate (BMR, as calculated using Schofield (1985a) equation) where a MET threshold of ‘1’ would be 1 x BMR. Sedentary time was classified and every data point <1.5 METs, light activity ≥1.5, <3.0 METs, moderate activity ≥3.0, <6.0 METs, vigorous activity ≥6.0, <10.2 METs and very vigorous activity >10.2 METs.
4.3 RESULTS

In order to fully demonstrate and describe the iterative provision-revision process undertaken in the present study, the results presented below show examples of the designs that were provided by the graphical design team followed in each instance by a responsive commentary of positive observations and suggested revisions provided by the concept team.

4.3.1 ITERATION ONE

Two of the five examples from the first set of designs can be found in Figure 4-a. The key elements of these initial designs were that they were largely all-encompassing, that is they included the activity pattern, summary statistics and multidimensional health targets on one page. There were subtle differences in the portrayal of 24 hour activity patterns such as the radial versus line format and the introduction of colour but the performance indices were relatively consistent, using a dot and circle format. Strengths of these initial designs were that they successfully transformed the raw minute-by-minute physical activity data into the information as set out in the three essential design needs. Furthermore, there was some degree of variability in the display of activity patterns suggesting that there might be more abstract formats with which to present this data. The use of icons for signposting the appropriate health target or summary statistic was also commended feature of these initial designs. Nonetheless, there were also a handful of suggested improvements identified by concept team that were fed back to the designers:
Figure 4-a. Examples of initial graphics generated by the design team.
**Point 1 – Multiple designs:** The Concept Team felt that for the purpose of testing a variety of feedback options on users it was important to have at least 2, or preferably 3, information graphics for the presentation of each specific information need. Ideally this would include quite diverse graphical options that ranged from something quite simple and easy to understand to something more informative but that possibly requires a little more explanation and time to fully comprehend.

**Point 2 – Information needs:** The Concept Team also provided further clarity on the specific information needs which included: 1) Day-to-day activity energy expenditure over a 7-day period (complete data); 2) Summary of weekly energy expenditure data (‘what it means’); 3) Comparison to recommendations and level of ‘risk’ identified; 4) Targets and goal setting (energy expenditure or calorie and activity targets); and 5) Comparison with other people i.e. norms. The first four of these were incorporated into the designs presented in iteration 1 (Figure 4-a) although items ‘3’ and ‘4’ were combined in the current schematics. The final need was an additional item highlighted for consideration that may help put an individual’s feedback into perspective.

**Point 3 – Clarity of message:** With regards to the clarity of the feedback designs, the Concept Team identified that words such as ‘METs’ might in fact be confusing for users and could be avoided by referring to the intensity of physical activity using the following terms: sedentary, light, moderate and vigorous. The revised briefing did however clarify that the use of these terms would not preclude the use of METs in activity-intensity calculations, but avoid the use of acronyms and the need to define terms and thus minimising the chance of information over-load to help a user’s understanding. Another factor identified in response to the iteration 1 designs was that the use of colour might be way to provide an extra dimension to the physical activity data and potentially enhance understanding. For example, it was suggested that to help the intended users comprehend the ‘risk’ of being insufficiently active, a scheme such as the traffic light system could be used as it would already be familiar
to many users (e.g. in food labelling). It was also proposed that for representing activity intensity, colour schemes merging from blue to red may be an effective index of sedentary to very vigorous intensity activity due to its potential conceptual associations with body temperature and/or calories ‘burned’.

**Point 4 – Computational challenge:** From a practical perspective, the Concept Team reiterated in their design feedback the importance that the chosen graphics can be re-created by members of the research team for individual users and on a case-by-case basis during subsequent research activities. It was also stated that one of the proposed aims and applications for the visual feedback developed in the present study was to provide end users with an opportunity to self-monitor their behaviour using an interactive mobile or web-platform. As such, the Concept team sought clarity on a method for creating graphics based on real data collected in a research context and using techniques that are not too computationally intensive for this purpose are possible (e.g. using a template)?

4.3.2 **Iteration two**

The second iteration of designs are shown in Figure 4-b, which saw a number of new formats and a notable introduction of colour to distinguish the different intensity thresholds in the activity pattern and summary graphics. In addressing the iteration one comments, the Design Team developed multiple options to address each of the 3 core information needs and explored both daily and weekly options for presenting activity patterns. The strengths of the iteration two designs included the cold to hot colour scheme that saw the sedentary, light, moderate, vigorous and very vigorous intensity thresholds visually defined as shown in the first two graphics in figure 4-b. The language used had also been softened and the figures were less text-dominant, with figures using visual keys to inform the user. Overall, these designs were seen as an improvement on those developed in iteration one however the Concept Team did provide a handful of revisions, which were fed back to the design team:
A) Activity patterns

B) Activity summary

C) Multidimensional health targets

Figure 4-b. Examples of the second iteration of graphics revised by the design team
**Point 1 – The key:** The Concept Team felt that the purpose of the more detailed key was to introduce and help users understand the terminology surrounding the distinct intensity thresholds. For the intended research and practical use it was recommended that the key did not need to be included on the same page as the feedback graphs themselves so that they did not use up space. In addition, it was proposed that a larger key could be developed with subsequent graphics using a condensed key and that the Design Team could revise the images for vigorous to brisk walk (flat or uphill), cycling, and swimming with text to also include jogging, for very vigorous to running, squash and basketball with text to include reference to high intensity competitive sports. A final suggestion was that some of the figures across the categories should also be made female so that there was an equal ‘sex’ distribution.

**Point 2 – Physical activity patterns:** The variability between daily and weekly physical activity pattern graphics was deemed sufficient for further testing however the Concept Team did recommend that all graphics should however include the grey coloured sedentary behaviour to enable users to identify inactive periods throughout the days and weeks. The Concept Team also felt that the graphics with horizontal segregations to identify activity intensity (e.g. Figure 4-b ‘A’) was conceptually confusing and proposed that a graph that displays the intensity colour as a vertical line from baseline be drawn up. A further request of the Concept Team was that the written detail and participant names preceding each graphic be removed to again bring the feedback itself to prominence, with a small key for reference. Finally, it was asked whether the weekly graphs could include a small bit of text that indicates the total number of calories burnt per 24-hour period to allow for an easy comparison between days.

**Point 3 – Summary options:** With regards to the activity summary graphics (Figure 4-b ‘B’), the Concept Team proposed that a third option such as a pie chart that also shows the magnitude of each distinct intensity threshold in terms of time and calories burned should be drawn up. The Concept team also expressed a preference for the
bar based graph to maintain the colour on the bars rather than the black and white variant and to retain the central threshold title and remove sleep from the graphic. It was felt that to make it more accessible and useful for users this information should also present as average daily values across the week (rather than the sum of week) and/or for a given day.

**Point 4 – Targets and recommendations:** In reviewing the multidimensional health targets (Figure 4-b ‘C’), the Concept Team felt that the visuals might be improved by the use of traffic light colours, as conceptually this provides a clear ‘hit, near or miss’ message to users such as with nutrition labelling and would support the visual discrepancy in interpreting performance relative to the target. There was also a request that a simple version that only codes based on the colours for each of the five physical activity dimensions was drawn up using these traffic colourings. The Concept Team also recommended that it would be helpful to users if the terminology was again made simpler as per the following suggestions: calorie burn score (rather than PAL or physical activity level), moderate activity (mins), moderate bouts (mins), vigorous activity (days) and sedentary time (% of day).

### 4.3.3 Iteration Three

The final iteration of designs created by the Design Team successfully acted upon all of the feedback provided by the Concept Team during iteration two. Figure 4-c shows the individual key, the 24-hour graded line graph, revised summary data bar and pie graphics and three variants of traffic light coloured multidimensional health targets. The designs also included the ability to make literal and cosmetic changes to their accompanying text. The final phase of this investigation was to test the functionality of the designs in order to test their efficacy, firstly in print format for an initial qualitative investigation with potential end users (Chapter 5 and 6) and secondly in an interactive web-based format as part of a randomised controlled self-monitoring based intervention trial (Chapter 7 and 8). To this end figures that could not be automatically generated using widely accessible Microsoft office software or that required extensive and timely manual formatting were dismissed as unfeasible. The
The final format of these visuals that were viably integrated with the intended technological application are presented in Figure 4-d and Appendix G.

A) Revised key and daily activity patterns

B) Revised activity summary graphics

C) Revised multidimensional health targets

Figure 4-c. Examples of the third iteration graphics generated by the design team
4.4 DISCUSSION

Advancements in wearable technology for physical activity tracking have improved the resolution and precision so that they now give 1,440 data points per day and over 10,000 per week. Potentially, the translation of this complex raw energy expenditure data generated by sophisticated multisensor physical activity monitors into clear and informative visual feedback presents a challenge. The current study however introduces several options of varying design complexity that can be used to portray these data. More specifically these designs indicate how the independent health-harnessing dimensions of physical activity can be captured and integrated into single integrated graphics along with innovative, and in some cases abstract, portrayals of activity patterns and daily average summary statistics.

This chapter demonstrates a number of ways in which the multiple aspects of physical activity that have been shown to be important for health can be integrated to create a single profile of personalised overall physical activity behaviour. Traditional physical activity feedback used in research and commercial settings has tended to focus on single outcomes such as moderate to vigorous exercise derived from questionnaires, steps from pedometers or accelerometer ‘counts’ that do not paint a complete contextual picture of physical activity (Thompson and Batterham, 2013). Even in popular commercial activity trackers such as the Nike+ Fuelband™ and Fitbit™ it is common to only see single scores for steps or calories or activity without the necessary context to judge if changes in these parameters are meaningful when it comes to health (Consolvo et al., 2012). It is hypothesised that the new holistic approach to physical activity feedback introduced in the present study will provide more empowerment and ownership of their behaviour to its recipient through enhanced awareness (Nutbeam, 2000). More specifically, having multiple health targets might raise awareness of certain aspects of an individual’s behaviour that was previously unthought-of and at the very least help recipients who were previously unsure gauge whether or not their current behaviour is appropriate.
As well as being sufficiently informative, another aim for the visual feedback developed in the present study was for the designs to encompass elements that would help motivate users into making positive behavioural changes. Previous technology-based interventions that utilise behavioural feedback and self-monitoring for the self-regulation of physical activity have been efficacious (Webb et al., 2010; Morrison et al., 2012) and visualisations that resonate clear health messages have been shown to positively influence health behaviour in other settings (Borgmeier and Westenhoefer, 2009; Campos et al., 2011; Jones and Richardson, 2007; Roberto et al., 2012). Researchers, commercial health providers and or policy makers could also usefully apply the visual feedback developed here to better inform certain populations of the important elements physical activity. The proposed aim for the feedback developed in this thesis is to utilise it as a preventive strategy in individuals who are insufficiently active and/or at heightened risk of future chronic disease. At this stage however the designs have been developed with no input from members of this target audience. For the multidimensional feedback to be effective they must not be confusing or misleading. It is also unknown what degree of support might be required to help interpret the feedback, which may also be a critical factor in their application as a behaviour change tool. A useful future direction therefore would be to adopt a user centred approach to refine these visualisations and ensure they are sufficiently comprehensible, informative and motivating (Yardley et al., 2015).

In conclusion, advanced technology has enabled the capturing of accurate physical activity data at a high resolution and thus affords a fantastic opportunity to give individuals in need of a lifestyle change comprehensive feedback about their behaviour. The present study has demonstrated several of the possibilities for presenting sophisticated physical activity data in simple, complicated and abstract formats. There are elements in the presented designs that help visualise daily activity patterns, quantify the time spent in physical activity intensity and depict a given individuals performance in relation to the key health harnessing recommendations. These data, which can be integrated in print, internet or mobile formats, would
foreseeably facilitate key self-regulatory behaviour change techniques for raising awareness, self-monitoring behaviour, goal-setting, and action planning. Future studies wishing to implement multidimensional feedback in a health-care or intervention setting should adopt a user-centred design approach to evaluate whether designs such as these are sufficiently clear, informative and motivating.
Figure 4-d. Final technology-enabled feedback designs portraying physical activity patterns (A-C), activity summary data (D-F) and health targets (G-I). These appear in larger format in Appendix G.
Chapter 5 The Understanding and Interpretation of Multidimensional Physical Activity Feedback

2. Can data from wearable monitors be turned into visual feedback?

3. What is the validity and reliability of the leading multisensor wearable monitors for measuring multidimensional physical activity?

3. Do end-users find personalised multidimensional feedback meaningful and useful?

4. Does personalised multidimensional visual feedback initiate a meaningful change in physical activity behaviour?
This declaration concerns the article entitled:

The understanding and interpretation of innovative technology-enabled multidimensional physical activity feedback in patients at risk of future chronic disease

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Candidate’s contribution to the paper (detailed, and also given as a percentage).

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<td>Formulation of ideas:</td>
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<td>The candidate was integral to the conceptualisation of the present investigation in its eventual format although the intention to conduct the study to inform the development of the Mi-PACT RCT was conceived by the Principal Investigator as part of the original grant application.</td>
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Design of methodology:

The candidate considerably contributed to the design of methodology used in the study including the development of the topic guides for interviews, the selection and creation of the feedback document, and the selection of qualitative analysis techniques.

Candidate contribution = 80%

Experimental work:

The candidate was responsible for all data collection in the study and for running the analysis. The remaining authors helped check and agree with the thematic coding of transcripts.

Candidate contribution = 90%

Presentation of data in journal format:

The candidate drafted the manuscript in its entirety, created the figures and tables and formatted it in accordance with the journal specifications. Other authors provided critical comment to help revise the manuscript.

Candidate contribution = 80%

Signed

Date

This paper reports on original research I conducted during the period of my Higher Degree by Research candidature.
5.1 BACKGROUND

Physical inactivity has a powerful effect on global health and an increase in activity would have an enormous impact on the burden of chronic disease (Lee et al., 2012). Of all the strategies implemented to positively change an individual’s behaviour, self-monitoring is one of the most effective (Michie et al., 2009; Dombrowski et al., 2012). In the past few years, technological innovation has transformed the landscape and a plethora of instruments are now commercially available for the self-monitoring of physical activity. These include devices produced by major international companies such as Fitbit®, Jawbone UP™, GENEActive™, Philips® DirectLife™ and Nike+ Fuelband™. Large technological manufacturers such as Samsung, Apple and Microsoft have also now entered the market (Chu, 2014; Rawassizadeh et al., 2015). Some of these devices have only limited published validity to date but it is noteworthy that one commercially available multi-sensor instrument from Bodymedia® is already classified by the US Food and Drug Administration (FDA) as a Class II medical device. Thus, as instruments become more accurate, affordable, comfortable and discrete (Chen et al., 2012) millions of people around the world are beginning to use physical activity monitoring technologies and such self-monitoring will become increasingly common in the future (Thompson, 2016).

It was recently demonstrated that using the data collected from even the most sophisticated physical activity monitors provides erroneous information about an individual’s physical activity unless this includes a multidimensional profile constructed across the key physical activity dimensions (Thompson and Batterham, 2013). It is quite possible for a given person to score highly in one physical activity dimension but low in another (e.g. one could engage in substantial vigorous intensity activity but still spend over 80% of their day sedentary) (Thompson and Batterham, 2013). This is a problem because people sometimes focus on just certain physical activity behaviours without taking into account other dimensions and this could lead to misguided perceptions and expectations. For example, an individual with a weight-loss goal who substantially increases their vigorous intensity structured physical activity might only see a relatively modest impact on overall energy expenditure.
Knowledge of all the important physical activity dimensions could remove the potential ambiguity in understanding how their behaviour relates to their goals as well as providing more behavioural options that align to their needs and preferences and offer sustainable solutions.

Although there is now have the technology to provide feedback that integrates the important multidimensional health-harnessing aspects of physical activity this potentially introduces new risks and challenges. An understanding of personal physical activity is integral to various models of behaviour change and regulation (Kirschenbaum, 1987; Weinstein et al., 1998). In this context, sophisticated multidimensional physical activity feedback could be seen as more confusing and/or difficult to interpret than simple unidimensional messages. Before we can capitalise on technological innovation, it is important to establish that people can understand multidimensional physical activity feedback in terms of what the feedback represents, the concept of different physical activity dimensions, and the overall meaning of personalised data. There is good evidence that people and patients prefer visual and meaningful images rather than numerical scores and these can be used to increase attention and comprehension of health education information (Edwards et al., 2002; Houts et al., 2006). Clearly, evaluating the design of the graphical images and representation of multidimensional physical activity feedback will be important for optimising its usefulness as a tool for behaviour change.

To date, there has been very little attempt to determine whether people can understand the information that is available and provided with the advent of increasingly sophisticated physical activity monitors. In particular, there has been no attempt to establish that people can handle potentially complex and conflicting information across the biologically healthful physical activity dimensions. This is especially important in clinical populations who would benefit most from a change in physical activity behaviour (e.g., as a route to manage their risk of chronic disease) (Patel et al., 2015). Thus, the purpose of this study is to explore the understanding, interpretation and potential utility of personalised multidimensional physical activity
feedback amongst patients at future risk of chronic disease to inform the development of interventions wishing to examine and adopt this approach as vehicle to support behaviour change.

5.2 METHODS

The present study sought to answer the following research questions:

- Do patients that have been identified as at heightened risk of cardiovascular disease and/or type two diabetes find the multidimensional visual feedback developed in Chapter 4 clear, informative and usable?
- Do healthcare professionals support the views of patients as to the utility of this feedback?
- What are the preferences in terms of graphic design and how can they be improved?

5.2.1 STUDY DESIGN

Having worked with professional infographics specialists (Chapter 4) to develop multidimensional physical activity visualisations the present study sought to determine whether patients and healthcare professionals who were presented personalised feedback during a one-to-one semi-structured interview on their objectively monitored physical activity could comprehend these designs and whether they subsequently found this information useful. Ethical approval for the study was obtained from the National Research Ethics Service Committee South West (REC reference 12/SW/0374, Appendix F).

5.2.2 PARTICIPANTS

Patients were invited to take part if they had been identified as being at moderate (10-19.9%) or high (>20%) risk of cardiovascular disease and/or type II diabetes based on their attendance of an NHS Health Check at one of two general practices. The NHS
Health Check calculates 10-year disease risk based on a number of factors including age, sex, Ethnicity, address, smoking status, family history of disease cholesterol/HDL ratio blood pressure and Body mass index (see appendix H for full list of factors). Of 244 eligible patients who were invited by general practices, 56 declared an interest and 30 ended up consenting to take part. In addition, purposive sampling was used to recruit 15 healthcare professionals (HCPs) including 3 general practitioners, 3 nurses/healthcare assistants, 3 research nurses, and 6 physical activity healthcare trainers from two regions in the UK (Bath and North East Somerset and Wiltshire). Descriptive characteristics of participants are shown in Table 5-a. HCPs were included to not only provide an insight to the interpretation of their own data and thereby be in a better position to judge its utility in practice, but also as they were exposed to a broader patient population. All participants provided written informed consent.

5.2.3 PROCEDURE

Participants were provided with an arm-mounted Bodymedia Armband (SenseWear® Pro 8.0, Pittsburgh, USA), which accurately estimates energy expenditure (Johannsen et al., 2010; Lee et al., 2014; Fruin and Rankin, 2004). Participants were instructed to wear the device for seven consecutive days commencing at midnight and asked to only remove the device for showering or water-based activities (Scheers et al., 2012b). Minutes spent in the distinct intensity thresholds based on metabolic equivalent cut points (METs) and multidimensional health target attainment were calculated (Thompson and Batterham, 2013). Intensity thresholds were set using ubiquitous cut-points as follows (where 1 MET is equivalent to the basal metabolic rate (BMR) for each participant as calculated using the age and sex-matched Schofield equation (Schofield, 1985a)): Sedentary activity = <1.5 METs; Light activity = 1.5-2.9 METs; Moderate intensity activity = 3.0-5.9 METs; Vigorous intensity activity = 6.0-10.1 METs and Very vigorous intensity activity = ≥10.2 METs (Thompson and Batterham, 2013). In order to complete the 7-day, 24-hour record, each minute of missing data where participants had removed the device as instructed was assigned that individual’s BMR (Schofield, 1985).
Table 5-a. Demographic characteristics of all participants included in the analyses

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Patient (n = 29)</th>
<th>HCP (n = 15)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sex</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>21 (72%)</td>
<td>6 (40%)</td>
</tr>
<tr>
<td>Female</td>
<td>8 (28%)</td>
<td>9 (60%)</td>
</tr>
<tr>
<td><strong>Age</strong></td>
<td>63 (7)</td>
<td>48 (10)</td>
</tr>
<tr>
<td>&lt;45</td>
<td>1 (3%)</td>
<td>4 (27%)</td>
</tr>
<tr>
<td>45 – 54</td>
<td>2 (7%)</td>
<td>6 (40%)</td>
</tr>
<tr>
<td>55 – 64</td>
<td>9 (31%)</td>
<td>4 (27%)</td>
</tr>
<tr>
<td>65 – 74</td>
<td>17 (59%)</td>
<td>1 (7%)</td>
</tr>
<tr>
<td><strong>Marital status</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single</td>
<td>2 (7%)</td>
<td>3 (20%)</td>
</tr>
<tr>
<td>Married/ Civil partnership/ Cohabiting</td>
<td>22 (76%)</td>
<td>7 (47%)</td>
</tr>
<tr>
<td>Divorced/ Separated/ Widowed</td>
<td>5 (17%)</td>
<td>5 (33%)</td>
</tr>
<tr>
<td><strong>Highest educational attainment</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>2 (7%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>GCSE or equivalent</td>
<td>7 (24%)</td>
<td>3 (20%)</td>
</tr>
<tr>
<td>A-Level or equivalent</td>
<td>3 (10%)</td>
<td>3 (20%)</td>
</tr>
<tr>
<td>1st Degree or equivalent</td>
<td>12 (41%)</td>
<td>5 (33%)</td>
</tr>
<tr>
<td>Higher degree</td>
<td>5 (17%)</td>
<td>4 (27%)</td>
</tr>
<tr>
<td><strong>Smoker</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>2 (7%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>No</td>
<td>27 (93%)</td>
<td>15 (100%)</td>
</tr>
<tr>
<td><strong>Height (m)</strong></td>
<td>1.74 (0.10)</td>
<td>1.73 (0.09)</td>
</tr>
<tr>
<td><strong>Weight (kg)</strong></td>
<td>82.0 (16.7)</td>
<td>76.7 (10.4)</td>
</tr>
<tr>
<td><strong>BMI (kg/m^2)</strong></td>
<td>26.9 (4.3)</td>
<td>25.7 (3.5)</td>
</tr>
<tr>
<td><strong>Waist circumference (cm)</strong></td>
<td>95.0 (12.6)</td>
<td>84.5 (10.4)</td>
</tr>
<tr>
<td><strong>Physical activity dimensions</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physical activity level</td>
<td>1.83 (0.31)</td>
<td>1.72 (0.21)</td>
</tr>
<tr>
<td>Daily sedentary time (% waking day)</td>
<td>68 (11)</td>
<td>69 (11)</td>
</tr>
<tr>
<td>Daily moderate activity (min/day)</td>
<td>134 (75)</td>
<td>107 (45)</td>
</tr>
<tr>
<td>Weekly moderate-vigorous bouts (min/week)</td>
<td>479 (361)</td>
<td>341 (208)</td>
</tr>
<tr>
<td>Weekly vigorous activity (min/week)</td>
<td>100 (147)</td>
<td>125 (128)</td>
</tr>
</tbody>
</table>

a= Values reported as mean (standard deviation)
b= Physical activity dimensions that were presented in the ‘health target’ section of the feedback were:
- Physical activity level (PAL) was the average total daily energy expenditure/basal metabolic rate (Kcal/day)
- Daily sedentary time was the percentage of a 16 hour waking day (8 hours of sleep was assumed and subtracted from the total sedentary time) spent sedentary (<1.5 METs)
- Daily moderate activity was the average number of single minutes of moderate activity (≥3 METs, <6 METs)
- Weekly moderate-vigorous bouts included all activity greater than 3 METs sustained for at least a sustained period of 10 minutes
- Weekly vigorous activity combined all the minutes of vigorous activity (>6 METs) accumulated over the monitored week
All participants (n = 44) were invited to attend a two-hour digitally-recorded one-to-one interview conducted by the candidate. Interviews primarily took place at the University of Bath (patients) or their place of work (HCPs). Participants were typically interviewed within 2-3 weeks of their physical activity monitoring period. The interview topic guides for HCPs and patients (Appendix I and Appendix J) were compiled with input from an expert panel of academics and health professionals including 3 senior health psychologists, 2 senior health physiologists, 2 social marketers, a general practitioner and a research nurse. They included questions to capture interviewees’ views on physical activity and the importance they place on it (prior to seeing feedback), the preferences and comprehension towards the various feedback designs and the impact of receiving personalised physical activity feedback in terms of its motivational properties and practical application. Aside from the interpretation of their own feedback, HCPs were questioned about anticipated understanding from their patient’s perspectives (rather than themselves). Participants were shown the designs in a random order derived by drawing numbers one, two or three representing the sequence as they appeared in the booklet, so that overall preferences were not influenced by exposure order. Each section of graphics and individual designs was given a brief verbal introduction by the interviewer.

5.2.4 PHYSICAL ACTIVITY DATA

As described in Chapter 4, the infographics we used to depict the physical activity data were created in collaboration with graphic design specialists Information is Beautiful©. An iterative process was used to develop three sections of information: activity patterns over a day or week, summary graphics of time and energy spent in varying activity intensities, and depictions of performance in relation to multidimensional health targets. Following a phase of piloting and refining initial designs with health professionals (n=2) and members of the general public (n=2), a final booklet containing three distinct visualisations for each section of information was developed and shown to participants at interview with their personalised data (an example of this booklet for one participant can be found in Appendix G). Figure
5-a provides two extracts and examples of the multidimensional physical activity profiles shown in section 3 of the personalised feedback portfolio.

![Multidimensional Physical Activity Profiles](image)

Figure 5-a. Two examples of the 3 variants of infographics depicting the multidimensional physical activity behavioural recommendations. **Green** represents a ‘hit’ target, **amber** a ‘near’ target (within 25%) and **red** a ‘missed’ target (>25% away). Graphic i) is a simple colour coded wheel format where each segment represents each dimension but has no magnitude; ii) uses a reference target bar to compare a coloured bar scaled to the relative value attained within each dimension; and graphic iii) places the individuals performance for each guideline as a bubble on a sliding scale relative to the target value represented by the central line.

### 5.2.5 Data Analysis

Audio recordings were transcribed verbatim in Microsoft Word and then uploaded to NVivo (Version 9.0, QSR, Southport, UK) for coding and data organisation. The principles of Framework Analysis were used to analyse the data (Ritchie and Spencer,
1994). A period of familiarisation with the dataset by the candidate was followed by a process of coding where *a priori* themes directed by the interview topic guide, unexpected emergent themes and recurring viewpoints were identified. The accuracy of the initial themes, derived from a subset of the data, was confirmed by other members of the research team, and then used to guide the indexing of the remaining transcripts. The coding process enabled the development of lower order themes to be charted and organised into salient higher order themes that manifest within the whole dataset. At the final stage of data analysis, the derived themes for both groups were compared and similarities and differences were identified.

5.3 Results

The analytical framework included two key components, the interpretation of the physical activity feedback designs and data (Figure 5-b), and the impact of personalised visual physical activity feedback on facilitation of health behaviour change (Figure 5-c). Indexing of lower order themes (peripheral circles) led to the emergence of two congruent higher order themes (inner circle) within each component of the framework. The lower order themes identified in the data that support these interpretations are quantified according to the number of respondents who shared that particular view. Lower order themes included in Figures 5-b and 5-c represent those that were identified in both patients and HCP groups. Additional lower order themes that were solely represented in one of the participant groups and example quotation extracts of the raw transcripts can be found in the supporting table (Table 5-b). Where views within a group are contrasting, the opposing perspective was presented as a distinct theme (e.g. ‘handle and use technology’ and ‘dislikes technology’).

5.3.1 Understanding of personal feedback

The higher order themes identified within the data included the ability of HCPs and patients to understand the comprehensive multidimensional feedback and the
enhancement of their physical activity knowledge (Component 1, Figure 5-a). Similar proportions of HCPs (93%) and patients (100%) championed the clarity of certain visual images and were unified in their views on some of the more specific features such as the colours and simplicity of the designs. Only a very few participants felt that the images were not sufficiently detailed and 83% and 88% of patients and HCPs were able to easily relate the feedback to their behaviour in a meaningful way. Within the second higher order theme, a greater proportion of patients (72% vs. 20% for HCPs) felt that the data provided them with new information whilst more than 65% of both groups were able to recognise and accept the multidimensional nature of physical activity. Both groups were able to identify the times during their monitored week in which they were active at certain intensities and a large proportion of participants found aspects of their own personal feedback surprising, revealing or misaligned to their initial perception.

5.3.2 Potential application for behaviour change

The two higher order themes characterised by the analysis within the second component included the motivation to change physical activity behaviour and the usefulness of the personalised visual feedback to support health behaviour change (Component 2, Figure 5-c). Many of the lower order themes alluding to the positive motivational properties of the personalised feedback were evident in similar relative proportions of patients and HCPs. For example, 83% and 73% respectively found the feedback inspiring compared to only 7% of each group who demonstrated apathy towards the information. The health target data and the use of traffic light colours were acknowledged as key factors motivating individuals to want to increase their physical activity. A key discrepancy between the HCP and patient groups was their belief on the ability of patients to self-monitor their behaviour using the personalised feedback (13% vs. 55%) and on the need for additional support and guidance (80% vs. 28%). The two user groups were, however, more unified in their views on the utility of using technology to manage the feedback, plan and set goals, and the need to ensure the data was available longitudinally rather than as a simple snapshot.
Figure 5-b. Component 1: Interpretation of the personalised feedback designs and data.

Two higher order themes, represented by the large central circles, included the ability to accurately understand the visual physical activity data (A) and the enhancement of physical activity knowledge (B). The magnitude of the peripheral circles representing the lower order themes supporting the central theme, relate to the proportion of participants within each group identifying with each theme as indicated by the key at the foot of the figure.
Figure 5-c. Component 2: The impact of personalised visual physical activity feedback on facilitation of health behaviour change.

Two higher order themes (inner circles) included the motivation to change physical activity behaviour (A) and the usefulness of the personalised visual feedback to support health behaviour change (B). The magnitude of the peripheral circles representing the lower order themes supporting the central theme, relate to the proportion of participants identifying with each theme as shown by the key at the foot of the figure.
Table 5-b. Extracts of raw data sources used to exemplify lower themes identified under the two components of the Framework analysis.

Identified themes are in a clockwise order that they appear in Figure 5-b and Figure 5-c within the main text and are accompanied by a quote and the percentage (%) of participants in which the theme was identified. Lower order themes under the dotted lines represent single items not included in the figures and represent those lower order themes that were solely identified in one of the participant groups (i.e. only patients or healthcare professionals) for each higher order theme.

<table>
<thead>
<tr>
<th>Lower Order Theme</th>
<th>Evidence (Quotations)</th>
<th>Patient (n=29)</th>
<th>%</th>
<th>Healthcare Professional (n=15)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component 1: Interpretation of the feedback designs and data</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher Order Theme: Understand Feedback Designs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clear and easy to interpret</td>
<td>...Yeah well that’s quite interesting just...I can clearly see which days I do activity, that’s obviously more activity throughout the day...</td>
<td>100</td>
<td></td>
<td>...Yeah I think for someone who is um, not doing any exercise at all that would be enough really, yeah definitely, that to me would be very simple for them to see. It’s very clear...</td>
<td>93</td>
</tr>
<tr>
<td>Not detailed enough</td>
<td>...No I don’t find that particularly helpful um, once you’ve analysed this one and this one that doesn’t really add anything to it, not to my mind...</td>
<td>38</td>
<td></td>
<td>...Um I guess the problem with that is it just shows me bad, but it doesn’t really tell me how much I need to change to make better...</td>
<td>53</td>
</tr>
<tr>
<td>Can relate data to their activity</td>
<td>...Remember that day yes I was playing in Bristol, kind of a long day. Gardening. That would probably have been travelling back from golf I suppose. It’s interesting that Pilates doesn’t spike up more...</td>
<td>83</td>
<td></td>
<td>...that’s why the temperatures and the calorie expenditure would be high in the evening. So it’s gym there and then, running classes there... and similarly here...Thursday with the circus as well...</td>
<td>87</td>
</tr>
<tr>
<td>Colours are helpful</td>
<td>...Well again I think the uh...the colour is going through all this you get to know what the colours represent so it makes it easier to read together...</td>
<td>66</td>
<td></td>
<td>...Right that’s really interesting and that is clear now because the colours the colours make that clear...</td>
<td>87</td>
</tr>
<tr>
<td>Certain graphics were confusing</td>
<td>...there’s a slight confusion in my mind I suppose because that is... but that is calories, you know the units change that’s minutes that’s percentage...but you only have to read it to understand it...</td>
<td>55</td>
<td></td>
<td>... The ‘E’ bar...it’s not clear...without spending time looking at it and analysing it. Whereas that, that’s quite clear isn’t it? Just by looking at it simply...</td>
<td>87</td>
</tr>
</tbody>
</table>
### Higher Order Theme: Enhances Physical Activity Knowledge

<table>
<thead>
<tr>
<th>Visual simplicity is key</th>
<th>...It’s just simpler it tells me exactly the same I can see my performance against the recommending one and it’s an easy comparison there, each of the categories and it’s nice and simple...</th>
<th>83</th>
<th>...I just like this one here because I think it’s very clear very visual very simple, and it’s straight to the point...</th>
<th>67</th>
</tr>
</thead>
<tbody>
<tr>
<td>Used to Seeing Graphics</td>
<td>...Keep it as plain as you possibly can and as simple as you can. I used to do lots of presentations with charts and things and I know simple, people understand...</td>
<td>48</td>
<td>...But maybe these targets, when you start presenting them together, it’s almost like there’s inconsistency between them. Yeah, so that’s the first impression...</td>
<td>-</td>
</tr>
<tr>
<td>Confused by multiple targets</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Recognise activity time</td>
<td>...Yeah yes. Especially when you can identify the exact time that that represents, as I say you can actually break it down into what it was that caused that spike. Excellent...</td>
<td>93</td>
<td>...Moderate mostly in the morning, lunchtime, and then...I don’t know it sort of fades out, very little in the evening. Very little vigorous exercise in the evening. Mainly moderate. And good night’s sleep...</td>
<td>67</td>
</tr>
<tr>
<td>Perception versus objective mismatch</td>
<td>...Yeah I am surprised that that to be honest with you the sedentary yeah, there is more there than, than I thought to be honest...</td>
<td>76</td>
<td>...yeah so I thought it’d be a lot higher than that. From what I think is vigorous activity I thought it’d been...but like you said it’s all right isn’t it...</td>
<td>73</td>
</tr>
<tr>
<td>Relate to diet/calorie intake</td>
<td>...how you fill in that calorie gap with food. That’s the next part of it really I suppose. Presumable if you’re filling yourself up with food the balance would change wouldn’t it...</td>
<td>66</td>
<td>interesting to see how many calories you’ve used each day... in comparison to, well I know what sort of food intake I consume,</td>
<td>47</td>
</tr>
<tr>
<td>Surprising or revealing</td>
<td>...I’m sort of, I’m surprised by the results really because although I feel healthy, and I eat well, I’m surprised that I’m not sort of just this side of the line. I would imagine that I am a bit too sedentary really far, for health but hey...</td>
<td>83</td>
<td>...I’m surprised I haven’t ever reached the category of very vigorous because sometimes when I’ve done a hard step class or something I think I’ve worked really hard, I’m quite...that surprised me, has surprised me...</td>
<td>93</td>
</tr>
<tr>
<td>Recognise options and choice</td>
<td>...Yeah it does. Because doing one would sort these two so...um, that would be my aim is to work on those two really. By the nature of it that would bring that one down wouldn’t it...?</td>
<td>66</td>
<td>...I like this idea that you say that you target one section, one segment, and um...and I think it’s a really good way of letting them work on something...</td>
<td>73</td>
</tr>
</tbody>
</table>
Confirms view of overall activity  
...Yes in that it confirms what I already knew to a point. Yeah it’s just nice to see it in front of you what your average week is like. So yeah I’m fine with that...  
...again it confirms the picture of an overall sedentary life with big bursts of energy here and there basically. Thank goodness I cycle, if I didn’t cycle id just become flat lined wouldn’t it...

Data is novel  
...Very interesting yes. I wondered what it was all doing, I must say it is interesting...

Component 2: The impact of personalised visual physical activity feedback on facilitation of health behaviour change

<table>
<thead>
<tr>
<th>Higher Order Theme: Motivated by Personal Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feedback inspires change</td>
</tr>
<tr>
<td>Discrepancy from target effective</td>
</tr>
<tr>
<td>Health targets are motivating</td>
</tr>
<tr>
<td>Targets /data seems unrealistic</td>
</tr>
<tr>
<td>Apathetic towards data</td>
</tr>
<tr>
<td>...it makes me feel that I must try harder. Room for improvement, but, then that’s all of us...</td>
</tr>
<tr>
<td>...It’d be nice to do that whole test again but this time...but then I suppose you’d try and achieve something more and see what you do but um, no it’s good...</td>
</tr>
<tr>
<td>...I think it’s just encouraging to have it all in front of you, and then go through it, and um....it makes me want to do more, so I think it would make other people want to do more...</td>
</tr>
<tr>
<td>...it’s encouragement that matters I think. Rather than showing people how inactive they are. That’s not going to help them to do anything about it...</td>
</tr>
<tr>
<td>...But, and that hasn’t, I’m not sure this will prompt me to do anything about it actually, uh because I thought I would be prompted to do more when I was wearing the monitors actually but it didn’t...</td>
</tr>
<tr>
<td>Objective feedback is impactful (for patients)</td>
</tr>
<tr>
<td>Traffic light colours impactful</td>
</tr>
<tr>
<td>May put patients off</td>
</tr>
</tbody>
</table>

**Higher Order Theme: Could use to change own (patients) behaviour**

| (Patients) would and could use tech | ...I’d love to and as I’ve said to you I’m sort of a silver surfer and modern technology is something that um, I don’t find easy but I keep sort of having battles with it and hoping I win. So I’d be happy to...I would be very interested... | ...even though some of our older people might not have the technology – even though the ones I tend to deal with in our specialist groups all seem to have computers – all the family have them, or they’ve got smart phones... |
| (Patients) would self-monitor | ...I’d want to have the monitor but then also have some way...what I’d like to do is have the monitor, and download the info onto my PC, I’d be able to take the monitor off, download the data at the end of the day, or at the end...do it myself, and I’d probably want to do it on a daily basis... | ...I think most people would be able to manage it, yeah. Yeah, definitely you might get the odd one two perhaps, you know... but I think most people would... |
| Support and advice needed | ...So um, that sort of information is what you would need to have available to support or whoever’s going to be their follow-up support would need that sort of information... | ...I think in people who aren’t already exercising I think they would need on-going support or prompting to continue doing something... |
| Monitor over time useful | ...No absolutely. Yes it’d be interesting if you could know it every and compare every week as I say one month to another and one season to another...as a relatively short period of time it wasn’t necessarily a normal week ... | ...I’d want to say right okay give me 6 months to get my act together and let me come back again and see if I’ve actually improved and I think that would be of benefit... |
| Would need to add context | ...could give a quick suggestion on ways you could change that pattern to your benefit and that would be easy to use as a basis I would've thought. You spend an extra 20 minutes a day on vigorous exercise you’re going to increase that a lot more than if you’re a sedentary person... | 59 |
| Would help plan or set goals | ... or you can tell it, well I’ve got free evening there or a free afternoon there and it can suggest an activity that you can do that would get you up to the target. Yes I like that! Yeah something proactive yeah... | 52 |
| (Patients) Not interested in technology | ...No I’m one of the few I don’t go on the computer a lot, no actually... | 10 |
| Feedback needs to be tailored | - | - |
5.3.3 Design preferences

The final aim of the present analysis was to explore the design preferences of participants the figures in order to inform the development of the platform for which the efficacy of this feedback could be tested in randomised controlled trials. Therefore, any common issues or recommendations for improvements to the feedback from the perspective of the interviewees were also sought. Figure 5-d portrays the individual preferences towards the various profile designs for each section of data provided to participants (Appendix G). As evidenced by the larger height of the stacked bars, both groups tended to favour the same presentations within each section, which included the seven day activity patterns (graph C), the time and energy summary pie charts (graph F), and the health target bars (graph H). Participants also suggested a variety of modifications that might improve the profile designs, which included, although were not limited to, the addition of colour of the 7-day activity pattern (graph C), more values on the graphs to support the visual data, a scale on the activity pattern graphs, explicit language in headings and greater resolution. Many HCPs (87%) and patients (66%) championed the colour scheme as an aid to their understanding of the data and suggested that the visual simplicity of graphics was important (67% HCPs and 83% patients).

![Figure 5-d. Personal preferences towards profile designs for each of the three sets of data](image)

Letters A-I represent the 9 variants in designs shown to each participants (as described in the example portfolio in Appendix G). Minor variations in total frequencies reflect instances where participants declared no particular preference to any graph.
5.4 DISCUSSION

The present study describes a qualitative evaluation of a promising and innovative way to present sophisticated physical activity profiles and feedback across key biologically healthful physical activity dimensions as developed in Chapter 4. Patients at risk of chronic disease and healthcare professionals who work with such patients expressed a clear ability to interpret the information and it was not perceived to be complex or confusing. The personalised feedback enhanced physical activity knowledge, was motivating and was reported to be a potential aide to the self-management of physical activity.

Physical activity has a critical role in the prevention of non-communicable disease (Lee et al., 2012) but translating this evidence into action has been challenging (Kohl et al., 2012). It has been proposed that traditional conceptually-narrow approaches to physical activity do not provide individuals with sufficient information about the important aspects of behaviour, nor do they necessarily enable an individual to find tailored physical solutions that align with their interests and needs and are sustainable (Thompson and Batterham, 2013). With technological innovation now already widespread, we are no longer constrained and can provide a much richer, more sophisticated and personalised profile regarding physical activity. Patients in the present study appear to value technology-enabled feedback about their activity and can grasp the innovative multidimensional portrayal of their physical activity. This gives encouragement that this sophisticated format of feedback is conceptually attainable for this population and that healthcare providers can trust individuals to handle more comprehensive physical activity information as this becomes increasingly accessible.

Participants in the present study also acknowledged an enhanced understanding of their own physical activity in response to receiving personalised feedback. Overall, a large proportion of participants found aspects of their own feedback surprising or revealing and demonstrated a misalignment between their perceptions and the objective data. A better understanding of their current physical activity could help
individuals identify their relative strengths and shortcomings, make more informed decisions on how they might improve and set realistic goals (DiClemente et al., 2001). For many participants the detailed minute-by-minute physical activity patterns helped them identify their activity and inactivity time, which could usefully be applied as a tool to communicate how even small changes can be important for reducing health risk (Erikssen, 2001). Encouragement can also be taken from the recognition of the options and choices in their multidimensional profiles, which, as an approach to the presentation of meaningful feedback, would offer patients the chance to find sustainable solutions aligned to their personal preferences and needs.

The provision of bespoke options and heightened awareness may provide individuals with a sense of attainable and volitional solutions rather than prescribed choice which, in turn, is likely to improve the quality of their motivation and prolonged engagement in physical activity (Standage and Ryan, 2012). A large proportion of individuals in the present study highlighted the multidimensional health targets, the use of a comparative discrepancy between target and performance and the traffic light colours as factors that inspired them to contemplate change. This alleviates fears that multidimensional feedback might be complex and/or confusing and, whilst the assertions made by the patients and HCPs about their desire to change are prospective, our results suggest that this approach may be a useful motivational resource if applied appropriately.

Many theoretical frameworks applaud the role of feedback, self-monitoring and goal-setting as key constituents for successful and sustained lifestyle modifications (Dombrowski et al., 2012; Greaves et al., 2011; Michie et al., 2009). However the challenge to date has been finding the most effective way of implementing such strategies (Michie et al., 2013b). Interestingly, in the present study, a large proportion of patients felt that they could effectively self-monitor their own physical activity behaviour without additional support using the presented feedback and expressed confidence in using technological platforms to do so. HCPs on the other hand were somewhat sceptical of patients’ ability to self-monitor in the absence of
any support and guidance. Speculatively, this contrasting view may be reflective of a greater wealth of experience that HCPs have with patients acting on their advice and/or the challenges associated with setting realistic goals, adhering to lifestyle modifications and sustaining behaviour change. Nonetheless, the optimism and enthusiasm of patients to use the feedback presented here suggests that this offers a promising strategy for supporting behaviour change. These findings are useful to researchers who are interested in capitalising on technological innovation to provide physical activity feedback across various biologically important and healthful physical activity dimensions. Prior research indicates that the effectiveness of technology-enabled health behaviour interventions is likely to be enhanced when the patient is involved in its development (Yardley et al., 2015; van Gemert-Pijnen et al., 2011) and particularly in the application of physical activity feedback (Consolvo et al., 2009b; Consolvo et al., 2008). In this regard, the results of this trial have been used to inform the development of two randomised controlled trials (Chapter 7 and Chapter 8) that will aim to determine whether the provision of multidimensional personalised feedback helps patients or inactive adults to change their physical activity and reduce risk of chronic disease.

There are however one or two limitations to the present research that should be taken into consideration. Firstly, although participants were identified as ‘at-risk’, on the whole the people who came forward for the study were a fairly well-educated, active group of patients (mean PAL of 1.83 and almost 500 minutes of moderate-to-vigorous physical activity) from an affluent part of the United Kingdom. It may be the case therefore that their initial comprehension of physical activity may have been fairly high and not be representative of other less-active or lower socioeconomic groups. Part of the rationale for interviewing healthcare professionals was to obtain a more representative perspective of ‘patients’ however further testing should be made in a more diverse sample. It should also be noted that this study only presented a small selection of printed visual feedback options developed by the research team and so there were no comparisons made between other formats or those of commercial devices or even a technological platform. Whilst the inclusion of other
sources would not have necessary helped examined the comprehension and usefulness of the novel, multidimensional concept it may have helped gain richer insight into the design preferences and usefulness of other behaviour change techniques that are supported by commercial activity monitors and applications.

In conclusion, using appropriate graphics and visualisations, multidimensional and sophisticated physical activity feedback can be presented to patients in a way that is informative and understandable rather than complex and confusing. For the first time, this study shows that a targeted clinical population can accurately interpret comprehensive multidimensional physical activity information and that this information is potentially motivating for this population. As technology for monitoring physical activity becomes more accurate and affordable, we can move beyond simple physical activity messages and there is an exciting opportunity to generate an integrated and holistic picture of physical activity that is more informative and tailored to an individual’s needs, preferences and abilities.
Chapter 6 THE COGNITIVE-AFFECTIVE RESPONSE TO MULTIDIMENSIONAL PHYSICAL ACTIVITY FEEDBACK

1. What is the validity and reliability of the leading multisensor wearable monitors for measuring multidimensional physical activity?

2. Can data from wearable monitors be turned into visual multidimensional physical activity feedback?

3. Do end-users find personalised multidimensional feedback meaningful and useful?

4. What is the immediate cognitive-affective impact of seeing personalised feedback?

5. Does personalised multidimensional visual feedback initiate a meaningful change in physical activity behaviour?
6.1 BACKGROUND

Physical activity is fundamental to the prevention and management of many chronic diseases and premature mortality (Lee et al., 2012). Despite widespread advocacy of regular physical activity by various health bodies there remains a high prevalence of inactivity worldwide (Kohl et al., 2012). Part of the problem could be that individuals are taking no notice of the recommendations towards physical activity, find it difficult to quantify the recommendations in relation to their activity levels or place relatively low importance upon them in the context of their lives and undervalue it as a ‘healthful’ behaviour with future benefit (Trost et al., 2002; Biddle and Mutrie, 2007). Alternatively, some individuals may value physical activity as an important part of their lifestyle but have a lack of understanding as to whether what they are doing is enough to achieve a health benefit (Godino et al., 2014; Allender et al., 2006). Wearable physical activity monitors can now capture minute-by-minute energy and provide accurate and objective information over long periods of time (Lee et al., 2014) which if appropriately deployed, could help individuals self-regulate their behaviour and make appropriate lifestyle changes (Chiauzzi et al., 2015).

In order to successfully exploit this advanced monitoring technology as a public health strategy the feedback that a patient or user receives should be in a manner that rationalises the behaviour, shapes the risk perception and stimulates the receiver (DiClemente et al., 2001). The traditional approach to promoting and clinically prescribing physical activity has been a blanket recommendation such as 150 minutes of moderate to vigorous physical activity per week (American College of Sports Medicine, 2013; Department of Health, 2011). For some, this ‘one-size-fits-all’ approach to physical activity promotion does not present a complete picture of physical activity that captures all the aspects that are important for health and therefore it might be confusing or insufficiently informative (Thompson et al., 2009; Gabriel et al., 2012). New approaches in our understanding of physical activity behaviour stress the importance of various independent health-harnessing dimensions of physical activity including total energy expenditure, sedentary time,
minutes of moderate activity and sustained bouts of moderate and vigorous physical activity (Thompson and Batterham, 2013). Personalised feedback may raise awareness of both the levels and the type of physical activity beneficial for health and how the individual is performing relative to a number of different health-harnessing dimensions of physical activity (Godino et al., 2013). Providing a more sophisticated and complete multidimensional picture of physical activity would be much more informative and motivating.

The common sense model of illness representation [CSM] (Leventhal et al., 2003) provides a useful framework for explaining how personalised feedback may encourage users to change their behaviour in terms of their cognitions and emotions. The CSM describes the thoughts and feelings that individuals develop about an illness when exposed to new sources of information such as internal physical cues (e.g. somatic symptoms) and external sources (e.g. advice from a health care team or visual information) (Hagger and Orbell, 2003). Whilst the CSM is traditionally used in the context of chronic illness management (Achstetter et al., 2016; Diefenbach and Leventhal, 1996; Hale et al., 2007; Meyer et al., 1985), its constructs can be usefully applied to the management of chronic physical inactivity. The cognitive aspect of illness representations comprise thoughts on: a) the identity of the health threat (what is the nature of my condition/problem (i.e. chronic physical inactivity)?); b) the cause of their condition (why am I not active enough?); c) the perceived consequences of the threat (what is the impact of not doing this (sufficient exercise) on my life?); d) the timeline involved in overcoming the threat (how long will I have to keep this activity up?); e) the control one has over the threat (what can I do about it?); and f) the coherence of thoughts around the health threat (how clearly do I feel I understand my behaviour?) (Leventhal et al., 1992). These illness representations along with the parallel positive or negative emotional response of the health threat are then used to develop a coping strategy (i.e. acceptance or denial of the issue) or action plans which are mediated by the inherent beliefs, experiences of the illness and the beliefs of significant others.
In this context visually evocative behavioural feedback may help people identify physical inactivity as a health threat to them and reinforce their interpretation of the consequence of being inactive. Information on several health-harnessing physical activity dimensions may also lead to more coherent thoughts about the opportunities to change in light of one’s personal cause (barriers) of inactivity and provide an improved sense of self-control over their behaviour and acknowledgement of the timescale required to so. Should the personalised feedback validate or disprove an individual’s perception of their behaviour we may also expect to see an ensuing positive or negative emotional response depending on the information received. According to CSM, the formation of these common sense thoughts and emotional responses following the retrieval of information will dictate the choice of coping mechanism and action plans and help the patient manage their behaviour (McAndrew et al., 2008). An understanding of this effect and any differences between the positive and negative feedback would help practitioners tailor their advice appropriately if deploying multidimensional feedback in practice during a one-off consultation. To this end, the present study employed the CSM to explore the immediate cognitive and affective response to receiving personalised multidimensional feedback to better understand its impact for individuals with both high and low activity levels, respectively, and examine how this feedback might enhance the value that people place upon physical activity as a health-harnessing behaviour.

6.2 METHODS

The present study sought to answer the following research questions:

- Are there differences in the immediate cognitive and affective reactions to personalised multidimensional physical activity feedback between individuals of high and low physical activity statuses?
- How do individuals channel these thoughts and feelings in terms of their coping mechanisms and action plans?
6.2.1 **Study design**

The present study represents a new analysis on data collected as part of a study aimed at determining whether multidimensional visual feedback was easy to interpret and sufficiently informative (Chapter 5). The present study provided an examination of the cognitive and affective responses and reflections to their own personal feedback over systematic three-stage process. The first stage involved the development of physical activity graphics that appropriately captured and depicted all health harnessing aspects of physical activity. The second phase involved all participants wearing a physical activity monitor for one week in order to generate personal feedback before a final stage in which participants were shown their feedback as part of a one-to-one semi-structured data-prompted interview (Kwasnicka *et al.*, 2015). Tenets of the CSM were used to examine and organise the codes as part of a framework analysis (Gale *et al.*, 2013). Ethical approval for the study was obtained from the National Research Ethics Service committee South West, UK (REC reference 12/SW/0374, Appendix F).

6.2.3 **Feedback**

The multidimensional visual feedback included information on an individual’s performance in relation to five independent health-harnessing physical activity targets, which were coloured in accordance with a tri-colour traffic light system indicating whether the target described below was hit (green), was near (amber, within 25% of the target) or missed (red, greater than 25% under the target). The five dimensions and their respective targets included physical activity level (target =1.75 x resting energy expenditure (kcal/day)), average sedentary time (<60% waking day), time engaged in moderate activity accumulated on a minute-by-minute basis (120 minutes/day), moderate to vigorous physical activity accumulated in at least sustained 10-minutes bouts (150 minutes/week) and total vigorous activity time (75 minutes/week). Participants were also showed a detailed visual breakdown and summary statistics of the time spent in each of the intensity thresholds on an average day. The threshold metabolic equivalents (METs) used to quantify sedentary, light,
moderate, vigorous and very vigorous activity were <1.8 METs, 1.8–2.9 METs, 3.0–5.9 METs, 6–10.1 METs and >10.2 METs respectively. Appendix G provides an example of one participant’s personalised feedback that they received during their interview.

6.2.4 PARTICIPANTS

A total of 44 participants were interviewed between March 2013 and September 2013. Patients were recruited from two general practices in Bath and North East Somerset and Wiltshire, UK and approached if identified as being at moderate (10–19.9%) or high (>20%) risk of cardiovascular disease and/or type 2 diabetes as calculated following a recent NHS health check (Appendix H). From a total of 244 patients who were invited, 30 were deemed eligible and willing to take part although one withdrew after signing informed consent. Purposive sampling was also used to recruit 15 regional healthcare professionals (HCPs) including general practitioners, nurses, healthcare assistants and physical activity health trainers who had experience working with such patients. In Chapter 5 the comparative and contrasting views between the groups of HCPs and patients were examined as to whether multidimensional visual feedback in this the format would be accurately interpreted and utilised from the perspective of patients. The present analysis was based on the individual’s cognitive and affective responses to their own personal data using the combined sample, which was subsequently split based on activity status.

6.2.5 PROCEDURE

Participants were provided with an arm-mounted Bodymedia Armband (SenseWear Pro 8.0, Pittsburgh, USA), which was shown in Chapter 3 to accurately estimate energy expenditure. Participants were instructed to wear the device for seven consecutive days commencing at midnight and asked to only remove the device for showering or water-based activities (Scheers et al., 2012b). Minutes spent in the distinct intensity thresholds based on metabolic equivalent cut points (METs) and multidimensional health target attainment (Thompson and Batterham, 2013) was calculated in Microsoft Excel. Gaps in the data from instructed removal of the
monitor for showering etcetera were assigned the estimated basal metabolic rate (Schofield, 1985).

All 44 participants subsequently attended a digitally-recorded, two-hour, one-to-one interview with the candidate. The interview topic guides were compiled with input from an expert panel of academics and health professionals (Appendix I and J). Amongst the topic guide were questions aimed at gauging the participants’ attitude towards physical activity prior to seeing feedback and their thoughts and feelings when presented with their personal activity data in a number of formats, as described in Chapter 5.

6.2.6 Data analysis

Audio recordings were transcribed verbatim in Microsoft® Word and then uploaded to NVivo (Version 9.0, QSR, Southport, UK) for coding and data organisation. An initial deductive phase of thematic content analysis (Hsieh and Shannon, 2005) was used to identify key themes pertaining to the cognitive and affective response to their personalised multidimensional visual feedback. The trustworthiness (Shenton, 2004) of the initial analysis, derived from a subset of eight interviews, was confirmed by an external expert reviewer, agreed by other members of the research team and then used to guide the indexing of the remaining transcripts. The identification of codes involving key constituents of the common sense model (Figure 6-a) in early thematic content analysis initiated a more refined phase of framework analysis in the remaining data sets (Gale et al., 2013). Once all transcripts were fully coded and checked, the research team looked at within subject patterns in order to classify common recurring viewpoints and using a qualitative descriptive approach distinguished and compared the views of individuals of high or low physical activity status (Table 6-b). For the most part, all participants were asked and subsequently responded to the same questions in relation to their attitudes and personal physical activity data. For some constructs outlined in Figure 6-a the healthcare professionals were asked to comment on behalf of their ‘typical patient’ and not of themselves (e.g. when discussing barriers and facilitators to physical activity). In these instances
responses of the 15 healthcare professionals were omitted from the analysis and the patient only results are indicated in the text and Table 6-b where appropriate.

**Figure 6-a. Common Sense Model of Illness Representation framework analysis.**

Higher order themes are indicated by the larger bold font whilst lower order themes are indicated by the italicised text.
6.3 Results

6.3.1 High and Low Active Participants

A total of 44 participants were included in the present analysis. Participants were assigned to be the low activity group (LAG, n=23) if they met none, one or two of the five physical activity targets presented as part of the feedback, and the high activity group (HAG, n=21) if they met three, four or all five of the health targets. Other demographic and activity information is displayed in Table 6-a. To further determine the appropriateness of this it was calculated that all five physical activity dimensions were significantly different between groups (p<0.001). No significant differences between groups were observed for sex, age, educational level or any anthropometric measurements.

6.3.2 Framework Analysis

In line with Common Sense Model, the six components of Illness representations (cognitions) were amalgamated from attitudes towards physical activity and the individuals’ opinions about their personal feedback. For identity the participants’ understanding of physical activity as a healthy lifestyle behaviour and their perception of their own physical activity levels was explored. For consequence their belief in how important being physically active was to their health and wellbeing was sought. Cause and control were evidenced in the personal barriers described by interviewees as hampering their ability to be more active. For the timeline component, the acknowledgement of the need for prolonged self-monitoring by interviewees was inspected. Finally, for coherence, the acknowledgment and comprehension of the options and behavioural choices available to them was determined. The immediate positive and/or negative emotional impact upon seeing the personalised information was also sought and the ensuing outcome expectancies including coping and action plans advocated to by participants were identified. Table 6-b indicates the proportion of the interviewees supporting each construct.
Table 6-a. Descriptive characteristics of all participants included in the analyses

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Statistic</th>
<th>Low Activity Group</th>
<th>High Activity Group</th>
<th>p diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients</td>
<td>n</td>
<td>15</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Healthcare professionals</td>
<td>n</td>
<td>8</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td>ns*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>n (%)</td>
<td>12 (52%)</td>
<td>15 (71%)</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>n (%)</td>
<td>11 (48%)</td>
<td>6 (29%)</td>
<td></td>
</tr>
<tr>
<td>Age (Years)</td>
<td>mean (SD)</td>
<td>58.6 (8.9)</td>
<td>56.9 (12.6)</td>
<td>ns</td>
</tr>
<tr>
<td>Marital status</td>
<td></td>
<td>ns*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single/ Widowed/ Divorced</td>
<td>n (%)</td>
<td>9 (39%)</td>
<td>6 (29%)</td>
<td></td>
</tr>
<tr>
<td>Married/ Cohabiting</td>
<td>n (%)</td>
<td>14 (61%)</td>
<td>15 (71%)</td>
<td></td>
</tr>
<tr>
<td>Highest educational attainment</td>
<td></td>
<td>ns*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Up to A-Level or equivalent</td>
<td>n (%)</td>
<td>10 (43%)</td>
<td>8 (38%)</td>
<td></td>
</tr>
<tr>
<td>First degree or higher degree</td>
<td>n (%)</td>
<td>13 (57%)</td>
<td>13 (62%)</td>
<td></td>
</tr>
<tr>
<td>Height (m)</td>
<td>mean (SD)</td>
<td>1.72 (0.11)</td>
<td>1.76 (0.08)</td>
<td>ns</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>mean (SD)</td>
<td>81.1 (16.7)</td>
<td>79.2 (14.0)</td>
<td>ns</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>mean (SD)</td>
<td>27.2 (4.2)</td>
<td>25.6 (3.8)</td>
<td>ns</td>
</tr>
<tr>
<td>Waist circumference (cm)</td>
<td>mean (SD)</td>
<td>92.6 (12.6)</td>
<td>90.6 (13.4)</td>
<td>ns</td>
</tr>
<tr>
<td>Physical activity dimension</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physical activity level (PAL ratio)</td>
<td>mean (SD)</td>
<td>1.66 (0.25)</td>
<td>1.96 (0.26)</td>
<td>.000</td>
</tr>
<tr>
<td>Sedentary time (% waking day)</td>
<td>mean (SD)</td>
<td>75.8 (7.3)</td>
<td>61.8 (10.1)</td>
<td>.000</td>
</tr>
<tr>
<td>Daily moderate activity (minutes)</td>
<td>mean (SD)</td>
<td>84.1 (30.9)</td>
<td>171.3 (63.9)</td>
<td>.000</td>
</tr>
<tr>
<td>MVPA bouts (minutes/week)</td>
<td>mean (SD)</td>
<td>240.4 (148.2)</td>
<td>643.3 (327.9)</td>
<td>.000</td>
</tr>
<tr>
<td>Vigorous activity (minutes/week)</td>
<td>mean (SD)</td>
<td>40.7 (55.6)</td>
<td>182.7 (166.4)</td>
<td>.000</td>
</tr>
</tbody>
</table>

Physical activity dimensions that were presented in the ‘health target’ section of the feedback were as follows: p diff: differences between high and low groups tested using independent t-test unless specified; ns: not significantly different between groups; *Tested using Pearson Chi-Square test for proportional differences
Table 6-b. Number (and percentage) of interviewees supporting each framework analysis construct.

<table>
<thead>
<tr>
<th>Objectively assessed activity group</th>
<th>Identity</th>
<th>Consequence</th>
<th>Cause / Control</th>
<th>Timeline</th>
<th>Coherence</th>
<th>Positive Affect</th>
<th>Negative Affect</th>
<th>Coping</th>
<th>Action planning</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Perceived High Activity</td>
<td>Perceived Low Activity</td>
<td>PA is Important</td>
<td>PA to PA n</td>
<td>PA Goals/ motives n</td>
<td>PA Long term PA n</td>
<td>Wants PA</td>
<td>Recognises PA</td>
<td>Options</td>
</tr>
<tr>
<td>High activity group</td>
<td>21</td>
<td>17</td>
<td>4</td>
<td>18</td>
<td>8</td>
<td>13</td>
<td>14</td>
<td>15</td>
<td>4</td>
</tr>
<tr>
<td>3-5 hit targets</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low activity group</td>
<td>23</td>
<td>10</td>
<td>13</td>
<td>12</td>
<td>2</td>
<td>5</td>
<td>6</td>
<td>13</td>
<td>17</td>
</tr>
<tr>
<td>0-2 hit targets</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

PA = physical activity; imp. Intentions = implementation intentions.

P = Patient only, the 15 HCPs did not provide specific personal views on this construct and therefore have not been included in the analysis.

Percentage of respondents

<table>
<thead>
<tr>
<th>0 – 24 %</th>
<th>25 – 49 %</th>
<th>50 – 74 %</th>
<th>75 – 100 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>High activity group colour scale</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low activity group colour scale</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NB. Table 6-b is presented to highlight any major differences in the type or focus of responses between individuals from the high or low activity groups within the context of the one-to-one interviews conducted as part of the present study. Participants may have had thoughts or feelings that would allude to the described constructs about their personal physical activity feedback that were not expressed as these constructs were not targeted by the interviewer or the topic guide a priori.
In assessing the interviewees’ attitudes towards physical activity prior to receiving feedback the identity component of Common Sense Model in the present context was deemed to be the perceived comprehension of the interviewees’ own activity status. It became clear that those in the higher activity group tended to have a good handle on their actual activity levels with 17/21 declaring themselves to be highly active:

*I like to think I’m a very physically active person, Um, I cycle to work, I play... I have a young family so you know, I try and play...as much...I try and encourage my kids to play sports as much as possible. We have a dog, we take the dog for walks. Our recreational activities, you know, I like to think we have a good balance. You know we like to sit down and watch a movie and eat pizza, but we also like to go out...go for a long walk.* [HAG, male]

In terms of what do I do, I spend as little time as possible sitting around. I’m active in the house, I’m active in the garden, since my husband was unable to, I do DIY. Um, I do three exercise classes per week. One in Aqua-kick, which is a sort of watery version of kickboxing, one in Pilates and one in yoga. [HAG, female]

A lower proportion of individuals in the low activity group admitted or acknowledged themselves to be insufficiently active where 13/23 perceived themselves to be low and 10/23 felt they were sufficiently high:

*Probably… I mean, I suppose I could do more, I would like to do more, they’re probably not sufficient really but my back is weak a but I suppose I ought to make more effort I probably don’t do enough.* [LAG, male]

*Well I think so…but you’re gonna tell me differently aren’t you? No I mean, obviously, my job is very sedentary. So I’m literally, I’m stuck in this room most of the day. So, I feel that I do need to make the effort to do something. So I do go to the gym, and I go quite a lot. I go most days apart from the days that I work all day, you know when I do a long day, but even then I do sometimes go.* [LAG, female]

Concerning the consequence component, physical activity behaviour was generally considered to be of more importance in terms of health and wellbeing in the high activity group (18/21) compared to the low activity group (12/23):

*I think brain power, I think you think better, you feel better, emotionally you’re better…I just think that rush of blood through the body and through the brain is like a cleansing operation I just feel…you just feel so much…well you just feel healthier…you may not be, but you feel healthier, you’re active you’re thinking…it’s very, very important.* [HAG, male]

For those in the high activity group the cause of inactivity, as evidenced by the perceived barriers towards being regularly or more physically active were largely due
to a physical inability to do more (8/12 patients) whilst 4 declared time or cost as the main obstacle:

_Uh, age and level of fitness stops me from going back and playing squash haha. Not so much age, level of fitness and level of training is stopping me from doing the more extreme walking under more difficult conditions. I tend to be very careful about you know how much an ascent and decent is, and been planned in my walks. I would like to be able to do more._ [HAG, male]

_I would like to run a bit more, not sort of athletic running, just being able to run but unfortunately that's been limited at the moment by the continence problem [HAG, female]

Those patients in the low activity group cited external barriers such as time and cost (5/15), or psychosocial barriers such as a dislike towards gyms, other priorities and a lack of social support (3/15) with only 2 citing any physical limitations:

_ Um...not having to work such long hours, but saying that, I do my running with the running club, but um...I’m really only second to them so next month I’ll be working in ... or something like that so not having to travel so far which, I suppose with the credit crunch there won’t be much work around this region so I’ve had to travel, but as things pick up hopefully I won’t have to travel so far and I can do stuff._ [LAG, male]

_I need more walking and it’s really odd because now that I don’t work all the time I’d like to go walking. My husband hates it, well he doesn’t hate it, but his idea of a walk is to the station and back. Um, but I don’t mind walking for a whole day, sort of 4 or 5 hours. My friends who I used to that with all moved away, one comes occasionally I suppose... It’s the lack of people to do it with I think, so that’s why I have to do the streets but it’s a bit boring._ [LAG, female]

Intrinsic reasons for being physically active (long term health, fitness or skill development, social) were more prevalent in the high activity group (13/14) than in the low activity group (5/15), whereas more extrinsic motives (guilt, body image, competition) or amotivation (shown by a declared lack of motive or non-response) were observed in the low activity group (6/15 and 4/15 respectively) compared to the high active group (1/14 and 0/14):

_I don’t think of it as physical activity, I think of it as doing things which I enjoy doing. I enjoy canoeing, I enjoy walking...not so keen on cycling but it’s a good way of seeing the countryside. I didn’t mention earlier I do swimming as well but that’s more of a winter activity. // it’s purely the enjoyment of being outdoors like I said with people, the scenery, the challenge of navigation um // It helps that some people I know are fairly active._ [HAG, female]

_And also I’ve started a new relationship with an old girlfriend I met from college since my divorce, so I knew her 25 years ago, so that’s an incentive as well so suddenly you’ve got to be back on your game, looking after yourself so you’re attractive for the opposite sex and I think...and also in Cornwall they’re mad for fitness they do everything there’s triathlons and running and boot camps, and surfing, you can do anything you want it’s all sort of beach based especially around_
this time and everyone’s out there with their tops off and I think ‘I’ve gotta get fit get tanned and get down there otherwise I’ll just be so-and-so’s weird boyfriend.’ [LAG, male]

The final two constructs forming the illness representations, timeline and coherence, were largely determined after the participants had been exposed to elements of their personal feedback. Similar proportions from both the high (14/21) and low (15/23) activity group suggested that in terms of timeline, they would want longer term monitoring to keep track of their physical activity behaviour:

Yeah I think increase and monitor, have it monitored every now and again to see what is happening over time as you get older, you know you likely do more of this sitting down and less of that...not sure that’s ever gonna increase but. No it needs to be sort of on-going doesn’t it? // Yeah I think so yeah very much so. That’d be a brilliant way of looking at what you’re doing...every month or so just having a check on where you’re at. Extremely useful. [HAG, male]

Um...well as it’s a snapshot in time presumably you’d have to really monitor yourself once you’ve changed your lifestyle is that something that would be... // Yeah well if you choose to do something about it, which I would like to, I would need to be able to see how effective any changes I made were...the only way of checking it is by using monitors I suppose. [LAG, male]

A similar proportion of participants form both the high (15/21) and low (17/23) activity groups also demonstrated coherence in their perceptions about the multidimensional nature of physical activity and the availability of a variety of options to improve their lifestyle and physical activity behaviour.

So I’m thinking, okay so where I’m missing my target, I’m thinking if I can convert some of this time into some of this time, that’ll take care of itself so...so that’s saying 70% sedentary time is 70% // so I wouldn’t actually...other than the formats and the layouts and things we talked about, I don’t think I would be...looking to add anything, yeah it’s what you do, what your target should be, what you should be doing for your state in your life and your physique, this is what you need to be doing. I’m kind of thinking would I want it to be a bit more uh...aggressive or more shocking? [HAG, male]

There’s a lot you can be doing that, you know, nice moderate activity where you’re using energy and it’s enough to be doing, without having to...go do the vigorous extreme sport, you can be doing simple things which are moderate, and that to say increase your....increase those parts into there. // Yeah definitely yeah. Nice, um, some targets, and some...how the targets are spread, now they’ve mentioned spread, I think it’d be a very useful look at it. [LAG, female]

6.3.4 Emotional response

Positive affect was coded where feelings of pleasure, reassurance or pride were taken from seeing the personalised feedback and reflecting on the implications of the provided feedback. As expected, those in the high activity group (19/21)
responded more positively emotionally in comparison to the low activity group (12/23). Further exploration of the particular aspect of the feedback that evoked these reactions differed between the health target data (i.e. graphs that visually display performance in relation to the five physical activity guidelines) and the activity pattern data (e.g. graphs that visually depict the active and sedentary time over a day). For high activity interviewees the health target data was more pleasing than the activity pattern data (15 vs. 4), whereas for the low activity participants this was proportionately equal (6 vs. 6).

Oh that’s nice. Gosh. That seems as if it’s...from my personal point of view I could be considered to be quite satisfied with that I imagine....Fine. Very satisfying if people need to know that isn’t it? And they can work that one out they see it, they relate that to that, so that’s fine...Yes it’s very gratifying, not satisfying, gratifying, that it’s all good. [HAG, female]

Um, well it makes me feel, I’m glad my job is fairly active so I do leap about and do stuff so that is good...Um, well I’m encouraged that I do spend quite a lot of calories on light and moderate in an ordinary day let's say. [LAG, male]

Negative affect was coded where feelings of guilt, worry or disappointment were expressed in response to seeing aspects the personalised feedback. In this regard, 11/21 of the high activity group exclaimed some degree of negative affect response whilst 19/23 of the low activity group expressed negative emotions. For participants in the active group, the main source of negative feelings were the activity pattern data (9) rather than the health target data (2). For the low activity group the activity pattern data evoked negative emotions for 11 participants compared to 8 from the health target data.

As I said I find it...well predictably disappointing how much time I spend on my ass basically. Um, yeah. My own stuff....you know I’m disappointed that I didn’t get any vigorous exercise at all during the whole time...I mean I’m guessing.... [HAG, male]

It makes me feel actually lazy. I have to admit that I’m ashamed of my lack of activity. // It certainly brought it home to me yes. Seeing it in black and white, it really sort of brings it home and makes me realize that I shouldn’t just talk about improving my activity or increasing my activity, I should actually do it. As Nike would say, 'just do it'. // Seeing it in front of me makes me realize that I have been rather um, inactive and there’s no reason for me to be inactive that’s the main thing. [LAG male]

In the high activity group there were no noteworthy proportional differences in the positive emotional response when looking at those who hit 3 and those who hit 5 targets however there were less negative feelings expressed in those who hit all five
guidelines. Similarly, there were more positive and less negative emotions observed in those low activity group individuals that did hit 2 targets compared to those who hit one or none.

6.3.5 Coping and action plans

In terms of the coping mechanisms, it was observed that relatively high proportions of patients in both the high activity (14/21) and in particular the low activity (20/23) groups appeared to accept and acknowledge the personalised feedback as an accurate, objective portrayal of their physical activity levels and thus that they would like to improve on a given aspect of their behaviour. There was however also a small proportion, 3 high active and 10 low activity participants, who attempted to excuse the visual data by expressing concerns that it perhaps is not a typical representation of their activity levels.

I will make an effort now you convinced me I should be. I know that I should be making more of an effort so...I'm grateful for that really. // Well not enough...well maybe that something is probably out of the question really, but I'd like to see that vigorous, make...just like to see more of this really. // Well it's being aware that I don't do enough exercise if you want to call it that but...that one as a result is good really, you need some kind of guidance of what you should be doing and what you should aim for so it's helpful. So I find that one is...you can read in the papers.....this is far better because it gives you actual figures. I find it's very useful [LAG, female]

No it's just not typical so it doesn’t really matter because I was stuck indoors all the time. I'm surprised I did that // I'm sure that’s not a normal week. The moderate activity is far, far more and the vigorous activity is probably a little bit more because of the walking, which I haven't done. // But it would’ve been more useful if it had been a normal week because then I could look at it and think perhaps 'oh I’m not walking’ or you know, you’re not doing this enough or whatever, but it would be useful for me but I think. [LAG, female]

The need to immediately seek out normative data by which to compare their own personal feedback to was a further coping reaction observed in interviewees from both the high (11/21) and low (14/23) active groups.

What does everyone else do? Does that mean I’m doing a lot of work? // Maybe some points of reference to tie it to the population as a whole, and I suppose you’re going to do exactly the same as you’ve done here; have 5 populations, the sedentary population, the overactive population and whatever, a few groups in between // Um, just knowing how it compares to the general population I think it....because when you get over the surprise of how much sedentary activity there is...maybe I shouldn’t be surprised maybe I am sedentary [HAG, male]

But it would be useful to know how that um, compares with what it should be for someone with my weight, height, age that would be a guide as to whether... Not the weight loss is an issue with
me, but it would give me a sort of target to say I’m using 2000 calories a day on average and I should be using 2 1/2 or 2.2. It would give me a guide as to whether I should be doing a little bit more and that may influence me. [LAG, male]

The concluding component of the Common Sense Model is the formation of action plans, to control the illness. In the present context, participants tended to express a general goal or intention to increase their physical activity, and in some cases identified more specific implementation intentions (i.e. how, where, when to perform physical activity). The presence of both goals and implementation intentions were higher in the low activity group patients (11/15 and 12/15 respectively) when compared to the high activity group (7/14 and 6/14).

It has and it’s...as I just indicated, I need to understand my pattern of work and rest really to see....um, if I could increase...this a bit. // I would look at that and think well actually I’m not enough on my moderate maybe I need a decent walk over the hill a bit more often. Because that could be perhaps moderate or depending if you’re walking pretty quickly and over the hill that’d be classed as vigorous then wouldn’t it? // If I got that through the post, I’d think ‘oh maybe I do need to be doing a bit more, walking or I need to be a bit more active in my general day’. [LAG, male]

Um, yes, um, and certainly I think from my point of view the moderates are definitely possible in my working, typical week. The vigorous, you know I have to make that extra effort to do, so if I wanted to do a bike ride, or if I wanted to swim I would have to physically do it and make a point of doing and putting in my diary and same with the very vigorous. But the moderate, doing more of the mid-range, it’s definitely something I can do and would do. // Is I guess the objective is to have a complete green circle and so by seeing how far you are out would you know influence you to say that only got to do another 10 minutes of this and what does that relate to in terms of activities. [LAG, male]

6.4 Discussion

This study examined whether a novel and sophisticated format of personalised multidimensional visual feedback might be able to produce powerful cognitive and affective responses in individuals of varying physical activity levels in the context of the Common Sense Model of illness representation. Specifically, these findings suggest that visual information depicting health-harnessing physical activity status and weekly activity patterns may elicit illness representations and strong emotional responses which in turn may provoke greater efforts to change behaviour (French et
al., 2006; Breland et al., 2012). The cognitive-affective response to personal feedback triggered the formation of coping mechanisms and action plans by the interviewees.

Despite widespread acceptance of physical inactivity as a fundamental antecedent to numerous chronic diseases and premature mortality (Warburton et al., 2006), it is seldom presented as an ‘illness’ in itself, and thus may not be for everyone a pivotal lifestyle concern. In accordance with the Common Sense Model which postulates that the formation of illness representations are a good predictor of adoption of health behaviours across a number of conditions (Hagger and Orbell, 2003), participants from the low activity group, who had more extrinsic motives and barriers and were more apathetic towards the importance of physical activity, demonstrated a heightened desire to change their behaviour and greater endorsement of coping and action plans after seeing their personalised data. The high proportion of participants from the low activity group who accepted their feedback and postulated specific goals or plans for future behaviour might be indicative of a raised appreciation of their activity levels [identity], belief about the health threat of being physically inactive [consequence] and an enhanced sense of competence about their ability to change [control]. Conversely, highly active individuals tended to show heightened awareness of their physical activity and placed greater value on its importance prior to seeing feedback, and perhaps had less of need to form new illness regulations.

Novel to the present study was the multidimensional portrayal of physical activity behaviour in line with several health-harnessing aspects of the behaviour, and the detailed breakdown of activity pattern intensity derived from contemporary wearable monitors. Many interviewees from both the high and low activity groups demonstrated a clear understanding of the multifaceted nature of physical activity and in doing so began to discuss their existing and future [planned] behaviour in this context. Several participants also expressed the desire to monitor their behaviour in the long term, acknowledging that this format of feedback would be more useful for maintenance of an active lifestyle. The development of two constituents of illness
representations, i.e. coherence and timeline, could enable patients to view the regulation of their physical activity behaviour in a more tangible and practically accessible way. If the desire for long-term objective feedback engendered a more regularly self-monitoring via intermittent weekly observations or even continuous monitoring, it could prolong engagement and in time facilitate a positive behaviour change (Greaves et al., 2011). The presentation of several physical activity options may indeed empower and enhance one’s motivation to change through the provision of tailored behavioural goals that align to their interests, preferences and needs.

Unfortunately, simply raising one’s awareness and intention towards adopting or changing health behaviour often is not enough to induce the necessary sustained action (Rhodes and Bruijn, 2013; Sniehotta et al., 2005). Interventions prescribing physical activity have shown to be moderately effective in the short term and any behavioural changes are very rarely maintained when measured in the long term (Orrow et al., 2012). There are suggestions that in order to install a meaningful and prolonged engagement in a given health behaviour there must be an emotional involvement or reason for change (Leventhal and Scherer, 1987; Mohiyeddini et al., 2009). Many participants in the high activity group expressed positive feelings of pleasure, reassurance and pride in responses to their feedback whereas the majority of low activity group participants expressed feelings of guilt, disappointment or apprehension. Given that the Common Sense Model postulates that the parallel cognitive and emotional processes can complement one another in initiating and maintaining a behaviour change (Diefenbach and Leventhal, 1996), these results suggest that receiving personalised objective feedback might be efficacious regardless of current activity levels. For those with high activity levels the feedback may serve as positive reinforcement that encourages sustained engagement, whilst for people with lower physical activity levels the guilt or disappointment may drive the initial uptake of new or increased physical activity.

A useful setting within which to deliver such feedback could be in as part of a patient consultation or health check (Chiauzzi et al., 2015). Human behaviour is complex and the present study has highlighted some areas of caution that practitioners should be
aware of. One example was the appearance, for some, of a conflict in the immediate coping mechanisms experienced by individuals in the low activity group where there was both clear acknowledgement and dismissal of the feedback. Another example was that the emotions experienced by the high and low activity individuals were not uniformly positive or negative, respectively. The multidimensional format of feedback means that there is a proportion of people clustered into the high and low activity groups who have had a degree of both shortcomings and successes in their health target attainment (i.e. met or missed one of the five guidelines). Although these ambiguities may appear problematic, if appropriately contextualised it would allow practitioners to better tailor their approach by building on the small victories of their patients to provide hope for the ones with low activity levels and continued motivation for those already highly active. Further studies could aim to unpick the salient aspects of visual feedback that initiate certain positive or negative cognitive-affective responses so that practitioners can apply the most important and evocative information that will likely foster rather than hinder adoption and maintenance of the target behaviour.

Inference of the data presented should be made with caution, as this was a cross-sectional study. The potential likelihood that the cognitive and affective responses and the ensuing goals or implementation intentions would result in actual behaviour change is, at this point, speculative. It should be noted that for the purposes of the present investigation the data-prompted nature of the study was sufficient for gauging the real time impact of a one-off assessment that may mimic a consultation and might enhance participants’ engrossment with the feedback shown (Kwasnicka et al., 2015). However, to determine the true efficacy of the multidimensional visual feedback for engendering a real change in behaviour, researchers should design rigorous longitudinal trials that assess the impact of this feedback over time (Peacock et al., 2015). Lastly, the present study had a reasonably diverse group of adults across age, education and occupation however this was a fairly small sample of individuals who actively volunteered for the study for what might have been an inherent interest in physical activity. Future studies are recommended to identify larger and more
culturally and socio-economically diverse cohorts within which to explore the impact of multidimensional visual feedback on cognitions, emotions and behaviour change.

This study demonstrated that personalised multidimensional visual physical activity facilitates the formation of illness representations and emotional responses which may in turn encourage patients with low activity levels to formulate a heightened appreciation of physical activity as an important health behaviour and evoke a desire to become more active. For individuals with low activity levels the cognitive-affective responses led to a better understanding and acceptance of their physical activity behaviour, which was lacking prior to receiving this feedback, and stimulated the identification of goals and plans that might improve their lifestyle. For individuals with higher activity levels, the need to further change their behaviour was less pertinent, however, the feedback did serve as a positive reinforcement that may influence long-term maintenance. As the price of wearable physical activity monitors falls, the opportunity to capture and present comprehensive, objective visual feedback such as that shown to participants in the present study will be increasingly accessible. The Common Sense Model may therefore offer insight as to how practitioners might be able to use objective personalised feedback as a vehicle to better engage patients in understanding and regulating their physical activity behaviour. Perhaps a useful context would be to provide a physical activity assessment and feedback as part of an overall health check to fortify its embodiment as a critical and desirable lifestyle behaviour. If objective visual feedback can be used to either reinforce or in some cases convince patients that they are not meeting the health recommendations for physical activity as well as instilling hope and opportunity for change then this may enhance the importance placed upon physical activity and help patients to initiate or maintain regular engagement with active pursuits.
Chapter 7 USING MULTIDIMENSIONAL INDIVIDUALISED PHYSICAL ACTIVITY FEEDBACK ON BEHAVIOUR AND HEALTH: THE MI-PACT STUDY.

1. What is the validity and reliability of the leading multisensor wearable monitors for measuring multidimensional physical activity?

2. Can data from wearable monitors be turned into visual multidimensional physical activity feedback?

3. Do end-users find personalised multidimensional feedback meaningful and useful?

4. What is the immediate cognitive-affective impact of seeing personalised feedback?

5. Does personalised multidimensional visual feedback initiate a meaningful change in physical activity behaviour?
This declaration concerns the article entitled:

Multidimensional individualised physical activity (Mi-PACT) - a technology-enabled intervention to promote physical activity in primary care: study protocol for a randomised controlled trial

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<td>Design of methodology: The candidate made a major contribution to a 90-page protocol document outlining the selection of assessment tools, the feedback platform design, application of the theoretical framework underpinning the trial and developed the trainer manual, which ultimately informed the protocol paper. Candidate contribution = 40%</td>
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<td>Experimental work: No experimental work was undertaken for the present paper*. The candidate made a major contribution (60%) to the ultimate data collection reported in the following chapter. Candidate contribution = n/a</td>
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<td>Presentation of data in journal format: No data was collected or presented as part of this publication* Candidate contribution = n/a</td>
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7.1 Background

Physical inactivity has substantial effects on global health and an increase in activity at the population level would have considerable impact on the future burden of chronic disease (Lee et al., 2012). In the United Kingdom, the Department of Health recently began a national programme (NHS Health Check) that aims to reduce chronic disease by identifying adults who are at increased risk and offering them personalised advice and support to lower their risk (2009). Given the strong evidence linking active lifestyles with a reduction in overall type II diabetes and cardiovascular disease morbidity and associated modifiable risk factors physical activity has the potential to increase the success of such initiatives (Gill and Malkova, 2006; Thompson et al., 2003; Gaesser, 2007; Jeon et al., 2007). Existing physical activity interventions in primary care have however been met with limited success and typically small improvements are not maintained (Orrow et al., 2012). New cost-effective approaches that stimulate meaningful long-term changes in physical activity are required and this is especially important in those identified as at risk of cardiovascular disease and type II diabetes.

To date, physical activity has typically been captured and recommended in unidimensional terms (e.g. 150 minutes of moderate intensity physical activity per week) (Haskell et al., 2007; Pate et al., 1995). Physical activity is a much more heterogeneous behaviour than this approach implies, with various dimensions known to have clear biological and health benefits (Thompson and Batterham, 2013). Indeed, past work shows that it is quite possible for an individual to score highly in one dimension of physical activity but low in another, while only very few people score consistently across all physical activity metrics (Scheers et al., 2013a; Thompson et al., 2009). This observation is a problem because people who focus on a single physical activity descriptor may form incomplete or inaccurate conclusions about the appropriateness of their behaviour. For example, many forms of structured physical activity have only a modest impact on overall energy expenditure (Turner et al., 2010). Weight loss is critical to some
health outcomes, or an outcome in itself, and it will be important for individuals aiming to lose weight (or prevent weight regain after substantial loss) to understand which aspects of physical activity have the largest thermogenic effect. In this specific scenario, a multidimensional approach will help people incorporate novel activity within the context of their existing behaviour such that the net effect on total energy expenditure is maximised (Thompson et al., 2014; Turner et al., 2010). Clearly, a multidimensional profile will provide greater insight, awareness, and deeper understanding than the reliance on more unidimensional feedback; enabling people to take greater responsibility for managing their physical activity.

New technologies, which include wearable devices and web-based applications, enable self-monitoring of physical activity and create opportunities for the provision of personalised feedback regarding the multidimensional nature of physical activity (Consolvo et al., 2009b; Lyons and Lewis, 2014). This type of individually tailored feedback tends to be more effective than generic messages about physical activity (Foster et al., 2013; Lustria et al., 2013). If appropriately deployed the provision of personalised multidimensional physical activity feedback may provide tailored solutions that raise ones capability (through increased awareness of health-harnessing physical activity and self-efficacy), opportunity (by offering alternative strategies to help remove barriers) and motivation (through a raise in autonomous forms of motivation) towards increased physical activity, three essential theoretical underpinnings of physical activity behaviour change (Michie et al., 2011c). Moreover, feedback and self-monitoring in combination with specific goal setting are acknowledged as key constituents of successful behavioural interventions that are unlocked by wearable technology (Michie et al., 2009; Greaves et al., 2011; Conn et al., 2011).

In order to exploit the opportunities for physical activity monitoring and multidimensional physical activity profiling, a website-based application for linking physical activity data with informational feedback was developed
(Chapter 4) creating an interface for self-monitoring and specific action planning. This was informed by the work undertaken in Chapter 5, in which visualisations were generated for the presentation of integrated physical activity profiles and demonstrated that patients at medium or high risk of chronic disease found this feedback to be informative, understandable and motivating. In addition, while patients reported feeling confident in using technology and feedback for self-monitoring physical activity, it was identified that supplementary in-person guidance may further support behaviour change. Differences in illness representations towards physical inactivity and emotional responses evoked by feedback between individuals of high and low physical activity status were also observed (Chapter 6), suggesting that tailoring the programme to a given individual to channel their interpretation of personised data into positive coping and action plans might be necessary (Noar et al., 2010; Noar et al., 2007). To this end it seems appropriate to provide personalised advice to participants to support their understanding and enhance the efficacy of this approach in supporting the adoption and maintenance a physical activity behaviour change. The Multidimensional Individualised Physical ACTivity (Mi-PACT) study is an exploratory randomised controlled trial aiming to determine whether the provision and self-monitoring of technology enabled multidimensional physical activity feedback with trainer support can facilitate a meaningful and lasting change in physical activity behaviour.

7.2 METHODS

The present study sought to answer the following research questions:

- Does personalised multidimensional physical activity feedback and self-monitoring using a web-based platform alongside in-person advice supports an increase in physical activity in men and women at risk of future chronic disease
- Is a change in behaviour sufficient to generate meaningful weight loss and/or improved metabolic control and reduced risk?
The following paragraphs describe the protocol for the Mi-PACT study adapted from Peacock et al. (2015), which was a randomised controlled exploratory trial designed and implemented by a collaborative team of academics and health professionals. As such, there were a number of procedures and processes performed by members of the research team other than the author of the present thesis. Notable examples include the screening and health assessments of participants, which was carried out by a local research nurse, and the delivery of intervention content, which was performed in a primary care setting by experienced health trainers. The present author did however make a significant contribution to the design of the study, the development of trial resources such as user guides and information sheets for participant and manuals for training of health trainers and the delivery of the training itself. The candidate was also responsible for conducting all body composition assessments, processing all physical activity monitors for the primary outcome data and undertaking and interpreting the preliminary analysis presented within this chapter.

7.2.1 STUDY DESIGN

Patients at risk of cardiovascular disease or type II diabetes were randomly assigned to receive usual care (control group) or trainer-led, technology-enabled personalised multidimensional physical activity feedback (intervention group) for a 3-month period. Assessments of physical activity, health and psychosocial variables were made at baseline, immediately post intervention and at a one year follow-up (Figure 7-a). Ethical approval for the study was granted by the National Health Service (NHS) South West 3 Research Ethics Committee (REC reference number: 13/SW/0179, Appendix K). The project was subsequently registered as a current controlled trial (ISRCTN18008011).

7.2.2 PARTICIPANTS/ELIGIBILITY

Men and women treated in primary care aged 40-70 years at medium (≥10 and <20%) or high (≥20%) risk of cardiovascular disease and/or type II diabetes
mellitus were invited to take part in the study. Risk was calculated from clinical data using well-established prediction algorithms for estimating a person’s 10-year risk of developing cardiovascular disease (QRISK®2) (Hippisley-Cox et al., 2008) and diabetes (QDiabetes®) (Hippisley-Cox et al., 2009) available at QResearch® (2014). As the focus of the present study was on prevention, people were excluded if they had existing coronary heart disease, chronic kidney disease (stages 3-5), diabetes mellitus, stroke, heart failure and peripheral arterial disease (as they were managed via existing care pathways). The Physical Activity Level (PAL) is a standard objective method of expressing total daily energy expenditure in multiples of resting metabolic rate. Individuals were excluded if they had an average daily PAL >2.0, which has been categorised by a FAO/WHO/UNU (2004) expert consultation as representing a highly active lifestyle. In addition, individuals were excluded for whom sufficient baseline physical activity data is not available or obtainable. To be eligible, individuals were required to provide at least 6 valid monitoring days (including both a Saturday and Sunday) with at least 80% of data for a given 24-h period (Scheers et al., 2012a).

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</tr>
<tr>
<td>8</td>
<td>5</td>
<td>Trainer session</td>
<td>✅</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>6</td>
<td>Trainer session</td>
<td>✅</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>7</td>
<td>Post-intervention assessment</td>
<td>✅</td>
<td>✅</td>
</tr>
<tr>
<td>52</td>
<td>8</td>
<td>12 month measurements</td>
<td>✅</td>
<td>✅</td>
</tr>
</tbody>
</table>

Figure 7-a. Study design for the Mi-PACT project.

Although an exploratory trial, it was deemed prudent and instructive to conduct formal sample size estimation. For this purpose, the specific outcome is mean
physical activity energy expenditure (expressed as PAL). The target effect size was a difference between intervention and control arms in the 12-month change in PAL from baseline to follow-up of 0.07. Based on previous data (Thompson et al., 2009), an increase in PAL of that magnitude would result in an increase of 10% in the proportion meeting the minimum physical activity recommendation of a PAL of 1.6 (Brooks et al., 2004), which the trial team define as the smallest worthwhile effect (Hopkins et al., 2009). With \( P=0.05 \), 90% power, and an assumed correlation between baseline and follow-up values of \( r=0.7 \), the required sample size with an Analysis of Covariance model (Frison and Pocock, 1992) was 108 in the intervention and 54 in the control. Allowing for 25% loss to follow up (attrition) resulted in a final target sample size of 144 in the intervention group and 72 controls. The assumed correlation between baseline and follow-up (the 12-month reliability) was a conservative estimate due to an apparent lack of long-term reliability data using the best objective measures. For the primary statistical analysis primacy was not attached to PAL, a priori, and multiple physical activity dimensions were examined. PAL permits a robust sample size estimate and is clearly important.

7.2.3 Recruitment

Six general practices within Bath and North East Somerset and Wiltshire were recruited to identify potential patients with variety in terms of socioeconomic status according to National General Practice Profiles and the English Indices of Deprivation (Sigal et al., 2006; 2010). Potentially eligible participants at these practices were recruited via two routes. Firstly, individuals in medium or high-risk groups (based on existing risk-score information in patient notes) were identified by searching practice databases. Secondly, due to a lack of risk information existing for all patients, individuals at potentially increased risk were selected based on certain risk factors (namely people with a body mass index (BMI) >30 kg/m² in combination with a total cholesterol level between 5.5 – 7.5 mmol/L and/or blood pressure >140/90 mmHg). This is consistent with Health Check criteria, and clinical data from baseline assessments will be used to verify that
individuals are in medium or high-risk groups, using QRISK®2 and QDiabetes® algorithms (Hippisley-Cox et al., 2008; 2009). Potentially eligible participants identified by these two sources were then approached by a letter from their general practitioner (GP). This recruitment letter emphasised that participation is entirely voluntary and that individuals will be free to withdraw at any time without any impact on their health care provision. A study information sheet and sample consent form was included with the letter so that patients had time to consider their participation. The invitation letter also included a free post reply slip for each patient to return a slip indicating whether or not they wish to learn more about the study. Individuals who returned positive replies were then contacted by the research team and continued to be screened if they were interested in taking part. Participants who were not interested in taking part after this initial contact weren’t contacted again.

7.2.4 PARTICIPANT SCREENING AND BASELINE ASSESSMENT

A telephone screening was conducted by a research nurse on all interested participants to re-confirm eligibility. In addition, information regarding marital status, ethnicity, smoking status, profession and education was also recorded. All potentially eligible participants were then invited to attend a 60-min baseline assessment clinic at their general practice following an overnight fast. Here, participants were provided with further explanation of the nature of the study and an opportunity to ask any final questions. Individuals who agreed to participate following the briefing were provided with an informed consent form, indicating their full understanding of the study and their protected rights for confidentiality and withdrawal from the study without giving a reason. For those providing written informed consent, concomitant medications and relevant clinical history were recorded and a questionnaire pack was issued for completion within the clinic. Subsequently, measurements of each individual’s blood pressure, weight, height, waist circumference and a blood sample were taken. During the clinic, individuals also received an activity monitor with oral and written instruction for use and were provided with a freepost envelope for
returning monitors to the research team. For those participants who chose to opt-in, a visit to the University of Bath was also arranged for the assessment of body composition via dual energy X-ray absorptiometry. Blood results were shared with each patient’s GP and patients with a fasting blood glucose of >7.0 mmol/l at this baseline stage were excluded from further participation as this was deemed likely to initiate further testing by the GP as indicative of probable diabetes. People successfully completing activity monitoring who were not highly physically active and fell into the medium or high risk groups (confirmed via recalculated risk scores using baseline measurements and the results of blood tests) were eligible for randomisation.

7.2.5 Randomisation/allocation

Eligible people were randomised to one of two groups. An unequal allocation ratio (intervention: control) of 2:1 was chosen, primarily to increase our experience with and amount of information on the new intervention (Dumville et al., 2006) (the small loss of precision with unequal allocation only increased the total N required by 20 participants). The trial statistician allocated participants remotely by concealed minimisation (Treasure and MacRae, 1998), providing balance across the trial arms for sex (male/female), age group (40-59 and 60-70 years), general practice, risk (medium/high) and physical activity level (PAL <1.75 or ≥1.75). Although individual patients are the unit of randomisation, it was felt that the threat of contamination within a practice was largely theoretical, especially given that the intervention is personalised.

7.2.6 Follow-up assessment

Follow-up data collection was taken immediately post-intervention at 3 and 12 months and included all of the same measurements completed during baseline assessment. These assessments were again undertaken at the patients’ general practice. Participants who opted-in for the assessment of their body composition at baseline were again invited to attend a repeat dual-energy X-ray
absorptiometry scans at the University of Bath after their follow-up clinics. Participants who completed all assessments received a £50 voucher.

7.2.7 Usual Care (Control Group)

The MiPACT trial was designed to assess effectiveness over-and-above existing ‘usual care’ alternatives. Participants allocated to the control group continued to receive usual care by their GP. Any care that they receive in relation to supporting changes in weight or physical activity was documented through self-report and examination of practice records at assessment clinics. In order to standardise exposure to healthcare professionals and content, participants in the control group attended a 20-min meeting with a lifestyle coach at their GP practice following their baseline assessment (i.e. week 0). At this session, participants received standardised information (including printed materials and links to internet-based resources) regarding cardiovascular disease and type II diabetes, the potential benefits of physical activity on reducing ‘risk’, current physical activity guidelines and ideas about getting more physically active. Standardised information and messages were consistent with other print and internet-based resources available in 2014 (for example, Department of Health: Change4Life (Pedišić and Bauman, 2015), NHS Choices: Live Well (2011)) and included reference to local opportunities where applicable.

7.2.8 Intervention: Overview

Mi-PACT is a complex intervention or ‘treatment package’ involving multiple components (Craig et al., 2008). The intervention content and iterative web-based platform was developed by the project team and drew heavily on previous formative research involving the generation of novel integrated physical activity profiles (Thompson and Batterham, 2013; Thompson et al., 2009). The content was further informed by the qualitative research with healthcare professionals and patients at risk of future chronic disease (reflecting the intended user group) in the development and evaluation of innovative ways of presenting personalised
multidimensional physical activity feedback that is informative, understandable and motivating as documented in Chapter 5 and Chapter 6.

The Mi-PACT technology consists of a Bodymedia Core physical activity monitor (BodyMedia, Inc., Pittsburgh, PA) and a web-based application or ‘platform’ developed in collaboration with Ki Health Innovation Ltd. Information graphics used for the presentation of data within the web-based platform were initially developed alongside graphic designers (Information is Beautiful ©) as described in Chapter 4. Draft designs were subsequently refined by the research team based upon the findings of in-depth qualitative interviews in patient groups and healthcare professionals (Chapter 5). Overall, patients preferred simple visual messages rather than more complex or abstract visualisations. However, as there is unlikely to be a definitive design solution to meet the needs of everyone, and to provide some choice, the Mi-PACT platform includes alternative graphical formats for displaying the same data (Figure 7-b).

The integrated physical activity profile captures physical activity across different physiologically important and mutually independent dimensions (Thompson and Batterham, 2013). Data are depicted in a simple wheel format using a traffic light colour-coding system as an index of attainment (Figure 7-b ‘A’). These data are also presented as colour-coded bars relative to guidelines; allowing an expression of magnitude for each dimension. Each participant’s profile captures five different dimensions of their behaviour. Thresholds concerning the amount of time spent in moderate or moderate to vigorous activity (i.e. dimension 2 and 3) were revised from those traditionally presented (e.g. 30 minutes per day or 150 minutes per week (Department of Health, 2011) in accordance with calculated reference values for 24/7 minute-by-minute physical activity monitoring observed for participants recruited for Chapter 3 and Chapter 5 (See Thompson et al., 2016 for a summary of this issue). Thus, the guideline values and boundary thresholds for each dimension were as displayed in table 7-a.
A) Multidimensional health target attainment

B) Daily physical activity patterns and summary graphs

C) Review section

D) Planning section

Figure 7-b. Features and examples of feedback and functions included on the MiPACT web-based platform.
Table 7-a. Definition and visual boundary thresholds for the five dimensions presented to Mi-PACT intervention participants as part of their personal feedback

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Definition</th>
<th>Boundary Thresholds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Sedentary time</td>
<td>100 – ((\text{METs} &lt; 1.8) / \text{waking day})</td>
<td><img src="image" alt="table" /></td>
</tr>
<tr>
<td>Moderate Activity</td>
<td>(\text{METs} \geq 3.0)</td>
<td><img src="image" alt="table" /></td>
</tr>
<tr>
<td>Calorie Burn</td>
<td>Sum all calories burned from 00:00 to 23:59</td>
<td><img src="image" alt="table" /></td>
</tr>
<tr>
<td>Moderate Bouts</td>
<td>(\text{METs} \geq 3.0 \text{ for } \geq 10\text{ consecutive min})</td>
<td><img src="image" alt="table" /></td>
</tr>
<tr>
<td>Vigorous Bouts</td>
<td>(\text{METs} \geq 6.0 \text{ for } \geq 10\text{ consecutive min})</td>
<td><img src="image" alt="table" /></td>
</tr>
</tbody>
</table>

The platform also includes visualisations for depicting time spent and energy expended within different intensity thresholds determined using metabolic equivalents (METs). These data are presented as minute-by-minute 24-h line graphs (using a ‘heat’ colour palette) and are summarised into daily and weekly totals (Figure 7-b, B). In order to convert energy expenditure to METs, age-specific equations are used to estimate Basal Energy Expenditure (Schofield, 1985). Activities with a MET value below 1.8 are considered as sedentary behaviour when using this specific monitoring technology (Swinnen et al., 2014; Scheers et al., 2012a). MET values greater or equal to 1.8 and less than 3 are considered to reflect light activity, while moderate and vigorous activities are calculated from MET values greater or equal to 3 and less than 6, and greater or equal to 6 (Haskell et al., 2007).

In addition to providing feedback in the form of integrated physical activity profiles for ‘Health’ and as ‘Activity’ within different intensity thresholds, there are reviewing and planning components to the platform. The ‘Review’ section displays personalised minute-by-minute data (as a greyscale silhouette to
emphasise activity patterning) that enables the individual to highlight, annotate or ‘tag’ and store information regarding discrete activities and behaviours as part of the self-monitoring process (Figure 7-b ‘C’). This ‘tagged’ information is then available as part of an individual’s historical data and viewable/editable on subsequent access of the platform. The ‘Plans’ section displays daily physical activity visualisations for the week and presents this information relative to the individual’s integrated physical activity profile (Figure 7-b ‘D’). In line with an implementation intention approach, there is an opportunity for the generation of specific plans regarding where, when and how to act. For example, the participant can explore the effects of exchanging sedentary behaviour for more positive behaviours (selecting from their personal ‘tags’ or from a database of activities) to realise the impact of any such substitution (Thompson et al., 2014) on a change in their physical activity profile.

7.2.9 TRAINING SESSIONS

In the Mi-PACT group, each participant had access to activity monitors and the web-based platform for the duration of the 3-month intervention. In addition, feedback in the form of personalised physical activity profiles was introduced, explained and discussed with participants in supportive one-to-one coaching sessions framed around the web-based platform. The decision to include healthcare trainer support rather than have participants undertake isolated self-monitoring of their personalised multidimensional feedback was made for a number of reasons. Firstly, it was anticipated that the use of the monitor and functions of the web-platform may for some be fairly novel and require a degree of technical support. Secondly, the behavioural feedback was considered by the just one of a number of mechanisms that perhaps alone would not be sufficient to drive a behaviour change. Indeed it emerged in Chapter 5 that whilst patients successfully interpreted their feedback, additional help was required to put their data and any goals into context as well as support the development of action plans. A final consideration was that any empathy or emotional support required by patients could only be provided a person.
Participants attended their GP practice for five consultations with a lifestyle coach: at baseline, and after approximately 2, 4, 8 and 12 weeks. In the first session, participants initially received the same standardised messages as in the control group. The primary aim of this session was to explain the multidimensional nature of physical activity, provide an understanding of which personalised behaviours have contributed to each dimension and to explain the options and choices that are available for change. A further objective was to familiarise the participant with self-monitoring using the web-based platform. For this purpose, each participant was given a Mi-PACT platform user manual and quick start guide along with an activity monitor and USB cable (for docking to their computer). Participants were given access to a personalised website account (protected by a login and password) and accompanying software for uploading their physical activity data. Participants were encouraged to experiment and engage in new and enjoyable activities (i.e., “trying different things”) while self-monitoring and exploring the functionality of the platform prior to their second session.

Sessions 2, 3, 4 and 5 were approximately 20-30 minutes in duration. Prior to meetings, coaches were encouraged to log-in to the platform and review participants’ profiles as a preparatory exercise to help inform session delivery. Once it was established that the participant was confidently self-monitoring and reviewing their data, the aim of the second session was to revisit the participants’ physical activity profile and to discuss aspects of their physical activity behaviour that they would consider changing. Here, there was a particular emphasis on identifying opportunities for achievable but sufficiently meaningful modification and specific goal setting regarding what, where and how to act. Participants who have low activity in every dimension have the most ‘choice’ and were guided through a menu of physical activity options. Participants who score well in one or more dimensions were supported in adding to their existing behaviour knowing that what they are doing is recognised. In terms of the tone of advice provided, coaches were trained to use neutral language and be autonomy supportive, such
that they would attempt and encourage choice (e.g. using terms such as “you may choose to” or “how would you” rather than “you should” or “you must”) and show empathy (e.g. “I appreciate why you might find this difficult”). These vocalisations were provided in a structured manner such that goals, strategies, and implementation intentions are clear, realistic, and well defined (Standage and Ryan, 2012). Appendix L shows the session outlines that were provided to health trainers.

Figure 7-c. General framework used to guide the health trainers delivering the Mi-PACT sessions.

The primary focus of subsequent sessions were designed to involve reviewing the impact of any changes and supporting all efforts the participant had made to be more active, as well as recalibrating specific goals and plans within the context of the individual’s existing behaviour and lifestyle. This process was predominately led by the participant and was therefore inevitably highly individualised. At the final session, participants were encouraged to consider their progress by using the multidimensional web platform to reflect on what has been achieved and to develop a future action plan towards long-term change.
Participants were urged to make the most of the web-based platform by wearing their physical activity monitor as much as possible (day and night) and to regularly upload their data and review their informational feedback over the 3-month intervention period. As the server has two portals, one for the participant and one for the research team, technical issues (e.g. with uploading data) were identified and resolved by the research team. For participants without access to a computer or the internet, coaches were able to facilitate the upload of data to the platform within their one-to-one sessions and the individual’s feedback was made available to them as a colour print-out where applicable. Participants with limited or no access to the platform outside of sessions were provided with a diary for recording what aspects of their physical activity they had consciously changed between sessions (i.e. for self-monitoring purposes).

7.2.10 Trial fidelity and the training of the lifestyle coaches

To ensure delivery was compliant to treatment protocol, a number of strategies to monitor and maximise trial fidelity were implemented as outlined by the National Institute of Health Behaviour Change Consortium across the established five domains of Study Design, Training, Delivery, Receipt, and Enactment (Bellg et al., 2004) This included: (i) the carefully recruitment of (appropriate) health trainers, (ii) the development of an accessible and operationalised treatment manual, (iii) the implementation of standardised health trainer training, (iv) training more-than-needed health trainers to protect against dropout, and (iv) the monitoring of adherence to treatment (e.g., recording of consultation meetings and provision of formative feedback to health trainers).

Five health trainers were recruited from the local community (including healthcare providers and other appropriate settings) with experience and qualifications as physical activity or lifestyle advisors. Intervention providers were added to the GP’s office for the intervention period. This mix of personnel was included in order to make the study as pragmatic and generalisable as possible to routine health care practice. Firstly, the health trainers participated in 2 days
of training conducted by members of the multidisciplinary research team, which included sessions on: (i) understanding the multidimensional nature of physical activity, (ii) familiarising with the web-based platform and self-monitoring technology, (iii) using the integrated physical activity feedback for setting specific goals and forming implementation intentions, and (iv) provision of information in an autonomy-supportive manner (facilitating the participant’s satisfaction of autonomy and competence inherent within multidimensional profiling).

All coaches were given a written manual to support delivery of the intervention and will give an opportunity to practice and receive feedback on delivery style and content. The manual included reference to general information on facilitating behaviour change adapted from the Department for Health NHS Health Trainer Handbook (Michie et al., 2008b). Whilst sessions were not specifically founded on self-determination theory per se, they were designed to be delivered in an autonomy-supportive style that placed emphasis on helping the individual participant finding personally enjoyable solutions within the confines of their existing interests and lifestyle. A final fidelity step in this regard was to measure the perception of autonomy support from the advisor for all intervention participants immediately post intervention using the Health Care Climate Questionnaire (Williams et al., 1996).

7.2.11 PRIMARY OUTCOME MEASUREMENTS: PHYSICAL ACTIVITY

The primary outcome measure was physical activity behaviour, which was directly assessed using a Bodymedia Core monitor (BodyMedia Inc., Pittsburgh, PA described throughout this thesis) for a 7-day period at all assessment points. The underlying raw data for minute-by-minute energy expenditure was used to extract multiple physical activity characteristics and determine the change in a given (multiple) dimension(s) of physical activity behaviour. Specifically, this included: overall energy expenditure (expressed as PAL); time engaged in moderate-to-vigorous physical activity accumulated on a minute-by-minute basis and in bouts of at least 10 minutes; time engaged in vigorous intensity activity
accumulated in bouts of at least 10 minutes; and, non-sedentary time. The
Bodymedia device was shown in Chapter 3 and by other authors (Johannsen et
al., 2010a; Mackey et al., 2011b; Lee et al., 2014) to accurately measure energy
expenditure relative to criterion measures of indirect calorimetry and doubly
labelled water, and has been increasingly used to quantify sedentary time,
physical activity and energy expenditure in experimental trials (Bond et al., 2014;
Barry et al., 2011). Participants were required to wear the monitor for at least 6
days (including a Saturday and Sunday) to be included in the analysis (Scheers et
al., 2012), and were instructed to only remove the device for showering and
water-based activities. A valid day required participants to wear the device for at
least 80% of a given 24-hour period. As described previously, minutes spent in
the distinct intensity thresholds based on metabolic equivalent cut points and
multidimensional health target attainment was calculated (Thompson and
Batterham, 2013). Data gaps were assigned estimated basal energy expenditure
using age and sex specific predictive equations (Schofield, 1985b).

A potential threat to any study that measures physical activity behaviour is
confounding due to a Hawthorne effect (i.e. changes in behaviour that occur
simply due to the special attention afforded by the intervention). Understandably, there was not an option in the present study to avoid notifying
individuals that their physical activity was being observed because the
intervention group could have become necessarily more aware of their physical
activity and thus potentially change their behaviour during specific outcome
assessment periods (e.g., for social desirability). In order to overcome this threat
and to avoid any short-term changes in behaviour associated with physical
activity outcome assessment, a sham physical activity monitor worn on the wrist
was given to all participants (intervention and control) in the one-month prior to
follow-up measurements. In most cases a genuine sham (i.e. an empty shell) was
used however at least 5% of sham monitors were real working units
(MotionWatch 8, Cambridge Neurotechnology Ltd., Cambridge, UK). The motion
watch records and stores data for up to 120 days with a 1-min sampling
frequency. Participants were told that some devices will be recording and others may not.

7.2.12 Secondary outcomes: Anthropometry, blood pressure and body composition

Participants were requested to remove any footwear and to wear only light clothing for anthropometric measurements. Body mass was measured on a calibrated electronic or balance scale to the nearest 0.1 kg, where participants were asked to stand in the centre of the platform with their weight evenly distributed on both feet. Height was measured using a stadiometer to the nearest 0.1 cm. Participants were requested to hang their arms freely with their heels, gluteal area and shoulders in contact with the stadiometer and with their head in the Frankfort plane (orbitale and tragion are horizontally aligned). The participant inspired for measurement, and the recorder brings down the headboard to compress the hair. From these collective measurements, body mass index was determined (kg/m$^2$). To assess waist circumference, participants were asked to remove or lift their top to allow access to the measurement site. In instances where the participant preferred not to expose their skin, the measurement was taken over the thinnest layer of clothing. With the participant standing with their feet together and weight evenly distributed, waist circumference was assessed by positioning an anthropometric tape midway between the uppermost border of the iliac crest and the lower border of the costal margin, with the tape placed around the abdomen at the level of the midway point. Following a deep inhalation and a gentle expiration, the measurement was taken at the end of the expiration, with the tape snug but not compressing the skin. Three consecutive measurements were made to the nearest 0.1 mm. Blood pressure was assessed using either an automated or manual sphygmomanometer after at least a 5-minute period of seated rest. With the arm supported at the level of the heart the measurement was taken from the brachial artery on three consecutive occasions (with the lower of the last two measurements being recorded).
7.2.13 SECONDARY OUTCOMES: DUAL ENERGY X-RAY ABSORPTIOMETRY

Total percentage body fat was estimated using dual energy X-ray absorptiometry (in participants who choose to opt-in for this measure). Descriptive information for each participant including date of birth, height and weight was entered into the software (Hologic, Bedford, UK) before they were asked to lie supine on the scanning table (Discovery, Hologic, Bedford, UK). Participants were positioned centrally with feet equally spaced and arms with an even gap from the trunk and asked to remain as still as possible during the 7-minute scan. Following completion of the scan, whole body composition analysis was performed with regions sectioned as recommended (Hologic, Bedford, UK). ‘Central adipose tissue’ (abdominal subcutaneous and visceral adipose tissue) was estimated from a central region between L1-L4, which has previously been shown to correlate with measures of metabolic health (Paradisi et al., 1999). Following an overnight fast, participants were required to consume 1 pint of water on waking (to ensure adequate hydration) and to void their bladder prior to assessment. This is important to minimise variations in hydration status between individuals and because body water affects lean mass estimates (Lohman et al., 2000). In addition, participants were instructed to only wear light clothing for the analysis and to remove all pocket contents and jewellery where possible. Fat mass index (FMI) was calculated using the equation FMI = total fat mass (kg) / height2 (m²); with participants classified according to FMI reference ranges for obesity classification (Kelly et al., 2009).

7.2.14 SECONDARY OUTCOMES: BLOOD SAMPLING AND ANALYSIS

Fasting blood tests were taken at the GP practice between 8:00 and 11:00 am. Participants who were not fasted on arrival were asked to complete the venepuncture on another occasion. Blood samples were drawn by the research or practice nurse from an antecubital vein and dispensed into vacutainer collection tubes (Becton Dickinson, Oxford, UK) containing the anticoagulants ethylenediaminetetraacetic acid or fluoride oxalate for plasma samples, and
serum-separator tubes for serum samples. Blood samples were marked with a project identifier code and participant study number before being sent to the Royal United Hospital Bath NHS Trust Clinical Pathology Laboratory. Samples were centrifuged at ambient temperature within 6 hours of collection (3120 g for 10 min). Samples were separated and analysed within 24 hours (except for insulin which was frozen at -20°C and analysed at a later date). Serum triglycerides, total and high-density lipoprotein cholesterol, plasma glucose, and C-reactive protein was determined using a Cobas 8000 (Roche Diagnostics Limited, UK). Low-density lipoprotein cholesterol was calculated using the Friedewald equation (Friedewa et al., 1972). Insulin analyses will be undertaken on a Roche E170 analyser (Roche Diagnostics, Mannheim, Germany). The assay employs a direct electro-chemiluminescence immunoassay utilising a mouse monoclonal antibody labelled with ruthenium and a second mouse monoclonal antibody coupled to paramagnetic particles.

7.2.15 SECONDARY OUTCOMES: PSYCHOSOCIAL DATA

The Psychological Need Satisfaction in Exercise Scale was used to measure perceived competence, relatedness and autonomy (Wilson et al., 2006) while motivational regulations for exercise was assessed using the BREQ-2 (Markland and Tobin, 2004). Leisure-time physical activity habit was measured using a four-item automaticity subscale of the Self-Report Habit Index (Verplanken and Orbell, 2003), vitality using the Subjective Vitality Scale (Ryan and Frederick, 1997) and competence using the Perceived Competence Scale (Williams et al., 1998b). In addition, subscales from the Intrinsic Motivation Inventory (McAuley et al., 1991; Ryan, 1982) were adapted to specifically measure the dimensions of physical activity-related interest/enjoyment, effort/importance and pressure/tension. Health status and quality of life was assessed using the SF-36 Health Survey Questionnaire (Brazier et al., 1992) and the EQ-5D 3L (EuroQol, 1996). In addition, the Department of Health’s Life-Stage Segmentation Toolkit (2008) was used to segment participants factoring in attitudinal and psychographic data (a person’s overall approach to life, including personality traits, values and beliefs) and within
the context of their social and material circumstances. In addition to the questionnaires completed at assessment centres, patients from the intervention group were provided with feedback form upon which to evaluate certain aspects of the platform (Appendix N). A total of 79 out of the 120 intervention participants successfully completed this form.

7.2.16 Data analysis

The analyses were undertaken on an intention-to-treat basis. A primary comparison between intervention and control arms of the 12-month change in physical activity using was made using an analysis of covariance model (Laird, 1983), with baseline values as the covariate to control for chance imbalances at baseline (accounting for any unequal variance due to the unequal allocation, and including the factors used in minimisation (Scott et al., 2002)). Confidence intervals, confidence levels, and magnitude-based inferences were also used to assess the clinical significance of any effect (Shakespeare et al., 2001; Batterham and Hopkins, 2006; Hopkins et al., 2009). The same analysis strategy is applied to each dimension of physical activity, with due account taken of multiplicity (Pocock, 1997). Secondary outcomes pertaining to differences in various markers of health, body composition and psychosocial outcomes between intervention and control participants were also evaluated by analysis of covariance that used the baseline values as covariates. Further analysis of interaction effects involving age-group or sex will be undertaken to inform sample size planning for any subsequent definitive trial or evaluation by the trial statistician. This analysis a linear mixed model to provide the mean intervention effect together with quantification (as a standard deviation) of the individual participant differences in response to the intervention (‘treatment heterogeneity’) (Atkinson and Batterham, 2015).
7.3 RESULTS

The following represents an interim analysis undertaken by the candidate of the Mi-PACT trial, which concluded in August 2016.

7.3.1 PARTICIPANTS

A total of 1484 patients who matched the GP screening inclusion criteria were invited from six general practices. Of these, 533 declared an interest in taking part although 257 were declared ineligible following the telephone screen. Of the remaining 276 patients who were invited for a baseline assessment screening a further 71 were excluded for being too active, low risk or for having elevated risk factors that required alternative treatment. One participant did not attend the assessment clinic leaving 204 participants eligible for randomisation. At baseline, participants had a mean (±SD) PAL of 1.69 (±0.16), undertook 535 (±260) minutes of moderate to vigorous intensity bouts per week and spent an average of 73 (±9) per cent of the waking day sedentary. The proportion of participants considered at moderate and high risk was 69% and 16% for cardiovascular disease and 44% and 18% for type two diabetes, with a respective average risk score of 14.4 (±6.3) and 13.5 (±9.4). Table 7-b displays other baseline characteristics for all 204 participants randomised into the study. There were sixteen participants who were lost to follow-up at 3-months and a further 2 at 12-months, leaving 186 participants available for the primary analysis. The flow of participants through the two arms of the study and primary exclusion reasons at telephone or face-to-face screening and is shown in the CONSORT diagram (Schulz et al., 2010) in Figure 7-c.
<table>
<thead>
<tr>
<th>Characteristic</th>
<th>AL (n=204)</th>
<th>Intervention (n=134)</th>
<th>Control (n=70)</th>
</tr>
</thead>
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<tr>
<td>Age (years)</td>
<td>Mean (SD)</td>
<td>63.6 (5.8)</td>
<td>63.9 (5.7)</td>
</tr>
<tr>
<td>40-55</td>
<td>N (%)</td>
<td>15 (7%)</td>
<td>9 (7%)</td>
</tr>
<tr>
<td>55-70</td>
<td>N (%)</td>
<td>92 (93%)</td>
<td>125 (93%)</td>
</tr>
<tr>
<td>Female</td>
<td>N (%)</td>
<td>73 (36%)</td>
<td>48 (36%)</td>
</tr>
<tr>
<td>Ethnicity (White British)</td>
<td>N (%)</td>
<td>180 (88%)</td>
<td>117 (87%)</td>
</tr>
<tr>
<td>Marital status</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Married/cohabiting etc.</td>
<td>N (%)</td>
<td>164 (80%)</td>
<td>106 (79%)</td>
</tr>
<tr>
<td>Single/divorced/widowed</td>
<td>N (%)</td>
<td>40 (20%)</td>
<td>28 (21%)</td>
</tr>
<tr>
<td>Education</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GCSE</td>
<td>N (%)</td>
<td>63 (31%)</td>
<td>45 (34%)</td>
</tr>
<tr>
<td>A-Level</td>
<td>N (%)</td>
<td>60 (29%)</td>
<td>34 (25%)</td>
</tr>
<tr>
<td>First degree</td>
<td>N (%)</td>
<td>58 (28%)</td>
<td>39 (29%)</td>
</tr>
<tr>
<td>Higher degree</td>
<td>N (%)</td>
<td>23 (11%)</td>
<td>16 (12%)</td>
</tr>
<tr>
<td>IMD</td>
<td>Mean (SD)</td>
<td>7.6 (2.3)</td>
<td>7.6 (2.3)</td>
</tr>
<tr>
<td>Smoking status</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-smoker</td>
<td>N (%)</td>
<td>89 (43%)</td>
<td>62 (46%)</td>
</tr>
<tr>
<td>Ex-smoker</td>
<td>N (%)</td>
<td>95 (47%)</td>
<td>62 (46%)</td>
</tr>
<tr>
<td>Smoker</td>
<td>N (%)</td>
<td>20 (10%)</td>
<td>10 (8%)</td>
</tr>
</tbody>
</table>

IMD = Index of Multiple Deprivation Decile.
Figure 7-d. CONSORT flow diagram for MiPACT participants
7.3.2 PRIMARY OUTCOME: PHYSICAL ACTIVITY

Mean 24-hour wear time within the seven-day assessments at baseline, 3- and 12-months was 99%, 98% and 98% respectively for the 184 participants who competed all three assessments and were included in the analyses. Table 7-c displays the mean time spent in each physical activity intensity threshold at the baseline, 3-months and 12-month assessments in both the intervention and control groups. For the group as a whole there were little differences in the mean (±SD) time engaged in sedentary activities across these three respective assessments where 703 (±88.2), 697(±87) and 703(±91) minutes per day were observed. Light intensity physical activity was lower over the 12-month study period moving from 130 (±60.8) minutes per day at baseline to 125 (±52) and then 122 (±55) minutes per day after 3 and 12 months. These small reductions were replaced by modest increases in moderate-intensity physical activity, which increased from 117 (±49) to 125 (±56) and then 123 (±56) minutes per day, and vigorous-intensity physical activity, which increased from 10 (±11) to 13 (±16) and then reduced to 12 (±13) minutes per day at the respective 3- and 12-month assessments. For the intervention group the weekly increase in moderate to vigorous physical activity was 69 minutes and the control group saw an increase of 33 minutes although the difference was not significant after controlling for baseline values in the outcome of choice and factors used in the minimisation sampling (Table 7-c). For other key physical activity dimensions presented as part of the multidimensional feedback there were no statistically significant differences between the intervention and the control group. PAL remained fairly stable in both groups at each assessment time point with a small relative increase of 0.03 (approximately 150 Kcal) observed in the intervention group, which was not significant (p<0.05) in the adjusted ANCOVA model. The intervention did seem to have small positive effects on increasing vigorous activity accumulated in single minutes by 15 minutes per week (d = 0.24) and in at least 10-minute bouts by 10 minutes per week (d = 0.31) at follow-up although again these were not statistically significant.
Table 7-c. Overall intervention effect for selected physical activity outcomes

<table>
<thead>
<tr>
<th></th>
<th>Intervention group</th>
<th>Control group</th>
<th>Adjusted mean difference ²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BASELINE Mean (SD)</td>
<td>BASELINE Mean (SD)</td>
<td>BASELINE Mean (SD)</td>
</tr>
<tr>
<td>Physical activity threshold</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sedentary ^ (min/day)</td>
<td>713 (89)</td>
<td>710 (88)</td>
<td>711 (93)</td>
</tr>
<tr>
<td>Light (min/day)</td>
<td>125 (61)</td>
<td>117 (51)</td>
<td>117 (54)</td>
</tr>
<tr>
<td>Moderate (min/day)</td>
<td>112 (47)</td>
<td>119 (56)</td>
<td>120 (57)</td>
</tr>
<tr>
<td>Vigorous (min/day)</td>
<td>9 (10)</td>
<td>14 (14)</td>
<td>12 (14)</td>
</tr>
<tr>
<td>Very vigorous (min/day)</td>
<td>0 (0)</td>
<td>0 (1)</td>
<td>0 (1)</td>
</tr>
<tr>
<td>Feedback dimensions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daily PAL (TEE/BMR)</td>
<td>1.67 (0.16)</td>
<td>1.70 (0.19)</td>
<td>1.70 (0.20)</td>
</tr>
<tr>
<td>Sedentary ^ (% of day)</td>
<td>74 (9)</td>
<td>74 (9)</td>
<td>74 (10)</td>
</tr>
<tr>
<td>MVPA bouts ^ (min/week)</td>
<td>511 (277)</td>
<td>606 (359)</td>
<td>586 (377)</td>
</tr>
<tr>
<td>Vigorous Bouts ^ (min/week)</td>
<td>17 (32)</td>
<td>33 (64)</td>
<td>28 (54)</td>
</tr>
<tr>
<td>Daily Steps ⁰</td>
<td>6761 (2349)</td>
<td>7390 (3026)</td>
<td>7156 (3133)</td>
</tr>
</tbody>
</table>

MVPA = moderate to vigorous intensity physical activity; PAL = physical activity level; TEE = total energy expenditure; BMR = basal metabolic rate; ^ A = to standardise sleep and wear time fluctuations the sedentary score assumes 8 hours (540 minutes) of sleep for each person at each time point. ^ B = only activity accumulated in at least 10 minute bouts at the >3MET (MVPA) or >6 MET (vigorous) thresholds were included. C = covariates in the model include baseline scores for each respective outcome and the categorical baseline variables used in minimisation (age, sex, Qrisk, QDiabetes and baseline PAL). ⁰ = Daily steps did not form part of the feedback that participants were given but have been included for comparisons with analysis of Chapter 8. * Difference is significant at p <0.05
These findings are corroborated by the magnitude based inferences displayed in Figure 7-e, which deem the long-term clinical relevance of the intervention effects to be largely trivial when exploring each physical activity outcome variable in isolation. Whilst the intervention was positively beneficial for vigorous activity and steps, the effect sizes of 0.24 (95%CI). There was however evidence of moderate to large individual responses for intervention participants across all physical activity dimensions as expressed as a standard deviation (95% confidence limits). For PAL the SDIR was 0.59 (-0.16, 0.86), non-sedentary time 0.30 (-0.47, 0.63), daily moderate activity 0.44 (-0.43, 0.75), moderate to vigorous-activity bouts 0.59 (-0.30, 0.89) and vigorous activity 1.03 (0.64, 1.30). There were no significant subgroup effects of age, sex or baseline high versus low activity status (PAL<1.75 vs. PAL >1.75) or for individuals characterised as low, medium or high diabetes or cardiovascular risk.

Figure 7-e. Magnitude based inferences for core physical activity outcomes at 12-month follow-up.

The point on the axis represents the effect size and the horizontal error bars the 95% confidence interval for the effect. In the graph the red shaded area is indicative of the most worthwhile harmful effect, the green is the most worthwhile beneficial effect and the amber indicates a trivial effect.
7.3.3 Health

Table 7 displays group level scores for each of the anthropometric and blood health markers collected as part of the MiPACT study and the relative mean difference between the changes in health status between the intervention and control groups. There were no significant differences for blood pressure, body fat percentage, weight, waist circumference or body mass index at either the 3-month or 12-month assessment. In terms of blood markers there was also little differences between the two groups at the three month assessment however at the 12 month assessment glucose and total cholesterol were significantly reduced in intervention participants with mean differences of 0.24 mmol/L ($F(1,180) = 3.95, p = 0.048$) and 0.29 mmol/L ($F(1,180) = 4.012, p = 0.047$) respectively. There was also a small but non-significant trend in the reduction of diabetes risk after 12-months for intervention participants. With the exception of systolic blood pressure, all other variables were non-significantly reduced for intervention relative to the control group when measured at the 12-month follow-up.

7.3.4 Psychosocial Variables

Raw data for all psychosocial variables across all 3 assessments can be found in Appendix O. There were no observed differences between the intervention and control groups in terms of changes in overall physical activity related need satisfaction after 3 or 12 months, nor for either autonomy, competence or relatedness subscales. Mean $(\pm SD)$ scores for perceived competence for physical activity measured in isolation did however significantly increase at 3-months for the intervention relative to the control group $(0.6 (\pm 1.4) \text{ vs. } 0.0 (\pm 1.7), p = 0.017)$ but was not maintained after 12-months. Immediately after the intervention there was an increase in autonomous motivation for intervention participants as determined by composite score between identified and intrinsic behavioural regulation $(0.4 (\pm 0.6) \text{ vs. } 0.2 (\pm 0.6), p = 0.014)$. Identified regulation itself was significantly increased at 3-months for intervention participants relative to controls $(0.5 (\pm 0.6) \text{ vs. } 0.2 (\pm 0.6), p = 0.002)$, but there were no significant changes for amotivation, external or introjected
behaviour regulation. Once again these effects were not observed at follow-up. There were no significant differences between any changes in physical activity habits reported by the two groups but there were significant increases in barrier self-efficacy (3.6 (±19.4) vs. -3.0 (±17.7), p = 0.025) and vitality (0.6 (±1.0) vs. 0.1 (±1.2), p = 0.005) experienced immediately after the intervention at 3-months. None of these effects remained significant at the 12-month follow-up assessment.

7.3.5 Intervention evaluation

As part of a formative evaluation participants from the Mi-Pact group provided positive feedback about the usefulness of the programme giving it an overall mean (±SD) score of 4.5(±0.8) out of 5. Anecdotal evidence from open questions on the same feedback form indicated that the programme was particularly useful for raising their awareness of their own physical activity levels. Participants were also complimentary towards the usefulness of the health trainer in supporting the intervention and the wearability of the device scoring them 4.0 (±1.0) and 4.2 (±0.9) out of 5 respectively. When asked to rate the usefulness of the specific platform features participants gave the multidimensional health target and activity pattern feedback 4.5 (±0.7) out of 5 and the planning and tagging sections just 2.7 (±1.8) out of 5. In explaining their scoring, many participants suggested that the more interactive features were fiddly, didn’t always work and were even unused by many. In addition, a process evaluation is currently being undertaken that will assess the trial fidelity in terms of intervention delivery and user experiences from quantitative and qualitative data collected during and after the intervention programme. These measures conform to National Institute of Health Behaviour Change Consortium guidance (Bellg et al., 2004) and include components such as the selective recording of consultation meetings, fidelity checklists by trainers at their consultations, adherence logs, web-based platform visits and focus groups of intervention participant responders and non-responders. This process evaluation should disclose the extent to which the health trainers adhered to the training and guidance and whether or not the Mi-PACT study was delivered as intended.
### Table 7-d. Mean (SD) baseline 3-Month and 12-Month scores for health parameters and intervention effects

<table>
<thead>
<tr>
<th>Variable</th>
<th>Intervention Group</th>
<th></th>
<th></th>
<th>Control Group</th>
<th></th>
<th></th>
<th>Adjusted Mean Difference (^A) (95% CI)</th>
<th>3M-BL change</th>
<th>12M-BL change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>3-Month</td>
<td>12-Month</td>
<td>Mean (SD)</td>
<td>3-Month</td>
<td>12-Month</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BASELINE</td>
<td></td>
<td></td>
<td>BASELINE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPB (mmHg)</td>
<td>132 (14.1)</td>
<td>129 (19.3)</td>
<td>132 (16.4)</td>
<td>133 (17.0)</td>
<td>132 (17.0)</td>
<td>133 (16.5)</td>
<td>-1.00 (-5.38, 3.37)</td>
<td>0.36 (-3.32, 4.04)</td>
<td></td>
</tr>
<tr>
<td>DBP (mmHg)</td>
<td>84 (9.0)</td>
<td>81 (10.3)</td>
<td>82 (9.2)</td>
<td>84 (10.9)</td>
<td>84 (12.0)</td>
<td>83 (10.5)</td>
<td>-2.15 (-4.51, 0.22)</td>
<td>-1.16 (-3.31, 1.00)</td>
<td></td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>84.0 (14.1)</td>
<td>83.1 (14.0)</td>
<td>82.6 (14.1)</td>
<td>86.8 (14.2)</td>
<td>86.1 (14.0)</td>
<td>86.4 (14.4)</td>
<td>-0.19 (-1.05, 0.66)</td>
<td>-0.90 (-2.10, 0.30)</td>
<td></td>
</tr>
<tr>
<td>Waist (cm)</td>
<td>99.5 (10.5)</td>
<td>98.3 (10.2)</td>
<td>99.0 (10.6)</td>
<td>101.3 (10.6)</td>
<td>99.8 (10.2)</td>
<td>100.8 (10.6)</td>
<td>0.22 (-0.81, 1.24)</td>
<td>-0.15 (-1.61, 1.32)</td>
<td></td>
</tr>
<tr>
<td>BMI (kg/m(^2))</td>
<td>28.7 (4.5)</td>
<td>28.4 (4.4)</td>
<td>28.2 (4.5)</td>
<td>29.5 (4.3)</td>
<td>29.3 (4.3)</td>
<td>29.4 (4.6)</td>
<td>-0.08 (-0.38, 0.21)</td>
<td>-0.32 (-0.73, 0.10)</td>
<td></td>
</tr>
<tr>
<td>Total body fat (%)</td>
<td>32.7 (7.6)</td>
<td>32.3 (7.5)</td>
<td>32.4 (7.8)</td>
<td>32.3 (8.2)</td>
<td>31.9 (8.4)</td>
<td>32.3 (8.5)</td>
<td>0.02 (-0.54, 0.59)</td>
<td>-0.25 (-0.94, 0.43)</td>
<td></td>
</tr>
<tr>
<td>Visceral body fat (cm(^2))</td>
<td>182.4 (57.2)</td>
<td>176.8 (55.5)</td>
<td>178.3 (59.0)</td>
<td>192.2 (66.2)</td>
<td>188.4 (57.2)</td>
<td>195.0 (72.2)</td>
<td>-2.45 (-9.45, 4.55)</td>
<td>-7.49 (-16.42, 1.44)</td>
<td></td>
</tr>
<tr>
<td>Fat mass index (kg/m(^2))</td>
<td>9.3 (3.3)</td>
<td>9.1 (3.2)</td>
<td>9.1 (3.3)</td>
<td>9.4 (3.5)</td>
<td>9.2 (3.5)</td>
<td>9.4 (3.7)</td>
<td>-0.20 (-0.33, -0.07)</td>
<td>-0.12 (-0.48, 0.11)</td>
<td></td>
</tr>
<tr>
<td>Glucose (mmol/L)</td>
<td>5.2 (0.4)</td>
<td>5.2 (0.5)</td>
<td>5.0 (0.9)</td>
<td>5.1 (0.5)</td>
<td>5.1 (0.5)</td>
<td>5.2 (0.6)</td>
<td>0.01 (-0.11, 0.12)</td>
<td>-0.24 (-0.48, -0.00)*</td>
<td></td>
</tr>
<tr>
<td>Insulin (mU/L)</td>
<td>9.4 (5.6)</td>
<td>9.5 (6.0)</td>
<td>10.2 (7.7)</td>
<td>9.7 (6.4)</td>
<td>10.1 (5.8)</td>
<td>10.5 (6.0)</td>
<td>-0.42 (-1.62, 0.79)</td>
<td>0.07 (-1.55, 1.69)</td>
<td></td>
</tr>
<tr>
<td>HOMA-IR</td>
<td>2.2 (1.4)</td>
<td>2.3 (1.7)</td>
<td>2.3 (1.9)</td>
<td>2.3 (1.7)</td>
<td>2.4 (1.5)</td>
<td>2.5 (1.6)</td>
<td>-0.05 (-0.37, 0.23)</td>
<td>-0.04 (-0.45, 0.38)</td>
<td></td>
</tr>
<tr>
<td>TC (mmol/L)</td>
<td>5.8 (1.1)</td>
<td>5.7 (1.0)</td>
<td>5.6 (1.3)</td>
<td>5.7 (0.9)</td>
<td>5.7 (1.0)</td>
<td>5.7 (1.2)</td>
<td>-0.09 (-0.28, 0.10)</td>
<td>-0.29 (-0.57, -0.00)*</td>
<td></td>
</tr>
<tr>
<td>LDL (mmol/L)</td>
<td>3.6 (0.9)</td>
<td>3.5 (0.9)</td>
<td>3.4 (1.0)</td>
<td>3.5 (0.9)</td>
<td>3.4 (0.9)</td>
<td>3.5 (1.1)</td>
<td>-0.04 (-0.21, 0.13)</td>
<td>-0.20 (-0.42, 0.02)</td>
<td></td>
</tr>
<tr>
<td>HDL (mmol/L)</td>
<td>1.6 (0.5)</td>
<td>1.6 (0.4)</td>
<td>1.6 (0.5)</td>
<td>1.5 (0.4)</td>
<td>1.5 (0.4)</td>
<td>1.6 (0.5)</td>
<td>-0.00 (-0.07, 0.06)</td>
<td>-0.06 (-0.14, 0.03)</td>
<td></td>
</tr>
<tr>
<td>Trigs (mmol/L)</td>
<td>1.4 (0.6)</td>
<td>1.3 (0.7)</td>
<td>1.3 (0.7)</td>
<td>1.4 (0.7)</td>
<td>1.5 (0.9)</td>
<td>1.4 (0.8)</td>
<td>-0.11 (-0.28, 0.06)</td>
<td>-0.95 (-0.26, 0.07)</td>
<td></td>
</tr>
<tr>
<td>CVD Risk (^B)</td>
<td>14.7 (6.4)</td>
<td>14.8 (6.2)</td>
<td>15.6 (6.8)</td>
<td>13.2 (5.9)</td>
<td>13.3 (5.7)</td>
<td>14.0 (6.2)</td>
<td>0.04 (-0.54, 0.62)</td>
<td>0.12 (-0.55, 0.78)</td>
<td></td>
</tr>
<tr>
<td>Diabetes risk (^B)</td>
<td>14.0 (10.7)</td>
<td>13.4 (10.6)</td>
<td>13.4 (10.6)</td>
<td>12.7 (6.9)</td>
<td>12.3 (6.7)</td>
<td>12.9 (7.2)</td>
<td>-0.12 (-0.70, 0.46)</td>
<td>-0.73 (-1.61, 0.15)</td>
<td></td>
</tr>
</tbody>
</table>

SBP = systolic blood pressure; DBP = diastolic blood pressure; TC = total cholesterol; LDL = low density lipoprotein; HDL = high density lipoprotein; Trigs = triglycerides; CVD = cardiovascular disease; HOMA-IR = Homeostatic model assessment – Insulin resistance (calculated by fasting insulin (mU/L) x fasting glucose (nmol/L)/22.5).  

\(^A\) = pairwise comparisons between the intervention and control groups at the 3 and 12-month assessments when controlling for baseline discrepancies for each outcome.  

\(^B\) = 10 year projected risk as calculated at QINTERVENTION.co.uk  

* = Difference is significant at p<0.05.
7.4 Discussion

The results represent a preliminary analysis undertaken by the present author of the Mi-PACT study, an exploratory randomised controlled trial testing the short and long term efficacy of a trainer-guided self-monitoring intervention using personalised multidimensional physical activity feedback delivered on a web-based platform. Assessments made directly following the 3-month intervention period and after 12-months follow-up reveal that the intervention had seemingly little impact at a whole-group level on changing any of the five key health-harnessing dimensions of physical activity behaviour when compared to a control group who did not receive any feedback or trainer support. As steps were not directly presented as part of the feedback, the significant yet modest long-term increase is perhaps indicative of an attempt to move more regularly but was perhaps not sufficient to influence any of the core behavioural dimensions. There was however evidence of individual response in the data suggesting that the programme was effective for certain participants and not for others beyond the variance experienced in the control group (Atkinson and Batterham, 2015). The homogenous nature of the group meant that a superficial subgroup analysis on the present cohort did not shed any light on the type of people who may have found this programme most beneficial (Brookes et al., 2004). The trial statistician will conduct a more comprehensive analysis involving mixed linear modelling over the coming months in an effort to fully examine the effectiveness of the intervention tool.

The present results do however offer one or two signs of encouragement as to the efficacy of using multidimensional physical activity feedback (Khan and Tunaiji, 2011). For instance, intervention participants provided positive feedback for the multidimensional feedback and activity patterns, the use of the armband monitor and the role of the health trainer. Accordingly, there was very good compliance in terms of training session attendance, usage of the website and wear time with the Bodymedia device used to capture and present feedback to participants over the course of the 3-month intervention period. All participants who were lost to follow-
up, withdrew from the study for health or personal reasons unrelated to the programme. The observed impact on several psychosocial variables may also be promising for multidimensional physical activity feedback. Relative to the control group, intervention participants felt more autonomous motivation and perceived competence towards physical activity immediately after the intervention (Ryan et al., 2009). Self-determination theory proposes that experiencing more autonomous forms of motivation, feeling competent and vitality interact to improve one’s psychological well-being and performance of desirable behaviours over time (Nix et al., 1999; Ryan and Deci, 2001; Williams et al., 1998b). Barrier self-efficacy, that is the sense that one could overcome common external barriers to physical activity, was also significantly increased for intervention participants at the 3-month time point (McAuley, 1992). Considering that deviations in these scores were diminished at 12-month follow-up it would seem that this change in motivation was directly linked to the programme.

The present analysis did not however find a positive whole-group impact on any physical activity behaviour. These results corroborate the findings of other feedback-based interventions that found that information alone is perhaps not sufficient for changing physical activity (Pal et al., 2013; Godino et al., 2013; Van Hoye et al., 2015). In their study, Godino and colleagues (2013) found that regardless of whether feedback was simple (i.e. one-off snapshot of physical activity level against reference guidelines), visual (i.e. simple feedback plus heart rate and movement patterns) or contextualised (simple. Visual plus information on the expenditure of specific activities and goals setting) there was no change in behaviour relative to one another or a no feedback control group. One similarity between the two studies that may have impacted the overall findings could be the relatively high baseline physical activity levels, which is thought to have a large bearing on the impact of physical activity feedback in other contexts (Bravata et al., 2007; Kang et al., 2009b). Godino et al. (2013)’s study recruited middle-aged men and women with a baseline physical activity level of ~1.70 and in the present study the baseline PAL was 1.68, both of which are greater than the UKs estimated median PAL of 1.61 (SACN, 2011). Of
particular relevance for the current approach was that by anchoring to a single dimension (PAL) for recruitment purposes meant certain participants could still score highly for other dimensions of their physical activity behaviour. Indeed, over half (52%) of participants who were randomised into the intervention arm of the study hit at least one of the remaining four health targets at baseline of which 13%, 18% and 5% achieved two, three or all of them respectively (Figure 7-e). This begs the question as to whether participants recruited to the present study were, on the whole, in need of a change in behaviour and the raised awareness and improved competence and autonomous forms of motivations reported by intervention participants may be a reflection that the feedback validates the appropriateness of their existing behaviour rather than stimulates the desire to change. Perhaps a useful upshot of this finding for future research is that for a more inactive population this type of multidimensional physical activity feedback may help initiate and sustain changes in behaviour (Teixeira et al., 2012a; Standage and Ryan, 2012).

![Bar chart showing the number of intervention participants who hit 0, 1, 2, 3 or 4 of the five health targets other than PAL at baseline.](image)

**Figure 7-f** Number of intervention participants who hit 0, 1, 2, 3 or 4 of the five health targets other than PAL at baseline.

Control participants weren’t shown their feedback but have been included for comparative purposes only.

That said there would still have been nearly half the participants would have observed no green hit targets at baseline. It is important then to additionally consider whether or not the intervention included enough persuasive elements to motivate receivers to change their behaviour (Teixeira et al., 2012b; Scholz et al., 2008; Sniehotta et al., 2005; Maes and Karoly, 2005). Feedback from participants suggested
that the tagging and planning functions of the Mi-PACT web-platform were confusing, fiddly and seldom used. In the present study the health trainers held the responsibility of adding context to each individual’s feedback and supporting behavioural changes through the discussions of goals and action plans however the onus was always on the participant to implement any changes in their day-to-day life. One might consider that the present feedback, which depicted ones performance in conjunction with five global health-harnessing recommendations on a rolling weekly resolution, left too much of a conceptual jump when it came to translating a global behavioural goal into smaller, specific, daily targets (Consolvo et al., 2009a; Consolvo et al., 2006). The intervention of Van Hoye et al. (2015) found that whilst there were no effects of feedback alone on behaviour, the combination of need-supportive coaching with real-time daily data did lead to positive outcomes. A useful solution in this context could be drawn from successful pedometer interventions that provide acute step targets and real-time feedback (Shuger et al., 2011; Hurling et al., 2007; Tudor-Locke and Lutes, 2009). Thus, to improve the efficacy of multidimensional physical activity feedback one might incorporate real-time feedback and targets for each of the key health-harnessing dimensions to further motivate and educate participants towards achievement of wider behavioural goals.

There are a number of challenges revealed by the present study that may need to be addressed. Firstly, there may also be an issue with the method of data analysis used to evaluate multidimensional physical activity in the present study particularly when treating the group as a whole. A potential problem with this approach is that not every participant within the study would likely have chosen, needed or been able to focus on the same dimensions as one another making the detection of wholesale changes across the whole group difficult. A particular strength of the present study is the 24-7 minute-by-minute physical activity monitoring that provides a complete picture of an individual’s behaviour but clearly there is a need to devise statistical methods to analyse physical activity in its entirety across all dimensions and account for the phenotypically variable baseline profiles, which may have had a large bearing on the individual responses to the intervention (Thompson and Batterham, 2013).
Secondly, the programme also seemingly helped significantly reduce certain health markers that could be clinically relevant to the patients at heightened risk of future chronic disease (Booth et al., 2008). Given the findings, there is a possibility that the significant changes to fasting glucose and cholesterol may be due to a heightened perception of improved lifestyle and dietary alterations brought on by being involved in the programme and interacting with health trainer than any changes to physical activity itself (Danaei et al., 2009; Ezzati and Riboli 2013). Alternatively, these improvements may be indicative of subtle changes in various aspects of physical activity behaviour that occurred outside of the assessment periods. Unfortunately in the absence of any continuous data on diet or physical activity over the course of the 12-month study period the actual aetiology of these health changes remains unknown and warrant further exploration.

In conclusion, these preliminary results offer promising signs that a trainer guided, web-based self-monitoring intervention utilising multidimensional physical activity feedback could be beneficial for changing physical activity behaviour through improved motivation, awareness and health. Given the infancy of this approach and certain challenges there are certainly refinements that may improve its impact on behaviour itself. Further studies could explore the efficacy of using multidimensional physical activity feedback in less active individuals who are at greater need for a change in behaviour. Additionally, efforts to enhance the efficacy of this feedback resource for supporting behaviour change would do well to incorporate more acute self-regulatory tools such as action planning, target setting and instantaneous feedback.
Chapter 8 The Impact of Personalised Multidimensional Physical Activity Feedback with Real-Time Data for Changing Behaviour and Health
8.1 Background

Regular physical activity is considered a key constituent of a healthy lifestyle and can help prevent and manage numerous chronic diseases (Lee et al., 2012; Warburton et al., 2006; Powell et al., 2011). The prevalence of chronic physical inactivity is rapidly increasing in the developed world driven by a shift from manual to sedentary occupations and technologically centred social environments (Ezzati and Riboli, 2013). In the UK alone, physical inactivity is thought to incur direct healthcare costs of around £1 billion per year and up to £5.3 billion indirect costs when the associated comorbidities and absenteeism are accounted for (Allender et al., 2007; Scarborough et al., 2011). Thus, to reduce the financial burden and improve people’s health and quality of life there is a critical need to redress the rising trend of chronic physical inactivity through wide-scale, cost effective initiatives. Personalised behavioural feedback is emerging as one of the most promising techniques for installing meaningful and lasting behavioural changes on individuals (O’Brien et al., 2015; Sherrington et al., 2016). This has also been corroborated by other analyses for working age and obese adults, which also champion the role of self-monitoring physical activity behaviour and goal setting (Webb et al., 2010; Greaves et al., 2011; Olander et al., 2013).

A promising avenue engendered by advancements in physical activity monitoring technology is the ability to capture richer and more holistic information that encompasses several independent, empirically-derived, health-harnessing dimensions of an individual’s behaviour (Thompson and Batterham, 2013). This data can be transformed into sophisticated multidimensional visual feedback and used to offer solutions that can be tailored to an individual’s needs and preferences. There are a number of foreseeable benefits to this approach: For one, personalised feedback may increase people’s knowledge of physical activity guidelines, which in the UK and US is thought to be low despite widespread promotion efforts (Bennett et al., 2009; Knox et al., 2013). Secondly, providing a multidimensional profile may
raise the awareness of alternative and otherwise unfamiliar physical activity recommendations that have known positive health benefits such as moderate to vigorous activity bouts, sedentary time and overall physical activity level (PAL) (Haskell, 2009). Thirdly, the provision of behavioural options may have an additional benefit in that it can help people focus their efforts and attention on areas of greater need or those that are the most realistic and achievable given the goals and ability of the individual. From a motivational perspective, this sense of choice may encourage sustained engagement via an enhanced sense of autonomy and competence experienced when selecting personalised targets and internalised regulation towards physical activity (Ryan et al., 2008; Teixeira et al., 2012a).

Early indications suggest that this novel approach to physical activity feedback presents a promising strategy for individuals who are insufficiently active and/or at heightened risk of future chronic disease. In Chapters 5 and 6 the immediate motivational and educational impact of personalised feedback was endorsed and a prevailing cognitive and emotional response was observed. This was particularly pertinent in individuals with low baseline physical activity whose feedback aided the formation of illness representations towards their inactive status and the development of positive coping and plans. Nevertheless, when tested for the first time in a randomised controlled trial over a 3-month period of self-monitoring with support from a health trainer this approach was not effective in encouraging meaningful changes in behaviour for ‘at-risk’ patients recruited from primary care. This, as discussed in chapter 7, may be due in part to the fact that a number of the patients were fairly active at baseline meaning that the feedback may have had a validating rather than motivating effect where persuasive properties toward their need and opportunity for increasing their physical activity may have been weakened. Whilst this might be true there was no conclusive evidence that individuals of lower physical activity found the intervention more beneficial and many participants applauded the usefulness of this novel feedback. Speculatively, for many participants the lack of effect may have been more a result of a lack of additional support to translate the formation of positive intentions brought on by a raised awareness of
physical activity behaviour and discrepancies in their own levels into action (intention behaviour gap). The health trainer might in principal appear useful for providing contextual support there is additional need for tools that enable other self-regulatory techniques involved in bridging the intention-behaviour gap such as the setting and monitoring of specific behavioural goals and the formation of implementation intentions (Carver and Scheier, 1982; Gollwitzer and Brandstätter, 1997; Scholz et al., 2008; Rhodes and Dickau, 2012b).

A key feature of popular commercial physical activity monitors that was not incorporated in the aforementioned randomised controlled trial (Chapter 7) is the ability to provide real-time feedback to motivate their users, perhaps most successfully through the administration of step goal targets (Fanning et al., 2012; Kang et al., 2009a). The use of pedometers for goal setting and self-monitoring of steps has been shown to successfully support increases in physical activity in a number of trials and in specific clinical populations such as overweight/obese, type-two diabetes and musculoskeletal disorders (Richardson et al., 2008; Tudor-Locke and Lutes, 2009; Funk and Taylor, 2013; Mansi et al., 2014). Furthermore, interventions using tailored pedometer feedback has also been shown to reduce the presence of certain health risk markers such as body mass index and blood pressure although unfortunately the long-term efficacy of these interventions on behaviour or health remains unconvincing (Bravata et al., 2007; Ogilvie et al., 2007). This might be down to an inability to conceptually translate steps into meaningful health outcomes such that individuals would find it hard to judge whether their increase in performance adequately benefits them once the monitoring has ceased (Consolvo et al., 2009b). Furthermore, whilst the ‘more-is-better’ principle seemingly works for highly motivated individuals who are already currently active, in the absence of appropriate context for individuals who are insufficiently active to begin with may not be able to utilise pedometers to their advantage.

Encouragingly, the FDA-approved Bodymedia device used throughout this programme of work has an accompanying portable display with the facility to present
up-to-the-minute feedback on calories, minutes of moderate activity, minutes of vigorous activity and steps. Moreover, the device permits the selection of personal daily targets for each of these parameters and accumulates scores over time and has been previously implemented in successful weight loss trials (Pellegrini et al., 2012; Shuger et al., 2011). Whilst these parameters do not entirely align to all of the important health outcomes presented as part of the multidimensional feedback developed and examined throughout this thesis, there are certainly potential advantages of utilising these two tools in tandem. If the multidimensional feedback serves as a driver for behaviour change as the qualitative results of Chapter 5 and Chapter 6 suggest, the use of real-time feedback may help individuals more resolutely gauge how to achieve the different guidelines. The daily calorie feedback, for example, would inherently help an individual work towards their individual PAL of 2.0 target, whereas the daily and weekly moderate to vigorous activity dimensions would be recognisable through close observation of the respective daily parameters. Conceivably, individuals could in time even learn to appraise their sedentary behaviour through the self-regulation of activity minutes and steps. Given the increasing abundance of commercial fitness trackers that incorporate the facility to present real-time data it would be useful to examine the efficacy of this twin approach.

8.2 METHODS

The present study sought to answer the following research questions:

- Does self-monitoring multidimensional physical activity with daily real-time feedback on calories, moderate to vigorous physical activity and steps lead to meaningful changes to physical activity behaviour?
- Are any changes made over six or twelve weeks sufficient to change markers of health?
8.2.1 Study design

The present study adopted a mixed-method randomised controlled exploratory trial design and has been registered on www.clinicaltrials.gov (Ref: NCT02432924). Ethical approval for the study was provided by the University of Bath Research Ethics Approval Committee for Health (REACH reference number: EP 14/15 10, Appendix P). Participants had their free-living physical activity and health assessed on three occasions. The first two assessments fell either side of a six-week self-monitoring intervention (or usual behaviour if control) with the third assessment following a further six-week period without feedback. After the final assessment participants from the intervention group were invited to undertake a one-to-one, semi-structured interview to learn if, how and why the intervention was useful for supporting a behaviour change. A summary of the study design is displayed in the PAT plot of Figure 8-a.

![Figure 8-a. Study design](image)

* Participants randomised into the control group were given the intervention in full for their own benefit if they opted in but it was not used to generate any data.

8.2.2 Participants and eligibility

Participants were male and females aged 40 to 70 years who judged themselves to be not highly active. The study was advertised through external university web pages,
twitter and local newspaper articles. Those who responded were sent a Participant Information Sheet and subsequently screened for eligibility via a telephone call. People were excluded if they were being treated for coronary heart disease, chronic kidney disease (stages 3-5), diabetes mellitus, stroke, heart failure and peripheral arterial disease. Participants were deemed eligible for the study if they had a physical activity level (PAL) of less than 2.0. PAL is a standard objective method of expressing total daily energy expenditure in multiples of resting metabolic rate (total energy expenditure/resting metabolic rate kcal/day). An average daily PAL of >2.0 has been categorised by WHO as representing a highly active lifestyle (FAO, 2004). In addition, individuals were required to provide at least 6 valid monitoring days of at least 80% of data for a given 24-h period (including both a Saturday and Sunday) to be included (Scheers et al., 2012a).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>All (n = 51)</th>
<th>Intervention (n = 36)</th>
<th>Control (n = 15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years) Mean (SD)</td>
<td>51.3 (8.4)</td>
<td>52.3 (8.2)</td>
<td>50.1 (8.3)</td>
</tr>
<tr>
<td>40-55</td>
<td>N (%)</td>
<td>33 (65%)</td>
<td>23 (64%)</td>
</tr>
<tr>
<td>55-70</td>
<td>N (%)</td>
<td>18 (35%)</td>
<td>13 (36%)</td>
</tr>
<tr>
<td>Female</td>
<td>N (%)</td>
<td>28 (55%)</td>
<td>20 (55%)</td>
</tr>
<tr>
<td>Ethnicity white British</td>
<td>N (%)</td>
<td>46 (90%)</td>
<td>32 (88%)</td>
</tr>
<tr>
<td>Marital status</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Married/cohabiting etc.</td>
<td>N (%)</td>
<td>42 (82%)</td>
<td>30 (83%)</td>
</tr>
<tr>
<td>Single/divorced/widowed</td>
<td>N (%)</td>
<td>9 (18%)</td>
<td>6 (17%)</td>
</tr>
<tr>
<td>Education</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GCSE</td>
<td>N (%)</td>
<td>3 (6%)</td>
<td>3 (8%)</td>
</tr>
<tr>
<td>A-Level</td>
<td>N (%)</td>
<td>4 (8%)</td>
<td>3 (8%)</td>
</tr>
<tr>
<td>First degree</td>
<td>N (%)</td>
<td>24 (47%)</td>
<td>17 (47%)</td>
</tr>
<tr>
<td>Higher degree</td>
<td>N (%)</td>
<td>20 (39%)</td>
<td>13 (36%)</td>
</tr>
<tr>
<td>Smoker</td>
<td>N (%)</td>
<td>2 (4%)</td>
<td>0 (0%)</td>
</tr>
</tbody>
</table>

Figure 8-b shows the flow of participants through the study. A total of 102 individuals made initial enquiries about volunteering for the study of which 57 were eligible and willing to undergo a baseline assessment. Of these participants who all provided
informed consent, five were excluded for being too active (PAL >2.0), whilst one withdrew from the study during their 7-day physical activity assessment due to an allergic reaction to the device. A total of 51 participants were therefore included in the study. Upon completion of the baseline assessment participants were randomised into one of two conditions, an intervention group (INT) or a waiting list control group (CON). In order to learn more about the intervention a 2:1 allocation was selected in favour of the INT group. It was calculated that a 30:15 sample size was required to detect a meaningful change in physical activity based on an effect size of 0.68 as observed previous pedometer interventions (Kang et al., 2009), 80% power and an alpha of 5%. To allow for potential dropout of ~25% an approximate sample of 55 adults were targeted. The randomisation was completed by a statistician external to the research team who did not disclose the any details of the randomisation plan prior to completion of the study recruitment. To balance characteristics of participants within each group the statistician stratified by gender and BMI (with 30 kg/m2 as the binary cut point) using a block size of six. This worked out as 9:5 for lean men, 13:6 for lean women, 7:2 for obese men and 7:2 for obese women giving an overall allocation of 36:15 in favour of the intervention group. No participants withdrew from the study after being randomised although one intervention participant declined to undergo the end of programme interview.

8.2.3 Measurement procedures

All participants deemed eligible to take part following a telephone screening call were invited to attend a baseline assessment that afforded them the opportunity to ask any questions about the study before written informed consent was signed. The session lasted approximately 45 minutes and involved the completion of a questionnaire pack, blood pressure, anthropometric measurements and a blood test. For the sake of the desired blood marker analysis participants were asked to attend the session having had no food or caffeine for a minimum of 10-hours. At the end of the session participants were also provided with a fully charged Bodymedia core armband and instructed to wear the device for seven consecutive days, removing the device solely for water based activities. Participants were also provided with a pre-
addressed envelope with which to return the activity monitor. All of these procedures were replicated at the six and twelve week follow-up assessments.

The questionnaire pack included a collection of validated instruments that are described at length by the respective cited authors. Where appropriate, the stem of the respective questions was altered from its original wording to refer to *physical activity* rather than *exercise*. To measure participant’s motivation as propagated by Self-Determination Theory the Psychological Need Satisfaction in Exercise scale (Wilson et al., 2006) was used to measure autonomy, competence and relatedness and the Behavioural Regulation in Exercise Questionnaire – 2 (Markland and Tobin, 2004) to explore the reasons for engaging in physical activity. The Perceived
Competence in Physical Activity (Williams et al., 1998b) was also included as a more specific measure of an individual’s self-belief. The Barrier Self-Efficacy scale (McAuley, 1992) was included to determine whether the intervention had any effect on people’s confidence to undergo physical activity in the face of common obstacles and the Self-Report Habit Index (Verplanken and Orbell, 2003) used to determine the automaticity of physical activity behaviour. The Subjective Vitality Scale (Ryan and Frederick, 1997) was used to detect changes in vitality, and the EuroQol-5D (EuroQol, 1996) and SF 36 Health Survey Questionnaire (Brazier et al., 1992) to detect changes in perceived health, wellbeing and quality of life.

Blood pressure was measured using an automatic sphygmomanometer immediately after the 15-minute period of isolated rest where participants filled out the questionnaire pack. Three measurements were taken and the average of the readings were used as the recorded value unless the first reading was discarded for being significantly higher. Participant height was measured barefoot to the nearest millimetre using a Seca Stadiometer, and weight to the nearest 100 grams using a set of digital Tanita scales. These measures were also used to calculate the body mass index (kg/m²) of each participant. Waist circumference measurements were taken to the nearest millimetre using a Hoechstmass tape measure placed parallel to the floor at the mid-point between the iliac crest and the lowest palpable rib after a gentle exhalation. The average of three measurements was taken providing they were within 0.5 centimetres of one another.

A 10ml venepuncture sample was also taken by the lead researcher at each assessment from a superficial forearm vein. Samples were immediately separated into EDTA and [clear] tubes (5ml per tube) and centrifuged to render the respective a-cellular serum and plasma components. These were pipetted into three Eppendorf’s and frozen at -20°C. Upon completion of the study a batch analysis method was used to determine the levels of glucose, insulin, total cholesterol HDL cholesterol, triglycerides and C-reactive protein for each participant at all three time
points. From the glucose and insulin scores, Homeostasis model assessment for insulin resistance (HOMA-IR; Turner et al., 1979) was calculated as:

\[
HOMA-IR = \frac{\text{Fasting glucose (mmol/L)} \times \text{Fasting insulin (mU/L)}}{22.5}
\]

LDL cholesterol determined using formula Low-density lipoprotein (LDL) cholesterol was calculated using the Friedewald et al., (1972) equation:

\[
LDL = \text{Total Cholesterol} - \text{HDL} - \frac{(\text{Triglycerides} \times 2.2)}{2}
\]

At the end of the study all health measurements were fed back to participants along with their physical activity data for all three assessments.

Physical activity was measured using the Bodymedia Mini device as described in Chapter 7 and validated in Chapter 3. Participants were provided with the monitor at assessment sessions along with wear instructions and a reply-paid envelope with which to post the device back to the lead researcher. Participants were instructed to wear the armband on the left arm for a full 7-day period removing the device only for water-based activities such as showering or swimming. To be included in the analysis participants were required to present a minimum of 6-valid days that included 80% wear-time (although allowances were made in the rare occasions where participants removed the device during sleep and estimated resting metabolic rate was assigned to missing data points to complete the 24-hour period). The minute-by-minute energy expenditure was used to determine each individuals physical activity level and time (minutes) spent in each of the activity intensity thresholds (Sedentary, <1.8 METs; Light, ≥1.8, <3.0 METs; Moderate, ≥3.0, <6.0 METs; Vigorous, ≥6.0, <10.2METs; and Very vigorous, ≥10.2METs). This data was used to determine changes in each of the key health harnessing physical activity dimensions used in the feedback. Mean daily steps were also determined at each assessment. In addition to its use as the objective physical activity assessment; data collected by the Bodymedia armband was processed through the web-based platform to generate the baseline multidimensional feedback (Figure 8-c).
Participants who successfully completed the intervention were invited to attend a one-to-one semi-structured interview to discuss their experience with the programme once all follow-up assessments were complete. The topic guide for these interviews (shown in full in Appendix T) included questions to capture participants’ views on the utility and retrospective and prospective impact of the intervention for them and unpick the particular aspects that were most useful and those that might be improved. The interviews typically lasted between 15 and 25 minutes and were recorded on an Olympus digital voice recorder. Audio files were transcribed verbatim and uploaded to NVivo for coding and analysis. In addition to the interviews, all intervention participants completed a feedback form that included rating scales for particular aspects of the both the real-time display (overall, personal targets, calories, steps, moderate and vigorous activity) and web-based feedback (overall, health targets, activity patterns, review function, planning function) that ranged from 1, not useful at all to 3, somewhat useful to 5, extremely useful, with a 0 if the element in question was not used.

8.2.4 INTERVENTION ARM

Participants randomised to the intervention group returned to the University of Bath at the earliest convenient opportunity to undertake a set-up session. Here they were shown multidimensional feedback on their weekly physical activity using the MiPACT web-platform as described in Chapter 7. Briefly, the website provides visual representations of the performance of a 7-day period in relation to five key health targets (Figure 8-d ‘A’): total energy expenditure, sedentary time, accumulated daily minutes of moderate activity, moderate activity bouts and vigorous activity bouts. Using a simplified and more detailed graphic, participants were shown each target attainment using a traffic light system where green would indicate a hit target, amber a near (within 20%) and red a missed target.

A) Multidimensional health target attainment
B) Daily physical activity patterns and summary graphs

C) Review section

D) Planning section

Figure 8-c. Features and examples of feedback and functions included on the MiPACT web-based platform.
Additional feedback was provided in the form of 24-hour physical activity patterns that were colour coded to indicate the intensity of activity at a given minute of the day (figure 8-d ‘B’). The web platform also included two interactive tabs whereby participants could tag activities to learn the specific intensity and energy expenditure of a given activity or period of time (figure 8-d ‘C’); and forward plan future activities that could be superimposed on a given weeks activity patterns to evaluate the impact of adding new or existing activities in on their health targets (figure 8-d ‘D’).

In addition, participants were provided with a new Bodymedia mini monitor (Pitsburg, USA), a smaller and more discrete model that use the same algorithms and sensors and the Bodymedia Core used for the assessments, and an accompanying real-time analogue display that synced data directly from the armband (Figure 8-c). The small clip on display provides instant feedback on total calories, steps, minutes of moderate activity and minutes of vigorous activity. As well as real-time data, the display also stored the total 24-hour values for the previous day and permitted the setting of personalised targets across each of the four activity metrics. If targets are met, a congratulatory message reads across the screen and an alarm sounds to inform the user of their success. Participants were instructed with the operating procedure for the device and encouraged to use it as often as they felt necessary during the six-week period. Over the course of the intervention the participant and researcher met a further three times to upload new data from the armband, at weeks two, four and six. These short 15-minute informal sessions also afforded each participant the opportunity for troubleshooting any technical queries, get help interpreting their personal multidimensional web feedback and discuss new plans of action for change. Each session was delivered in an autonomy supportive manner, which placed emphasis on the participant driving discussions and never being prescriptive of how to change behaviour (Fortier et al., 2012; Teixeira et al., 2012a).
Figure 8-d. Bodymedia device and accompanying real-time feedback display.

Data for calories, steps moderate-intensity activity and vigorous-intensity activity is updated on the display via Bluetooth every minute and the user can also retrieve total scores for the previous day, their personalised target and a running trip that accumulates until it is reset for each parameter (See Appendix Q for details).

8.2.5 Waiting List Control Arm

The waiting list group were encouraged to carry on with their usual behaviour as normal until they had had 2 further assessments. The first of these assessments was conducted a minimum of six-weeks after the date of their randomisation, and the second one a minimum of six weeks following the successful return of their second assessment activity monitor. This meant that they were aligned as close as possible to the timeframe of those participants in the intervention group. At the time of revealing their allocation, waiting list participants were informed that upon completion of the 12-week assessment they would be able to receive the self-monitoring intervention in full (Figure 8-a).

8.2.6 Analysis

The primary analysis was a comparison between intervention and control group participants for 12-week change in physical activity using an analysis of covariance (ANCOVA) model (Laird, 1983), with baseline values as the covariate to control for chance imbalances at baseline (accounting for any unequal variance due to the unequal allocation, and including the factors used in balancing the groups (Sex and BMI status) (Scott et al., 2002)). In light of the sub-optimal sample size, confidence intervals, confidence levels, and magnitude-based inferences was used to assess the
clinical significance of the effect (Shakespeare et al., 2001; Batterham and Hopkins, 2006; Hopkins et al., 2009). This analysis strategy was applied to each dimension of physical activity. Adjusted ANCOVAs that control for baseline discrepancies between the intervention and control participants were also used to determine any significant changes in health outcomes or psychosocial data. The one-to-one interviews were interpreted using a qualitative survey response approach.

8.3 RESULTS

8.3.1 PRIMARY OUTCOME: PHYSICAL ACTIVITY BEHAVIOUR

All 51 participants had complete data for the primary outcome assessments made between 12-week follow up and baseline and were therefore included in the primary analysis. Total 24-hour wear time across the week for the three assessment time points was, on average, 98%, 96% and 95% for the intervention group and 95%, 95% and 95% in the control group. Table 8-b shows the ANCOVA results and mean difference between the intervention and control group 12-week change scores and effect sizes for each of the physical activity intensity thresholds and other behavioural outcomes assessed. Figure 8-e, panels ‘A-F’, show the mean (SD) scores across each of the five platform dimensions and steps for both the intervention and control participants.

Relative to the control group, individuals receiving the multidimensional and instant feedback intervention showed significant reductions in daily sedentary time at 12 weeks with an observed mean difference (95% CI) of -42 (-76.6, -5.6) minutes. This was explained by an increase of 14 (-3.1, 32.1) minutes of light activity, 23 (-0.2, 46.5) minutes of moderate activity and 2 (-1.9, 5.5) minutes of vigorous activity per day. In terms of the activity targets, weekly moderate to vigorous activity as a whole was significantly increased in the intervention group regardless of whether it was accrued in single minutes with a mean difference (95% CI) of 191 (15.1, 366.9) minutes...
(F(1,45) = 4.78, p = 0.03) or in sustained 10-minute bouts with a mean difference of 180.7 (35.2, 326.1) minutes (F(1,45) = 6.23, p = 0.02). PAL also significantly increased by 0.09 (0.01, 0.16) for participants in the intervention group relative to the control group (F(1,45) = 5.465, p = 0.02) as was the number of steps taken per day, which saw a mean difference of 1148 (478, 1818) relative to the control group (F(1,45) = 5.939, p = 0.02). Correlations were run to explore the heterogeneity of physical activity outcome variables. Reductions in sedentary time were strongly correlated with increases in moderate (r = -0.89) and light-intensity (r = -0.81) activity (p<0.01) and weakly with vigorous activity (r = -0.29, p<0.05). Increases in moderate activity only mildly correlated with increased vigorous (r = 0.28, p<0.05). A similar pattern was observed with the multidimensional feedback outcomes where changes in PAL were strongly associated with increased moderate to vigorous bouts (r = 0.86), reduced sedentary time (r = -0.89) and steps (r = 0.72) but were not associated with vigorous bouts.

### 8.3.2 Magnitude based inference and sub-group analysis

In light of the small effect size and inflated chance of type II error magnitude based inference was undertaken detect the clinical significance of these results. Figure Z shows the adjusted effect sizes for selected physical activity outcomes and the likelihood of the intervention effect being clinically relevant, based on the smallest meaningful effect size of 0.2 with a benefit of 25% and harm risk 0.5% (Hopkins, 2013). From this analysis it is likely that the intervention has no negative effects on any of the physical activity dimensions after 12 weeks. Relative to the control group, the intervention has a high probability of showing clinically meaningful changes in bouts of moderate to vigorous activity and steps, and likely to improve PAL, and reduce sedentary time.
Table 8-b. Overall intervention effect for selected physical activity outcomes

<table>
<thead>
<tr>
<th></th>
<th>Intervention</th>
<th>Control</th>
<th>Adjusted***</th>
<th>ANCOVA</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BASELINE</td>
<td>12W CHANGE</td>
<td>BASELINE</td>
<td>12W CHANGE</td>
<td>Mean difference</td>
</tr>
<tr>
<td><strong>Physical activity duration</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sedentary* (min/day)</td>
<td>754 (73)</td>
<td>-31 (69)</td>
<td>751 (65)</td>
<td>10 (50)</td>
<td>-40.2 (-76.1, -4.3)</td>
</tr>
<tr>
<td>Light (min/day)</td>
<td>102 (43)</td>
<td>10 (37)</td>
<td>100 (45)</td>
<td>-3 (28)</td>
<td>14.0 (-77.6, 44.7)</td>
</tr>
<tr>
<td>Moderate (min/day)</td>
<td>96 (45)</td>
<td>19 (44)</td>
<td>102 (33)</td>
<td>-6 (31)</td>
<td>22.3 (0.0, 44.6)</td>
</tr>
<tr>
<td>Vigorous (min/day)</td>
<td>8 (9)</td>
<td>2 (6)</td>
<td>7 (7)</td>
<td>-1 (5)</td>
<td>2.2 (-1.4, 5.8)</td>
</tr>
<tr>
<td>Very vigorous (min/day)</td>
<td>0 (2)</td>
<td>1 (2)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0.1 (-0.3, 0.5)</td>
</tr>
<tr>
<td><strong>Feedback dimensions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daily PAL (TEE/BMR)</td>
<td>1.60 (0.16)</td>
<td>0.06 (0.13)</td>
<td>1.62 (0.13)</td>
<td>-0.02 (0.10)</td>
<td>0.09 (0.01, 0.16)</td>
</tr>
<tr>
<td>Sedentary time* (% day)</td>
<td>77 (8)</td>
<td>-3 (7)</td>
<td>78 (7)</td>
<td>1 (5)</td>
<td>-4.3 (-8.0, -0.5)</td>
</tr>
<tr>
<td>MVPA bouts** (min/week)</td>
<td>429 (264)</td>
<td>102 (272)</td>
<td>416 (198)</td>
<td>-66 (167)</td>
<td>180.7 (35.2, 326.1)</td>
</tr>
<tr>
<td>Vig. activity** (min/week)</td>
<td>29 (47)</td>
<td>9 (40)</td>
<td>18 (30)</td>
<td>-8 (25)</td>
<td>15.8 (-7.9, 39.5)</td>
</tr>
<tr>
<td>Daily Steps</td>
<td>7610 (2212)</td>
<td>1159 (2260)</td>
<td>7767 (2296)</td>
<td>-341 (1116)</td>
<td>1148 (478, 1818)</td>
</tr>
</tbody>
</table>

*to standardise sleep time the sedentary score assumes 8 hours (540 minutes) of sleep for each person at each time point. Therefore the percentage is of an assumed 16-hour waking day.

** Only activity accumulated in at least 10 minute bouts at the >3MET (MVPA) or >6 MET (vigorous) thresholds were included.

***Covariates in the model included baseline values for each dependent variable, sex, baseline weight and age.

MVPA = moderate to vigorous physical activity; PAL = physical activity level; TEE = total energy expenditure; BMR = basal metabolic rate; Vig. = vigorous intensity activity.
Figure 8-e. Mean (SD) scores across each of the physical activity outcomes on which participants received feedback for the three assessments.

Intervention participants are represented by the blue bar and control participants by the orange bar. The middle time point has been softened for easier visualisation of the change with the primary baseline to follow-up assessment (where 1 = baseline, 2 = post intervention and 3 = 12 week follow up).
The numbers in the central columns represent the percentage probability based on the likely effect of the intervention showing a meaningful effect of at least $d = 0.2$. The dots and bars represent the actual effect size ± 95% CI.

Table 8-c displays the means (±SD) for each of the physical activity outcomes when stratified by sex (male vs. female) and baseline physical activity level (there were no notable differences for age or baseline body mass index (e.g. >30 kg/m² vs. <30 kg/m²)). Although the sample size did not permit robust statistical testing and conclusions, it does appear that the intervention was particularly effective for individuals of low baseline physical activity levels and for females. It should be noted that the females in present study were of lower baseline physical activity levels compared to males and further studies are warranted to unpick the clinical significance of the interactions found in sex and baseline activity levels (Table 8-d).

Table 8-c displays the means (±SD) for each of the physical activity outcomes when stratified by sex (male vs. female) and baseline physical activity level (there were no notable differences for age or baseline body mass index (e.g. >30 kg/m² vs. <30 kg/m²)). Although the sample size did not permit robust statistical testing and conclusions, it does appear that the intervention was particularly effective for individuals of low baseline physical activity levels and for females. It should be noted that the females in present study were of lower baseline physical activity levels compared to males and further studies are warranted to unpick the clinical significance of the interactions found in sex and baseline activity levels (Table 8-d).
Table 8-c. Subgroup effects for sex and baseline PAL using a cut point of 1.6. The scores represent the mean (SD) 12 week change in main outcomes.

<table>
<thead>
<tr>
<th>RAW</th>
<th>Mean (SD)</th>
<th>Sex</th>
<th>Baseline PAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Female</td>
<td>Male</td>
</tr>
<tr>
<td>Sedentary (min/day)</td>
<td>CON</td>
<td>13 (44)</td>
<td>7 (61)</td>
</tr>
<tr>
<td>Moderate (min/day)</td>
<td>CON</td>
<td>-14 (19)</td>
<td>3 (41)</td>
</tr>
<tr>
<td>PAL</td>
<td>INT</td>
<td>0.09 (0.11)</td>
<td>0.03 (0.14)</td>
</tr>
<tr>
<td>(TEE/BMR)</td>
<td>CON</td>
<td>-0.03 (0.08)</td>
<td>-0.02 (0.12)</td>
</tr>
<tr>
<td>MVPA bouts (min/week)</td>
<td>INT</td>
<td>133 (275)</td>
<td>63 (271)</td>
</tr>
<tr>
<td>(min/week)</td>
<td>CON</td>
<td>-115 (70)</td>
<td>-9 (229)</td>
</tr>
<tr>
<td>Vigorous (min/week)</td>
<td>INT</td>
<td>6 (32)</td>
<td>26 (58)</td>
</tr>
<tr>
<td>(min/week)</td>
<td>CON</td>
<td>-5 (27)</td>
<td>-5 (44)</td>
</tr>
<tr>
<td>Steps (steps/day)</td>
<td>INT</td>
<td>1568 (2424)</td>
<td>648 (1993)</td>
</tr>
<tr>
<td>(steps/day)</td>
<td>CON</td>
<td>-253 (1238)</td>
<td>-442 (1047)</td>
</tr>
</tbody>
</table>

PAL; physical activity level; TEE = total energy expenditure; BMR = basal metabolic rate; MVPA = moderate to vigorous intensity physical activity; INT = intervention group; CON = control group

Table 8-d. Mean (SD) differences in age, body mass, and physical activity level between male and female participants in the intervention and control groups.

<table>
<thead>
<tr>
<th></th>
<th>Females</th>
<th>Males</th>
<th>Inactive (PAL &lt;1.6)</th>
<th>Active (PAL ≥1.6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>28</td>
<td>23</td>
<td>26</td>
<td>25</td>
</tr>
<tr>
<td>INT</td>
<td>20</td>
<td>16</td>
<td>20</td>
<td>16</td>
</tr>
<tr>
<td>CON</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Age (years)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>51.1 (7.5)</td>
<td>54.3 (8.9)</td>
<td>52.0 (8.2)</td>
<td>53.2 (8.4)</td>
</tr>
<tr>
<td>INT</td>
<td>51.7 (7.9)</td>
<td>55.0 (8.4)</td>
<td>53.4 (8.3)</td>
<td>52.4 (8.3)</td>
</tr>
<tr>
<td>CON</td>
<td>49.5 (6.5)</td>
<td>52.9 (10.5)</td>
<td>48.0 (6.8)</td>
<td>53.8 (9.3)</td>
</tr>
<tr>
<td>Baseline BMI (kg/m²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>27.7 (4.7)</td>
<td>28.4 (5.1)</td>
<td>28.4 (5.4)</td>
<td>27.7 (4.2)</td>
</tr>
<tr>
<td>INT</td>
<td>27.8 (4.8)</td>
<td>29.1 (4.9)</td>
<td>29.0 (5.3)</td>
<td>27.6 (4.3)</td>
</tr>
<tr>
<td>CON</td>
<td>27.6 (4.7)</td>
<td>26.9 (5.5)</td>
<td>26.6 (5.7)</td>
<td>27.8 (4.5)</td>
</tr>
<tr>
<td>Baseline PAL (TEE/BMR)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1.56 (0.14)</td>
<td>1.66 (0.14)</td>
<td>1.50 (0.08)</td>
<td>1.74 (0.09)</td>
</tr>
<tr>
<td>INT</td>
<td>1.57 (0.16)</td>
<td>1.65 (0.16)</td>
<td>1.49 (0.09)</td>
<td>1.74 (0.10)</td>
</tr>
<tr>
<td>CON</td>
<td>1.55 (0.12)</td>
<td>1.70 (0.08)</td>
<td>1.51 (0.08)</td>
<td>1.72 (0.06)</td>
</tr>
</tbody>
</table>

TEE = Total energy expenditure; BMR = Basal metabolic rate
Table 8-e presents the adjusted mean difference between the intervention and control group for each of the health outcomes measured at assessments. Over the twelve weeks there were no significant differences in any of the health outcomes measured between intervention and the control group. Mean differences at group level indicate trends towards a reduction in health risk for all markers in favour of the control group with the exception of systolic blood pressure.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Intervention</th>
<th>Control</th>
<th>I vs C</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>12W change</td>
<td>Baseline</td>
<td>12W change</td>
</tr>
<tr>
<td>SPB (mmHg)</td>
<td>127 (13.9)</td>
<td>-1.22 (10.18)</td>
<td>119 (11.6)</td>
<td>-2.93 (11.37)</td>
</tr>
<tr>
<td>DBP (mmHg)</td>
<td>88 (9.4)</td>
<td>-1.08 (10.04)</td>
<td>80 (9.0)</td>
<td>1.80 (5.75)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>83.1 (14.3)</td>
<td>-0.18 (2.75)</td>
<td>79.1 (14.7)</td>
<td>0.79 (1.44)</td>
</tr>
<tr>
<td>Waist (cm)</td>
<td>92.5 (12.3)</td>
<td>-2.72 (3.22)</td>
<td>90.2 (11.2)</td>
<td>-2.46 (3.04)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>28.4 (4.9)</td>
<td>-0.05 (0.87)</td>
<td>27.2 (4.9)</td>
<td>0.31 (0.59)</td>
</tr>
<tr>
<td>Glucose (mmol/L)</td>
<td>5.4 (0.7)</td>
<td>-0.03 (0.45)</td>
<td>5.0 (0.6)</td>
<td>0.26 (0.51)</td>
</tr>
<tr>
<td>Insulin (µU/L)</td>
<td>50.2 (28.7)</td>
<td>-4.5 (18.83)</td>
<td>37.8 (16.1)</td>
<td>5.3 (11.91)</td>
</tr>
<tr>
<td>HOMA-IR</td>
<td>1.8 (1.2)</td>
<td>-0.22 (0.62)</td>
<td>1.2 (0.6)</td>
<td>0.23 (0.42)</td>
</tr>
<tr>
<td>Cholesterol (mmol/L)</td>
<td>5.6 (0.8)</td>
<td>-0.23 (0.54)</td>
<td>5.6 (1.1)</td>
<td>-0.07 (0.89)</td>
</tr>
<tr>
<td>LDL (mmol/L)</td>
<td>3.7 (0.7)</td>
<td>-0.17 (0.68)</td>
<td>3.7 (0.9)</td>
<td>-0.18 (0.55)</td>
</tr>
<tr>
<td>HDL (mmol/L)</td>
<td>1.3 (0.4)</td>
<td>0.00 (0.15)</td>
<td>1.3 (0.4)</td>
<td>0.07 (0.18)</td>
</tr>
<tr>
<td>Triglycerides (mmol/L)</td>
<td>1.4 (0.9)</td>
<td>-0.13 (0.71)</td>
<td>1.3 (0.7)</td>
<td>0.09 (0.54)</td>
</tr>
<tr>
<td>CRP (mg/L)</td>
<td>2.1 (2.8)</td>
<td>-0.13 (2.29)</td>
<td>1.5 (2.1)</td>
<td>1.18 (3.36)</td>
</tr>
</tbody>
</table>

I = Intervention; C = Control; SBP = systolic blood pressure; DBP = diastolic blood pressure; TC = total cholesterol; LDL = low density lipoprotein; HDL = high density lipoprotein; Trigs = triglycerides; CVD = cardiovascular disease; HOMA-IR = Homeostatic model assessment – Insulin resistance (calculated by fasting insulin (µU/L) x fasting glucose (mmol/L)/22.5). BMI = body mass index; X diff = pairwise comparisons between the intervention and control groups at the 12-week assessment when controlling for baseline discrepancies for each outcome.
Raw data for all psychosocial measurements across all three time points can be found in Appendix R. Relative to the control group there were no significant changes in autonomy, competence or relatedness over the course of the intervention. There was however a significant reduction in extrinsic regulation for physical activity from baseline to 12-week follow-up (p=0.03) and a small but non-significant increase in intrinsic motivation. Perceived competence for physical activity increased during the 6-week intervention (p=0.05), as did barrier self-efficacy (p=0.02). During the programme, the intervention group’s sense of pain was significantly reduced and fatigue increased compared to the control group (both p=0.01) although these effects were not sustained at the 12-week follow-up. Intervention participants’ emotional wellbeing was however raised at the end of the study (p=0.03). No further significant changes were observed.

8.3.5 Qualitative analysis and evaluation of intervention

The following quotes are taken to exemplify the responses that led to each interpreted construct as described. [Participant characteristics succeeding each quote represent their sex, age and baseline physical activity level].

All intervention participants championed the feedback as useful for raising their consciousness and awareness of their own physical activity behaviour of which 66% cited an improved understanding of the time they spend inactive:

“I think it’s, it’s changed, it’s changed my day to day activity, and I am a lot more conscious of the fact that I am sitting a lot, and part of it, there was a realisation that I wasn’t very active.” [Male, 46, 1.48]

“Yeah I think I was probably overestimating what I was doing, I thought I was more active than I was in a way so... when you see it it’s like oh you are actually doing as much as I thought I’d probably on my feet but I’m not necessarily so doing anything that is going to benefit me stop so yeah it’s definitely made me more aware of the need.” [Female, 42, 1.42]

More than half the intervention participants postulated that physical activity was now more of a priority having been through the programme and that it reinforced their belief that physical activity was a means to improved health:
“Um, well it certainly hasn’t become any less important. I probably would say that it has become more important because the awareness breeds that sort of feeling, you know, that this is something that is not just a one-off, you know. Over a three-month period, it’s, it’s life and it should continue.” [Male, 59, 1.72]

“And then hopefully, my hope is, as i.e., as I lose weight... Because that’s one thing I haven’t done is lost weight... um, is once I have lost more weight that I will feel fitter and then I can up that target. But I don’t want to try and do too much, too soon.” [Female 62, 1.25]

The self-monitoring also helped individuals gauge how much physical activity was required to meet certain health recommendations and increased:

“I found it interesting, you know? Because I know how many steps it takes me to go down our town and round and back to the house it’s at about 1800 I think. And I know how many is to go to the railway and things like that.” [Female, 63, 1.37]

“But of course that whole thing then tipped me nicely over and I was... So it had that useful upturn, and equally, as I said before, it helps me gauge just exactly how much distance I need to be covering to meet a, sort of a standard target.” [Male, 48, 1.65]

According to 80% of participants the programme inspired them to increase their physical activity levels, and two thirds claimed that the multidimensional nature of the feedback helped find personal solutions:

“So I knew that I had to just get back into doing something... And having that monitor was almost like a critical friend, it was there to say "you can do this".” [Female, 48, 1.55]

“Yes that really helped and then over the six-week period, every week I was trying to do a little bit more and like I say, it’s not very difficult to do it it’s just that now you are conscious of it and you are aware of it that you have to achieve so many steps per day.” [Male, 48, 1.87]

“And it’s achievable without knocking myself flat you know I can do it in little steps and I can move myself forward in little ways rather than try and charge at a wall and break through a wall. It is much easier that way. So again using the word empowerment it has sort of empowered me into thinking I could do this.” [Male, 54, 1.39]

Some participants said that during the six-week programme they would consciously go out of their way to achieve the targets and many put added emphasis on steps as a key, achievable daily motivator:

“Um, and I did find it motivating, and I did, um, you know, I was known to leave the house at kind of five minutes to bedtime to walk around the block at the time ... Or spend five minutes doing star jumps to try and get some kind of vigorous activity in. So yes, having the targets I found very helpful, and yeah, and motivating and interesting and fun.” [Female, 56, 1.56]

“Um, I did actually, I surprised myself in how easy it was to make step goals. I didn’t think I walked that much but as soon as I was just tracking it, it was like "actually I’m not far off daily amounts if I just do a little bit more and better hit that target.” [Male, 41, 1.53]
Having completed the programme, over 60% of the intervention group felt they were now being more proactive about fitting physical activity into their routine:

“Making a conscious almost, not a plan, plan is probably a bit too grand, but saying “right each week I must do a certain amount of activity” and I plan that and think about it and so... The type of person I am, I’m quite a sort of structured and quite organised person so just building that into my routine is a change in my behaviour.” [Male, 53, 1.86]

Conversely, there were a handful of participants who alleged to have had an illness or injury during the programme that hampered their progress:

“Right, um, it was slightly complicated by the fact that I was ill right in the middle of it so... I started off really motivated and felt really good about it and it was building very well. And then unfortunately, after about a month I guess, I got this fluey type thing, which really did kick in and, made it a bit of a struggle to do as much and build as much as I wanted to do it. And then of course it’s sort of came to the end of the programme really so I don’t feel like I did it as much justice as I would have liked to have done.” [Female, 67, 1.58]

Two-thirds of participants expressed further intentions to take up new, or more activity and approximately half of the group felt confident that they could maintain their levels after the programme and/or had made lasting behavioural changes.

“Yeah it definitely made me think a bit more about the moderate bouts of activity and how important they are. And it made me more keen to do things like walking the dogs and, you know, walks to school and I wouldn’t the thought that to be useful before. And I think ‘oh they are quite a useful way of getting in extra steps’.” [Female, 43, 1.71]

In addition, some participants felt they had improved their confidence and sense of competence and others expressed a greater enjoyment for physical activity and an improved sense of health and wellbeing as a result of improved activity levels:

“Yeah. I mean, variety... yeah, I think that’s been really helpful, actually. Because it’s less boring and, um, you don’t perceive it as... I think my perception of what exercise was and what it actually is very different now. So now activity isn’t exercise. Activity is just anything.” [Female, 45, 1.52]

“Knowing how more confident I am, which I, perhaps if I wasn’t recording it somewhere I wouldn’t have been aware of that...So that’s erm, yeah that’s a nice position to be in, having seen confidence increase with various things, various types of activities, it’s a nice position to be in for sort of in the future.” [Female, 48, 1.51]

There were many participants who said that they missed not having the activity monitor once it was removed after six weeks and in fact by the time the interview had come round following the end of the intervention, 31% of participants had
purchase a commercial physical activity tracker for personal use whilst a further 51% said they were considering acquiring a device:

“It has spurred me on to get one of these, to actually buy one of these Fitbits. Which is just going to continue to let me know in real-time exactly what I’m doing and very similar in fact it is in steps and calories burnt off and what have you and the fact everyone else in the office have got one.”  
[Female, 60, 1.52]  

“Which I suppose sounds really obvious when you say it, but it hadn’t ever linked with me before. And, I now have a little Fitbit because I want to now… I’ve become slightly obsessed with steps.”  
[Female, 63, 1.37]

For many of the intervention participants, the real time display was a favourable component for the self-monitoring of activity and more important than the website feedback:

The instant display I think is what... I mean, I did go online that that's in retrospect, you didn't get to see that until you had already done it. Whereas in today's society we want instant answers so having the display and being able to look at it, um, was, you know, was motivating.”  
[Female, 62, 1.25]  

Um, the, the monitoring device, I found I used the little tiny daily, daily monitor, all the time...that was almost obsessive!  
[Male, 46, 1.48]

This was supported by the feedback provided by participants upon completion of their initial six-week intervention. Table 8f shows the mean and SD scores for all 36 participants. Overall the real-time display was judged to be more useful than the web-platform with the step counter being the most popular output followed by minutes of moderate and vigorous activity then calories. The use of personal targets was also deemed useful. The least useful, or indeed used, components of the web platform were the interactive action planning and review functions. That said, there were still a reasonable proportion of participants who made reference to the multidimensional feedback as being a useful way of viewing the overall picture and some even described it as the wake-up call:

“...You see on the computer screen and it was just flat line, I think that that is, visually, or when you look at it and you look at the figures and you look at that... that had probably quite an impact. And I think that that is... Probably the wake-up call which will remain with me, yeah, visually seeing it.”  
[Male, 64, 1.72]

When asked to evaluate the intervention during the interviews participants suggested that their engagement with the feedback on the web-platform may have
been improved if it was more readily available, and that sitting down at a computer felt counterintuitive to being [more] physically active:

“Because I could only look at it at certain times at home without being able to do it when I wanted to do it was frustrating...If you see what I mean? So, just only having a sort of biweekly uploaded my information... I wish I could have just done it as and when and seen more feedback.” [Male, 41, 1.53]

“I think to be perfectly honest it was...it was sort of time element of it. I didn’t feel that I had the time just to sit and...and look at it, which I probably should have done, but it felt as if the more instantaneous response from the monitor was actually...or the display was...was what I needed on a day to day basis.” [Female, 52, 1.64]

Data also revealed that for certain participants there were one or two issues with the device itself in terms of either trusting the feedback or its wearability:

“The exercise I tend to do is like cycling and the bottom half of my body it probably won’t show a great deal of vigorous activity. Which, okay it is the limitation of the technology and the technology at that time, but I was mildly irritated by that.” [Male, 55, 1.50]

Finally, A handful of participants made recommendations for improved utility of the monitor and feedback system, which included the need for more prompts and guidance, increased tie to their health data [i.e. collected at assessment sessions] to evaluate the impact of more physical activity or for motivation:

“10,000 steps is nice and easy cause that’s just walking, you can just incorporate that into your daily activity, but then the vigorous activity, I could do it if I go for a run, but any other way I wouldn’t know. I only had ideas of cycling and rowing and though there are suggestions, but a programme of how you can achieve them would have been helpful.” [Female, 45, 1.60]

“So if you said to me your cholesterol is 5 at the end of the study you told me my cholesterol...well...I found out my cholesterol...because you know cholesterol response to exercise had dropped to 3.5 that would have been a big encouragement.” [Female, 55, 1.61]

Table 8-f. Mean (SD) scores for each evaluated intervention components included as part of the real-time display and the web-based multidimensional platform (see Appendix 5 for the evaluation form, which asked participants to score the features from 1 (Not at all useful) - 5 (Extremely useful) or 0 if the feature not used).

<table>
<thead>
<tr>
<th>REAL-TIME DISPLAY</th>
<th>WEBPLATFORM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>Calories data</td>
</tr>
<tr>
<td>4.5</td>
<td>4.0</td>
</tr>
<tr>
<td>(0.8)</td>
<td>(0.9)</td>
</tr>
</tbody>
</table>

Mod. = Moderate-intensity activity; Vig. = Vigorous-intensity activity
8.4 Discussion

The aim of the present study was to determine whether a six-week intervention of personalised multidimensional feedback combined with real-time feedback would help individuals improve their physical activity behaviour. When assessed at follow-up significant changes were observed in all physical activity parameters with moderate to large effect sizes apart from for vigorous-intensity activity. The intervention was more effective for individuals with a lower baseline physical activity level and for females. There were no significant effects on any of the health markers at the follow up, however subjective health and wellbeing did increase for intervention participants relative to the control group. During qualitative interviews conducted after their follow-up assessment the majority of intervention participants attributed their behaviour changes to heightened awareness and consciousness of their existing and expected physical activity levels, improved intentions and motivation to change and the use of real-time data and daily targets.

Given the increasing and widespread prevalence of inactivity and associated non-communicable diseases physical activity monitoring technology may represent a useful preventative strategy at an individual level (Chiauzzi et al., 2015; Piwek et al., 2016). Commercial activity monitors are typically marketed at, and used, by young adults who have high baseline physical activity levels as a means to monitor exercise performance meaning the effectiveness for clinical or inactive populations remains undetermined (Patel et al., 2015). Encouragingly however, the results of the present study suggest that self-monitoring using dual approach of multidimensional and real-time feedback might be successful in increasing the activity levels of adults with low baseline physical activity levels. Also encouraging is that the intervention was well received and effective in middle to older-aged adults, a group in which commodities and heightened risk of diabetes and cardiovascular disease become increasingly prevalent (Jousilahti et al., 1999; Choi and Shi, 2001). Although no significant changes were observed in any of the biomarkers or physical health measures, given the observed trends and positive intentions for maintenance of their improved behaviour this form of monitoring may have a meaningful impact on health over a
longer period of time (Sigal et al., 2006; Bassuk and Manson, 2005; Thompson et al., 2003).

On average, relative to the control group, the intervention participants in the present study reduced their sedentary time by 42 minutes per day (or 4 hours 51 minutes per week) and transformed this into 14 minutes per day (1 hour 35 minutes per week) of light activity and 28 minutes per day (3 hours 11 minutes per week) of moderate to vigorous physical activity. Significant changes in PAL of 0.09 were also observed between the intervention and control group, which for the ‘average’ individual in the present study with a resting metabolic rate of 1625 (±245) kcal equates to an increased physical activity energy expenditure of approximately 130 (±20) kilocalories per day and almost 1000 over the week. Finally, a significant relative increase in steps of 1500 per day (or ∼10500 per week) was also found after just 12 weeks. Moreover, the moderate-to-large effect sizes observed for most of these physical activity outcomes just six-weeks following the intervention of the same duration are similar to those observed in other successful instant feedback interventions using real-time physical activity feedback of longer durations (Bravata et al., 2007; Kang et al., 2009a). Furthermore the present approach has shown effectiveness on key behavioural outcomes where using multidimensional physical activity feedback alone did not. This may be indicative that the addition of real-time data makes the feedback more tangible and motivating compared to solely web-based multidimensional information.

A strength of the present investigation was the post follow-up qualitative evaluation that enabled the identification of salient intervention components that intervention participants found particularly useful. This evaluation also provided a useful insight into why these effects may have been observed. On the whole, there was a positive reaction to the multidimensional feedback, which was seemed to be particularly useful for raising the awareness and consciousness of the individual recipients physical (in)activity. This finding in consistent with the observations of patients following a cross-sectional snapshot of this format of personalised feedback (Chapter
5) and other randomised trials (Godino et al., 2013; Van Hoye et al., 2015). Seemingly, the reason that a large proportion of participants with low baseline physical activity felt more motivated to change their behaviour was the powerful stimulus provided by observing high levels of sedentary time and sub-standard visual discrepancies for various behavioural recommendations. The ability to act upon this heightened awareness was then subsequently facilitated through the provision of real-time daily monitoring on multiple aspects. This offers support for the findings observed in Chapter 6 where low-activity individuals receiving ‘negative’ feedback formed illness representations regarding their physical activity status and had a heightened desire to monitor their behaviour to support an improvement. Despite the absence of a long-term follow-up assessment, encouragement can be taken from the positive actions and intentions of participants towards maintain their improved behaviour and the purchasing of commercial devices for continued self-monitoring.

Interestingly, there were very few differences in certain psychosocial factors that may have theoretically helped explain the favourable change in behaviour between the intervention and control group. For example, need satisfaction in response to physical activity remained relatively stable in both groups although perceived competence measured in isolation did improve. Similarly, behavioural regulation factors remained comparatively stable with the exception of external regulation, while physical activity habit remained comparatively non-significant. Barrier self-efficacy, that is the ability to overcome obstacles to engaging in physical activity, did however change significantly. The lack of observed change in perceived autonomy, competence and relatedness in the physical activity context may be due to high levels at baseline leaving little room for improvement. The perceived competence scale (Williams et al., 1998a) may have shown a more favourable changes for intervention participants due to the instruments focus on general physical activity rather than ‘personally challenging’ physical activities described by the PNSE (Wilson et al., 2006). With regards to the internalisation of physical activity behaviour, there were a number of intervention participants who acknowledged an increased enjoyment for regular activity, which may explain the reduction in external regulation and
heightened determination to sustain an active lifestyle even in the face of barriers. That said, the lack of observed change on more internalised forms of motivation may be influenced by the fact that even self-monitoring of personalised feedback remains to some extent, by nature, an external driver of change. It is recommended that further studies employing a much larger sample size would be needed to fully understand the influence of personalised multidimensional feedback on self-determined motivation.

Another noteworthy observation was the increase in activity for individuals in the control group at the 6-week assessment. Speculatively, this may be due in part to a reactivity response (Intille et al., 2012) in participants who weren’t also provided with a physical activity monitor for the intervention period (and thus reinstating the novelty of this tool for the assessment of physical activity). The intervention participants may have been desensitised to device monitoring them and thus provided a truer representation of their behaviour whereas control participants, yet to receive any intervention might have been subject to a momentary Hawthorne effect (Hallal et al., 2012b). Another factor might again be the unequal allocation and thus small sample size in the control condition in which a handful of participants (4/15 in the present study) saw an unusual substantial increase in their behaviour during the 6-week assessment week that disproportionately influenced the group mean. Whilst this effect was not observed again at follow-up and control participants scores returned to near-baseline values, larger sample sizes and longer assessment windows might be required to allow for any reactivity to subside.

Given the exploratory nature of the trial there were inevitably a couple of limitations to the study design that should be considered when interpreting the findings. It is acknowledged that contrary to the intervention conducted in Chapter 7, the smaller sample size, shorter follow-up period and use of a non-clinical population means that inference of the results should be met with caution when generalising these findings as a successful preventive strategy. There were also one or two issues with the intervention tool itself that may have impeded the effectiveness of the programme.
The parameters presented by the real-time display in the study didn’t completely map on to all the physical activity dimensions used as part of the multidimensional web-feedback. Moreover, there was a technological glitch involving the integration of the two formats of feedback, which meant that the intervention participants couldn’t completely self-monitor both in isolation as uploading data from the Bodymedia device to the website meant the real-time display reverted to default rather than the personally calibrated settings. Whilst these issues did not present too big a problem logistically, given that the participant was able to meet with a member of the research team every two weeks to upload and interpret their armband data and recalibrate their personalised targets, it may explain while the display feedback was looked upon more favourably by the intervention group (Dennison et al., 2013).

In fact, there were a number of participants who mentioned at interview that retrospective data was less useful than immediate results that they had ownership of and that sitting at the computer felt counterproductive to leading a healthy lifestyle. Technological advancements observed in commercial based activity trackers and smartphone applications could help eradicate these issues to optimise the delivery, and perhaps effectiveness, of the present approach where multidimensional health-harnessing dimensions are successfully integrated (Case et al., 2015; Fanning et al., 2012; Ozdalga et al., 2012).

In conclusion this exploratory randomised controlled trial represents the first attempt at combining multidimensional feedback with real time data across a number of important health harnessing dimensions of physical activity as a means to help individuals change their behaviour. The results of the study offer promise that this approach may be an effective resource by which to help individuals who are not meeting the recommended levels of physical activity initiate and maintain healthy lifestyle changes. In combining sophisticated health-associated personalised feedback with tangible daily targets helps individuals find personalised solutions for change. Further testing involving refined technological solutions and longer follow-up periods are required to explore the wider and long-term impact of this approach on behaviour and health.
Chapter 9 GENERAL DISCUSSION

1. What is the validity and reliability of the leading multisensor wearable monitors for measuring multidimensional physical activity?

2. Can data from wearable monitors be turned into visual multidimensional physical activity feedback?

3. Do end-users find personalised multidimensional feedback meaningful and useful?

4. What is the immediate cognitive-affective impact of seeing personalised feedback?

5. Does personalised multidimensional visual feedback initiate a meaningful change in physical activity behaviour?

6. Does multidimensional plus real-time physical activity feedback support a change in behaviour?
The aim of this thesis was to investigate whether using personalised multidimensional physical activity feedback could be an effective strategy to help inactive individuals make positive behavioural changes. In reviewing the literature it was clear that physical activity is a more complex behaviour than has been traditionally conceptualised and communicated through recommendations and that individuals can be classified as high or low activity depending on the definition used. Individuals can independently score high or low for sedentary time, physical activity level, daily accumulated moderate minutes, moderate to vigorous intensity activity in 10-minute bouts and vigorous activity. In theory, presenting an individual with a multidimensional profile that provides information on all health-harnessing components of physical activity behaviour would afford more options for behaviour change and present solutions that can be aligned to the individual’s needs and preferences. Excitingly, technologies with which to monitor physical activity have rapidly improved in recent years and so the opportunity to accurately capture all of these important aspects of an individual’s behaviour is now much more accessible. To this end the current body of work attempted to develop a novel format of technology-enabled feedback that would appropriately characterise an individual according to five important dimensions of physical activity. In subsequent studies the immediate and long term impact of this approach was explored in terms of cognitions and emotions, behaviour and health. The specific research questions for each chapter of the present thesis can be summarised as the follows:

**Chapter 3:** Do we have a wearable monitor that accurately and precisely captures the multiple dimensions of physical activity behaviour that are important to health?

**Chapter 4:** Can we transform raw minute-by-minute energy expenditure into functional visual graphics that depict the multidimensional nature of physical activity?

**Chapter 5:** Do healthcare professionals and patients at heightened risk of future chronic disease find the feedback designs clear, informative and useful?
Chapter 6: What is the immediate cognitive and effective impact of seeing personalised visual physical activity feedback?

Chapter 7: Is self-monitoring with multidimensional physical activity feedback efficacious in helping individuals make long-term changes to their physical activity behaviour?

Chapter 8: Does the combination of multidimensional and real-time feedback improve lead to more pronounced changes in physical activity behaviour?

9.1 SUMMARY OF FINDINGS

The first challenge, described in chapter 3, was to find a practical and affordable measurement tool that would accurately capture daily physical activity with the necessary precision to present all of these important health-harnessing dimensions of behaviour. Two of the leading multisensor physical activity trackers were tested in an experiment that involved a lab validation protocol, a repeatability trial and a free-living component. The results of this trial showed that the two devices performed similar to one another, only 13% total error compared to a criterion and approximately 5% variation between measurements of the same activity. On the basis of having an advantage in terms of cost and functionality, the Bodymedia armband was selected for all subsequent experiments in the current programme of work. The second challenge, Chapter 4, was to try and develop a format of feedback from raw minute-by-minute energy expenditure data that would clearly distinguish the multiple components of physical activity behaviour and include visually persuasive design features. An iterative design process involving a graphic design team led to the creation of several visual feedback designs of varying complexity that encompassed activity patterns and health targets and could be successfully integrated with technological platforms.

Having established an appropriate measurement tool and a functional format for presenting multidimensional feedback a qualitative study was undertaken on a
clinical population of potential beneficiaries to inform the development of a potential intervention. The specific aim of chapter 5 was to learn whether the designs were sufficiently informative and usable so that they could be refined if necessary. Having recruited 15 health care professionals of varying roles and 30 adult patients who were at elevated risk of future chronic disease each participant was asked to wear the Bodymedia armband device for a week and then comment on their personal multidimensional feedback presented in a number of formats during a one-to-one interview. In short, it was deemed that the multidimensional feedback I presented was largely comprehensible, informative as to the multidimensional nature of physical activity and motivating for many participants. A second analysis of the same interviews is detailed in chapter 6 and evaluates the immediate cognitive and emotional impact of the personalised multidimensional feedback. In this study particular attention was given to the distinctions between the thoughts and feelings of individuals who were highly active and those who were lowly active. This framework analysis was guided by the common sense model of illness representation (Leventhal et al., 2003) and showed that the visually evocative personalised feedback served to evoke coherent thoughts regarding physical activity as a means to improved health for many participants. The designs used in the study additionally appeared to induce powerful affective responses that were positive in nature (pleasure, reassurance etc.) for people with high activity levels and negative (guilt, disappointment etc.) for those with low activity levels. For the low active individuals the feedback also appeared to encourage the formation of coping responses action plans and heightened desire to change behaviour.

Building upon the lessons learned from these initial studies the final phase of the present body of research was to test the efficacy of providing multidimensional feedback in an exploratory randomised controlled trial. The study described in chapter 7 was conducted in a primary care setting whereby 204 patients at heightened risk of diabetes or cardiovascular disease were recruited by their GPs to undergo a 12-week trainer led self-monitoring intervention and were assessed at 12-month follow-up. Using a 2 to 1 allocation of intervention versus usual care control
condition and accounting for individuals who were lost to follow-up, 120 patients were provided with a Bodymedia armband with which they were able to upload to a web-based platform that displayed their multidimensional feedback, activity patterns, and interactive screens to tag activities and plan new ones. During this 3-month period participants met with a health trainer five times to troubleshoot the technology, discuss options and plans on how to change their behaviour. The 64 participant usual-care control group received just a one-off session with the trainer at the start of the 3-months where they were given general health messages. An interim analysis of this programme showed that the feedback was well received, informative and had a positive impact on individual’s motivation towards physical activity but did not change behaviour itself on a global level. In a second randomised controlled trial involving 51 participants and a shorter intervention and follow-up period of 6 and 12-weeks respectively there were however more substantial behavioural effects. The key addition in this second intervention trial (Chapter 8) was the use of real-time feedback, which presented instantaneous data across calorie burn, moderate and vigorous activity and steps (as a proxy for non-sedentary time) on a small portably display. Combining the personalised multidimensional feedback with this real-time data had a significant moderate to large impact on most physical activity outcomes when measured 6-weeks after the intervention had finished, particularly in individuals of lower baseline physical activity levels.

9.2 INTERPRETATION OF THE OVERALL FINDINGS

The overarching aim of this thesis was to develop and test the efficacy of multidimensional feedback for changing behaviour and improve health. Taken as a whole, across the qualitative and randomised controlled trials there are promising signs that this sophisticated behavioural feedback can positively influence an individual’s motivation to change behaviour and raise awareness and understanding of the multiple ways in which physical activity can benefit ones health. An interim analysis of the Mi-PACT trial showed little global behaviour change when looking at
the whole group effect in intervention versus control participants for important physical activity dimensions, although further analysis by the appointed trial statistician may be more revealing in this sense. In the present thesis there were however indications that self-monitoring using the web-based multidimensional feedback platform in combination with real-time feedback did encourage a change in behaviour when measured six-weeks after a six-week intervention period. The effect sizes in this trial were similar to those demonstrated in pedometer only studies (Bravata et al., 2007; Kang et al., 2009) but greater than those observed in trials using more sophisticated formats of feedback (Goode et al., 2016). A qualitative evaluation of this particular programme suggested that for many participants the instant, rather than web-based, multidimensional feedback predominately drove this behaviour change. Consequently, whilst the multidimensional physical activity feedback tool developed throughout this thesis was well received, informative and motivating, the results of the intervention trials suggest that in its current format it perhaps not enough to instil meaningful, prolonged changes in physical activity and improve health without the addition of acute real-time feedback. There are nevertheless a handful of important considerations one should bear in mind when interpreting the results described in this thesis and important lessons for the refinement or adoption of this approach for future behaviour change interventions.

9.2.1 STUDY DESIGN – WHICH SUPPORTING TOOLS ARE BEST?

Discrepancies in the study design make direct comparisons between the two intervention trials difficult, although there are one or two noteworthy distinctions that may help interpret the present findings. Returning to the key theoretical underpinnings of physical activity behaviour change and the intervention development literature outlined in chapter 2 it becomes apparent that intervention tools and techniques used in Chapter 8 made it a more active intervention than the one Mi-PACT trial (Michie et al., 2013a). Active interventions that engage users in the intervention and drive a change rather than passive interventions that aim to motivate through information alone have been previously shown to be more effective in initiating behaviour changes in physical activity (Van Hoye et al., 2015;
Vandelanotte et al., 2007; Pellegrini et al., 2012) and other health behaviours (Albarracín et al., 2005). Upon reflection, the use of more advanced technology rather than the presence of a health trainer might have better endorsed more self-regulatory behaviour change techniques and thus supported the posited influence on one’s capability, opportunity and motivation to change their behaviour (Michie et al., 2011c).

Notably, the presence of real-time feedback and personalised targets across dimensions might enable more proactive development and review of action plans and implementation intentions than the more comprehensive and holistic ‘bigger-picture’ (Gollwitzer and Sheeran, 2006; Prestwich et al., 2003). This notion was supported by many of the interviewed intervention participants in Chapter 8 who stated that the real-time feedback served to inspire short-term strategies to meet certain step, calorie or activity-intensity targets if there was a shortfall on a given day. In contrast, the core multidimensional visual feedback presented as part of the website only displayed retrospective data, which, by nature, was in the context of physical activity recommendations accumulated over a weeks’ worth of monitoring. Whilst the generation of this feedback was rolling so that individuals could upload as frequently as they desired and see high resolution activity patterns it meant that any subsequent self-regulation of behaviour through self-monitoring and goal-setting needed to be driven by the individual themselves rather than occurring inherently through a real-time display. Even individuals who formed intentions to change based on their historic multidimensional profile and accordingly set progressive targets or goals didn’t have the capacity to make any finite adjustments towards their achievement. One might argue that the day-to-day changes should be less relevant given the intended impact from a health perspective was more a global, chronic behaviour change. However, differences in observe, group-level behaviour change across the two trials suggests that the significant follow-up effects observed in Chapter 8 may have resulted from participant’s ability to be reactive in the intervention phase that led to an improved learning of the levels of behaviour necessary to meet different recommendations set out on the website.
Another possible influence on the ultimate effectiveness of the two independent trials was the delivery of the intervention via a health professional versus a researcher. In attempt to provide further context for participants around their multidimensional feedback in the absence of daily targets and real-time data more emphasis was put on the role of the health trainer in Chapter 7. These health trainers were employed from the community if they had experience with GP referral, or physical activity/lifestyle coaching experience and underwent 3 hours of contact time (1 hour baseline and 4x 30 minute sessions at 2, 4, 8 and 12 weeks). In the shorter intervention period documented in Chapter 8 the only point of contact was the lead researcher, who met participants at baseline for up to one hour and then 20 minutes at 2, 4 and 6 weeks. In both studies the trainer or researcher was responsible for introducing the intervention participants to their web-based feedback, explaining the multidimensional approach to physical activity and offering technical support. In an effort to test the efficacy of the real-time data little emphasis was placed on helping participants develop specific goals or action plans and were only discussed if initiated by the participant.

It is possible that despite thorough training in the operation of the technological platform and interpretation of the feedback was provided for the health trainers involved in the larger trial trainers were less familiar with these components compared to the researcher delivering the shorter intervention who was extensively involved in the development and conceptualisation of the resource. This may have led to better transfer of knowledge for participants who might have otherwise struggled to grasp the multidimensional concept. It is also plausible that the experience and expatiations of the trainer may have differed between intervention participants. For example, a patient entering the study based on a health check assessment and the aim to reduce their chronic disease risk may have desired a directive approach to help understand how physical activity could help them. In this sense a ‘coach’ who provided more of a regime may have been more suitable to help bridge the otherwise abstract contextualisation of physical activity and health
(Gabriele et al., 2011). Contrary to this approach, trainers were instructed to create an empathetic, autonomy supportive climate to empower the patient in the larger intervention as this is theorised to support longer term maintenance of behaviour (Ryan et al., 2009; Ryan et al., 2008). In contrast, the participants who volunteered for the real-time feedback intervention did so by self-assessing themselves as being insufficiently active and therefore conceivably began the programme with more impetuous and drive to change their behaviour, which may explain its enhanced influence on behaviour (Ogilvie et al., 2007).

9.2.2 Study sample – who might multidimensional feedback be best for?

Perhaps the most important distinguishing factor between the two intervention trials was the difference in characteristics of the recruited populations. With the exception of the risk score used to identify participants for the larger trial, the inclusion criteria for the two interventions were identical however there were some subtle yet ultimately very important distinctions between the two study groups that conceivably had a large bearing on the primary outcome results of the two trials. One such difference between the trial groups was the baseline activity levels where for the larger study a mean PAL of 1.69 was observed compared to 1.61 in the chapter 8 trial. This discrepancy is potentially a product of the respective recruitment strategies where individuals volunteered for one study with a mind-set that the intervention would help them reduce their disease risk irrespective of their perception of activity levels, whilst the smaller trial participants were more directly recruited on the basis of feeling insufficiently active. A much higher proportion of screened and consented patients were excluded for having a baseline PAL >2 in the larger intervention trial of Chapter 7 (16%) compared to Chapter 8 (6%). The Chapter 8 study group, whose PAL is very similar to the UK median of 1.61 reported by the Scientific Advisory Committee on Nutrition (2011), recruited insufficiently active individuals whilst the mean PAL in the larger trial would put many participants in the moderately active camp according to FAO (2004) cut-points. This is important considering that in the more successful intervention described in Chapter 8 there were large differences in the behaviour change people who had lower baseline physical activity levels were. For example, the
mean difference between the intervention and control groups change in moderate to vigorous physical activity after 12 weeks was +270 minutes per week for those with a baseline PAL below 1.6 compared to +60 minutes per week for those who started above this threshold.

One explanation for this effect is that based on the PAL >2 inclusion criteria set for each trial may have, in hindsight, been too high. One of the other reasons for anchoring the inclusion criteria to PAL was that conceptually the ‘calorie burn’ guideline represented the dimension most difficult to achieve as it and as it captures physical activity energy expenditure in its entirety and would therefore always leave room for improvement for every participant. Given the results however it might also be reasonable to speculate that PAL isn’t perhaps as conceptually relevant to people as it rarely features in commonly advocated physical activity recommendations (Haskell, 2009) and thus the importance placed on this aspect is inherently dampened. This is particularly relevant when considering that individuals can on the whole still receive an overall positive message about their behaviour even if their PAL score was below 2 and there were a number of instances where even at baseline individuals had hit the minimum guidelines in other dimensions such as moderate and vigorous activity. The findings of Chapter 6 suggest that the less favourable the message depicted in an individual’s multidimensional feedback elicited a negative emotional response and heightened intention to change behaviour through cognitive coping mechanisms and the formation of action plans. With this in mind, the results of the two intervention trials appear to confirm that for insufficiently active individuals a message indicating ‘failure’ evokes the necessary motivation to increase their levels, whilst for already highly active contemporaries a positive ‘accomplished’ message simply serves to reinforce that they are already achieving a sufficient amount of physical activity. While it is important to acknowledge that those with the lowest scores across multiple dimensions have the greatest opportunity to change their behaviour, encouragement can be taken that those who are most in need of a change in physical activity behaviour appear to receive the biggest effect following a multidimensional feedback-based intervention.
Not only were the individuals in the larger trial more active than those recruited to the instant feedback trial, but also much more homogenous in terms of age and sex of the participants. The nature of the risk score calculations, which accounts for common risk factors and is thus amplified by advancing age (Hippisley-Cox et al., 2008; 2009), meant that a high proportion of participants in the larger trial were over 60 years (79%). The mean ± SD age in the larger trial was 63.6 ± 5.8 whereas in the instant feedback trial it was 51.3 ± 8.4. Moreover, the risk calculations described by Hippisley-Cox et al., (2008; 2009) used to recruit participants in the larger trial understandably offset the relative risk of males and females meaning that two thirds of the cohort were male compared to just 45% in the instant feedback trial. In terms of age, there was no indication from the qualitative work undertaken throughout the thesis that the inclination to change was any different but the fact that the trial with the younger cohort evidenced more pronounced behaviour change suggests that younger adults may be more receptive to the technology used to deliver the multidimensional feedback (Broady et al., 2010; Selwyn et al., 2003). Older adults, whose historical use of information communication technology would not be as extensive as younger contemporaries, may, for example, have required more training and guidance when operating, understanding and exploiting the interactive features of the web-based platform (Wagner et al., 2010). There may also be an issue with regards to the strategizing of the intervention as self-monitoring, feedback and goal-setting may in fact be detrimental for physical activity for older adults (French et al., 2014).

In terms of sex, there were signs that the interventions were more effective for females. While it is true that the females in this study were of lower baseline activity levels compared to the males and thus carry the implications as described above, it is important to also consider why females may have been more successful in increasing their physical activity behaviour. One theory might be that the motives or behavioural regulations for undertaking physical activity and engaging with the intervention programmes differed for males and females (Davis et al., 1995). Another
might have been that the females in the study were more embracing of the multidimensional philosophy that tailored personalised solutions and subsequently increased daily activity that encompassed more physical activity dimensions whereas males more competitive and anchored to the concept of sport and exercise (Bauman et al., 2012; Caspersen et al., 2000; Allender et al., 2006). Whilst this wasn’t directly measured in the present study, there is evidence to suggest that male and females tend to generally accumulate physical activity in these different domains (Bélanger et al., 2011).

9.2.3 Multidimensional physical activity conceptualisation and presentation

Emerging epidemiological and physiological evidence suggests that other characteristics, or dimensions, of physical activity such as total energy expenditure and sedentary time can have powerful effects on health independently of and individuals accumulated moderate-to-vigorous activity, which had lead some authors to call for more integrated conceptualisations of physical activity behaviour (Thompson and Batterham, 2013; Gabriel et al., 2012). It was posited in Chapter 2 that the provision of personalised multidimensional physical activity feedback would provide people with a plethora of options to change which might increase their capability, opportunity and motivation to engage in more. That said, feedback that is too abstract and complex might in fact diminish the likelihood of its impact on behaviour change (Godino et al., 2011) and although the visual graphics used throughout this thesis were carefully devised and refined to make them as comprehensible as possible multidimensional physical activity may, by nature, still pose a conceptual challenge for some individuals in deciding if and how they need to improve (Hermsen et al., 2016). This issue may be particularly pertinent for those individuals who received a mixed message at the start or indeed throughout their intervention where attainment of one or two guidelines (i.e. daily moderate and weekly vigorous activity) might in fact undermine the shortcomings of others (i.e. calorie burn and sedentary time). In the acute qualitative development study described in Chapters 5 the majority of participants seemingly understood the multidimensional concept and even (hypothetically) expressed a desire to achieve all
five physical activity dimensions regardless of their observed profile. In reality however it might be that given the restraints and habits of daily living participants would have found it easier to settle for those victories and ignore missed dimensions. Indeed in the analysis of Chapter 6 receiving positive messages served to validate and reassure participants’ perceptions of their activity levels rather instil a heightened desire to achieve more. It might also have been the case that some of the recommendations around total calories and sedentary time would potentially be quite novel constructs given their omission from traditional guidelines (Haskell et al., 2007).

With regards to the persuasive elements of the present work it is important to also consider designs of visual feedback used to portray an individual’s multidimensional physical activity profile throughout the present programme of work. Some authors have suggested that to evoke a more persuasive message behavioural feedback should include both a comparison with a standard and comparison to a reference group (Kok et al., 2004). A lack of normative data for many of the dimensions meant that the latter component wasn’t available for the current studies however should more research groups across diverse populations adopt this approach to evaluate populations’ holistic physical activity status this feature could certainly be built in. That said, the provision of normative data or social comparisons is not necessarily predictive of physical activity behaviour and so efforts must be made into understanding how to frame and support this information (Bauman et al., 2012). Another aspect of the designs that may have might have been fallible was the use of the traffic light system, which may have softened the punch provided by personalised multidimensional feedback. At the start of the programme the research team were keen to not demotivate participants and so included the amber category to mitigate against any potential off-putting negative feelings. The term ‘target’ was also changed to ‘guide’ again so that individuals didn’t set their sights particularly in light of the adapted thresholds that may have conceptually if not behaviourally raised the bar too much. The traffic light system has been shown to have some efficacy in terms of nutrition labelling (Hawley et al., 2013; Sacks et al., 2009; Feunekes et al., 2008)
and given the dose response nature of physical activity was deemed appropriate for translating a secondary message of some is better than none (Powell et al., 2011). While these measures may have contributed to the high retention observed in the two intervention trials (18/204 participants in the larger study withdrew for health reasons and none in the smaller trial) it may have had less impact than if the message was a curter one of 'pass or fail' (Witte and Allen, 2000). Indeed, this would have been the case for participants who were regulating their physical activity using the instant feedback display and targets as no intermediaries were present. Similarly, the most potent cognitive (e.g. intention to change) and emotional (e.g. feelings of discontent) responses were observed in those who would have received the most unfavourable personalised feedback. Therefore the visual discrepancy between an individual's performance and target attainment may itself be enough to understand what needs to be achieved (Consolvo et al., 2012; Consolvo et al., 2006), and a simpler and more definitive message around adequate levels may be sufficient to drive the necessary action.

One final consideration is in the assessment of multidimensional physical activity behaviour. Multidimensional physical activity provides a much more appropriate assessment of ones behaviour as it captures a number of independently important components that can impact health. One potential strength of this holistic approach is that it provides people with a dynamic, interchanging point of focus, meaning that an individual could give attention to one aspect of their behavioural goals at one point in time and then another dimension at another. This would certainly be beneficial for the user on an acute level as they may wish to adapt their type of physical activity weekly based on their mood, energy levels or social commitments (Withall et al., 2011; Lee et al., 2008; Booth et al., 1997). Alternatively this dynamism may occur at a chronic level – i.e. with naturally occurring seasonal variations in activity patterns that perhaps affect some dimensions more than others (Pivarnik et al., 2003; Matthews et al., 2001). Even for those individuals who do maintain a consistent goal and anchor to the same behavioural dimensions throughout the monitoring period, it is very unlikely that every individual who is receives
multidimensional feedback will pick the same guideline. This possibility for dynamic inter- or intrapersonal behaviour focus does not come without problems however as the heterogeneous interplay between aspects of physical activity poses an issue when it comes to the statistical assessment of behaviour (Tukey, 1977). Clearly there is a need for alternative and more complex statistical methods that develop a composite score that takes into account all of the key, health-harnessing dimensions and their respective longitudinal changes.

9.3 Future directions

The work presented in this thesis represents the first attempt at exploiting multidimensional physical activity feedback as a behaviour change strategy. Observations made in the qualitative developmental phase of this thesis (Chapter 5 and 6) and evaluations made with participants who had been through an intervention (Chapter 7 and 8) imply that the provision of personalised feedback in its present format certainly heightens an individuals’ awareness and knowledge of current their current activity levels and that the multidimensional concept. It would also appear that this information is useful for raising intention towards increasing physical activity, particularly for individuals who receive a somewhat negative picture from low activity levels. Discrepancies between the study designs and results of the two randomised controlled trials make determining whether this raised understanding is sufficient to motivate a receiver into action unclear. Certain suggestions for future research to address specific limitations of the interventions have been made within the respective study chapters. Based on the considerations discussed in this chapter and wider emerging literature a number of recommendations for future research are proposed that would help refine the message and design of the self-monitoring tool and optimise its deployment as a behaviour change strategy. Having undergone a full iteration of conceptualisation, development and efficacy testing it would be useful to build on the lessons learned and return full circle to the beginning of this process. Figure 9-a summarises the suggested courses of action that could be taken at each
key developmental phase utilised in this thesis. It is important to consider that these suggested future research directions are not necessarily reliant on one another, but each could ultimately improve the effectiveness of multidimensional physical activity feedback for changing behaviour.

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<tr>
<td><strong>Conceptualisation of multidimensional physical activity message</strong></td>
<td><strong>Development and design of personalised multidimensional feedback</strong></td>
</tr>
<tr>
<td>• There are multiple, independent health harnessing dimensions of physical activity behaviour.</td>
<td>• Do any dimensions of physical activity supersede the the importance of another, and are there others?</td>
</tr>
<tr>
<td>• This helps provide more options for behaviour change that can be tailored to ones preferences and needs.</td>
<td>• Does hitting all five independent health targets lead to improved health over hitting just one?</td>
</tr>
<tr>
<td>• Multidimensional physical activity may serve to enhance ones capability, opportunity and motivation.</td>
<td>• Is there a statistical method of collapsing all dimensions into a single holistic score?</td>
</tr>
<tr>
<td><strong>Efficacy of multidimensional feedback for behaviour change</strong></td>
<td></td>
</tr>
<tr>
<td>• A trainer led 12 week intervention using web-based feedback may not improve behaviour in at-risk patients.</td>
<td>• Are there alternative ways to communicate the health risks of inadequate physical activity levels?</td>
</tr>
<tr>
<td>• Multidimensional feedback in real-time may enhance the impact of this approach.</td>
<td>• What are the most powerful and stimulating design features of multidimensional feedback?</td>
</tr>
<tr>
<td>• More useful for individuals with lower physical activity levels and possibly females and/or younger adults.</td>
<td>• What psychological processes occur when provided with positive versus negative behavioural feedback?</td>
</tr>
</tbody>
</table>

Figure 9-a. Lessons learned from the present body of work and suggested research questions that would advance multidimensional physical activity feedback.
As a behavioural change strategy where the aim is to help an inactive or at risk individual increase any aspect of their physical activity the provision of multidimensional feedback offers much promise. Individuals will gain a heightened awareness of a number of independent behavioural components and should thus be able to focus on as little or as many as their environment, lifestyle and preferences allow (Bauman et al., 2012). What remains unclear however is the link between multidimensional physical activity and health, that is, the real impact on ‘health’ status of increasing a specific type or number of dimensions. Understanding the presence and severity of health risk is thought to be critical to many theories of behaviour change (e.g. (Ajzen, 2011; Schwarzer, 1999; Leventhal et al., 1992; Bandura, 1998; Janz and Becker, 1984). The link between physical activity and health is perhaps less perceptually recognised than is the case with other lifestyle behaviours such as the multiple aspects of diet with increased adiposity, smoking and sunscreen protection with certain types of cancer or contraceptive behaviours with HIV/AIDS (Keeney et al., 2009; Crepaz et al., 2006; Pollard et al., 2008). This lack of clarity may have been exacerbated by the presence of a multidimensional profile particularly as certain targets were adapted from the typical recommendations to align with the more stringent 24-hour measurements. Speculatively, this was more pertinent an issue for the clinical population recruited in Chapter 7 who entered the study with the motivation to improve their health risk score compared to those recruited to Chapter 8 who explicitly volunteered in an effort to become more active. Furthermore, the heterogeneity of physical activity was reinforced throughout this thesis in participants who achieved certain dimensions but not others. Many participants expressed disappointment at not being able to hit the vigorous activity target despite scoring well in PAL sedentary and moderate activity. For these individuals it would be important to clarify the message and be able to definitively downplay the need to achieve any vigorous activity.

With little research using multidimensional physical activity assessments to date it is hard to unpick whether any of the key dimensions have precedence over the others.
For example would an increase in PAL without changing moderate to vigorous activity physical activity have the equivalent impact on overall health compared to if the reverse was true? Likewise, it is also unclear whether increasing all five of the physical activity dimensions would bring additional benefits relative to just improving one or two. Recent suggestions have for example found that increasing moderate to vigorous activity by an hour a day may counteract the ill effects of prolonged sedentary time (Ekelund et al., 2016). Further efforts are required to determine the health links when accounting for all independent aspects of physical activity and large epidemiological studies that profile both multidimensional physical activity and various important health markers would do well to build up large enough databases to explore these factors. This might initially seem like a headache for epidemiologists in that it is more convenient to treat physical activity as a single exposure or outcome. However, this is familiar territory and there will be innovative solutions. For example, it may be possible to learn from parallel situations such as the metabolic syndrome where multiple inputs are used to generate a criterion-based score for physical activity. It may even be possible to determine the absence of any healthful physical activity across the key dimensions and we might call this something like the ‘Physical Inactivity Syndrome’ (Thompson and Batterham, 2013). The upshot of this clarification for practitioners and self-monitoring technologies would be more persuasive powers and better advice or strategizing of patient’s behavioural plans. It may also increase the likelihood of widespread adoption by researchers, public health advocates and technological companies, which in turn will help this novel conceptualisation of physical activity, imbed into everyday practice and norms.

9.3.2 Design: make visual feedback more engaging and more persuasive

As discussed in Section 9.2.3, the visual impact of the feedback used in the present study might have been improved to provide a plainer assessment of the appropriateness of one’s current physical activity levels. Seeing aspects of behaviour as ‘amber’ for example may have served to weaken rather than reinforce any sense of necessity to increase physical activity. Although fairly comprehensive as a first attempt, one issue with the iterative design phase covered in Chapter 4 and Chapter
5 was a lack of objective testing of the feedback designs to appraise the impact of seeing personalised feedback. Specifically, the qualitative person based approach (Yardley et al., 2015) used to inform the development of the web-based feedback platform compared holistic visual options (i.e. whether one format was clearer than another) but the finer details (i.e. strength of message) weren’t as extensively evaluated as such an approach would have not been feasible in an interview setting. In Chapter 6 there were suggestions that the provision of personalised feedback did contribute to the formation of illness regulations and emotional responses that may have in turn abetted the subsequent coping and action planning response (Jones et al., 2015; Breland et al., 2012; McAndrew et al., 2008). That said with the exception of determining whether these cognitive-affective responses were derived from activity pattern or health target data there was again a paucity of information about the specific features that fostered this impact. A better understanding of the most informative and engaging aspects of personalised feedback that evoke the strongest cognitive-affective responses could help future studies attempting to initiate a health behaviour change create more universally persuasive visualisations. It would also help interventionists and health practitioners tailor their advice more appropriately and offer the necessary cognitive support to foster positive behavioural outcomes (Lustria et al., 2009; Noar et al., 2007).

One solution by which to achieve this objective might be to employ eye-tracking software to pick out the most salient and universally eye-catching components of the feedback (Asan and Yang, 2015; Duchowski, 2007). Eye tracking software uses reflective inferred technology to detect whether eyes fixate or saccade on a particular piece of information, which in turn can indicate certain cognitive processes (Goldberg and Kotval, 1999; Goldberg et al., 2002). For example, long fixation rates may lead to uncertainty with information processing; high rates of fixation tend to demonstrate areas attractive to an individual; whilst fluctuations in eye movement can be symbolic of critical cognitive process or attentional shifts (Jacob and Karn, 2003; Asan and Yang, 2015; Holmqvist et al., 2011). For one, this technical approach would be an appropriate way of determining preferences and understanding of the
overall designs if presented side-by-side. It would also be useful for determining the 
most favourable aspects of a multidimensional physical activity profile and whether 
the traffic light system utilised throughout this programme of work was a suitable 
design format. To answer these questions one should recruit a number of individuals 
who have activity statuses ranging from collectively active or inactive (i.e. all red or 
green) with a number of variable mixed profiles in between. One could then examine 
whether there are any preferences in terms of particular dimension, i.e. if all 
coloured the same is it the one with the least visual discordance between the 
performance and the target; and the colour scheme, i.e. if feedback displays a 
collection of red, amber and green health targets which is the most attractive, off- 
putting or confusing.

In addition, future research could also make a more objective assessment of the 
cognitive-affective impact of seeing personalised feedback to develop the 
observations made in Chapter 6. Instruments such as the Illness Perception 
Questionnaire (Moss-Morris et al., 2002), the Risk Behavior Diagnosis Scale (Witte et 
al., 1996), Outcome expectancies (Schwartz, 2006) and the measures of positive and 
negative affect (Watson et al., 1988), may be useful for gauging risk perception, 
emotional responses, outcome expectancies and behavioural intentions in response 
to an immediate presentation of feedback. One method that would help decipher 
whether the impact alters depending on whether individuals receive ‘positive’ or 
‘negative’ feedback message could be to frame an individual’s physical activity 
feedback as insufficient, mixed and sufficient in a 3-phase randomised cross-over 
study design (Mills et al., 2009). More specifically, participants would wear a physical 
activity monitor for a week on three occasions and subsequently receive either the 
true profile they would have generated or a manipulated format that depicted an 
unexpected positive ‘hit-all’ or negative ‘missed-all’ targets feedback. To determine 
whether thoughts and feelings change over time, or if a particular message is more 
evocative, the aforementioned assessments of key theoretical psychosocial 
antecedents of behaviour change could be made at baseline, and immediately
following each session within which personalised multidimensional feedback was presented (Stone and Shiffman, 2002).

9.3.3 (RE) TEST THE EFFICACY OF REAL-TIME MULTIDIMENSIONAL PHYSICAL ACTIVITY FEEDBACK

The success of this novel approach to self-monitoring multiple health-harnessing dimensions of physical activity as a public health strategy ultimate relies on the advancements in wearable eHealth technology used capture behaviour (Patel et al., 2015; Chiauzzi et al., 2015; Piwek et al., 2016). As technology constantly aims to become faster, more intelligent and easier to use so too might the expectations and levels of engagement of its users and making it vital to adapt accordingly to changing trends (Kumar et al., 2013). As of 2016, the Bodymedia device used throughout this thesis the ceased production and so future work will need to find innovative technological solutions for accurately capturing and presenting multidimensional feedback. Fortunately, commercially available physical activity trackers that integrate multiple sensors are becoming more affordable and popular (Thompson, 2015; Alley et al., 2016; Evenson et al., 2015). Studies examining the reliability and validity of such monitors are also increasing and thus it is likely to be only a matter of time before these instruments can provide sufficient resolution to reflect the different physical activity dimensions (Bai et al., 2015; Sanders et al., 2016; Hekler et al., 2015). The success of the combined multidimensional and real-time daily feedback exploratory trial is particularly promising as it utilised a number of features and behaviour change techniques commonly supported by these commercial wearable monitors and their applications (Lyons and Lewis, 2014; Bort-Roig et al., 2014; Direito et al., 2014; Mercer et al., 2016). Despite the apparent success of real-time feedback in promoting sustained changes in physical activity behaviour the potential of the technology used in Chapter 8 was by no means optimised. A useful upgrade on this approach would be to design a real-time display that presents accurate information across all health-harnessing dimensions including sedentary time, which was missing from the real-time feedback display (Sanders et al., 2016). If individuals could then choose what and how they were going to change their behaviour based on an initial profile and then use real time feedback in those very
specific dimensions this might be able to support more individuals in making a positive behaviour change.

In order to optimise this approach for wider dissemination and inform future public health efforts wishing to utilise and advance this strategy there is also a need to tease out which active ingredients and intervention functions were the most effective in supporting the observed change in behaviour (Michie et al., 2013b; Johnston et al., 2013). Given the study design and homogenous nature of the participants recruited for the Mi-PACT study it is difficult to draw any definitive conclusions about the relative contribution of the simple digital instant feedback display or the more sophisticated multidimensional web-based platform to the observed behaviour change. A suitable study design would be a randomised controlled trial with four intervention arms: one providing solely multidimensional feedback, one providing just instantaneous feedback, another providing a combination of both approaches and a final group providing a no intervention control condition. The trial described in Chapter 8 was limited to a localised population, small sample size and short follow-up duration and so the proposed study would also benefit from a longer follow-up period and a larger and more diverse sample (Fraenkel et al., 1993; Campbell et al., 2000; Grimes and Schulz, 2002). Finally, it remains unclear how useful, or perhaps even detrimental, the involvement health trainer was for the larger trial. Clearly there are a number of ways a trainer could be deployed to support in such an intervention however to make eHealth behaviour change strategies more pragmatic and cost-effective it would be useful to understand their efficacy (Heath et al., 2012).

A useful addition to the aforementioned randomised controlled trial in this context would be to further break down the technology-enabled feedback conditions to include or exclude face-to-face support and one would recommend undertaking a detailed process evaluation using quantitative and qualitative measures to fully understand the impact of technological feedback and face-to face support (Moore et al., 2015).
9.4 CONCLUSIONS

This thesis presents an initial enquiry into the efficacy of technologically-enabled multidimensional physical activity feedback for the self-monitoring of health-harnessing behaviour. Based on the understanding that there are several important components of physical activity behaviour that can independently impact health the present thesis hypothesised that personalised feedback could support a change in behaviour by raising awareness of distinct behavioural solutions reduce barriers to physical activity. The results demonstrate that complex data from sophisticated monitoring technologies can be transformed into clear visual information that helps to raise individuals’ awareness and understanding as to the options for acquiring healthful physical activity and their own levels of behaviour. There was also evidence that the provision of personalised feedback in this format may evoke the formation of illness representations, emotional responses and improved self-determined motivation towards physical activity behaviour.

Accordingly, there are early indications that multidimensional physical activity feedback represents a promising strategy for encouraging individuals of low baseline physical activity levels to increase their physical activity, particularly when used in conjunction with real-time feedback that incorporates and promotes important self-regulatory techniques. There are clearly refinements to both the design and mode of delivery that may improve the effectiveness of this approach and further investigation into the psychosocial processes is warranted to better understand the motivational mechanisms of multidimensional feedback. As technology advances and becomes increasingly affordable in the coming years there will be exciting opportunities to further develop and apply this novel conceptualisation of physical activity behaviour on a wider scale that reaches individuals who would benefit most from increased physical activity.
REFERENCES


American College of Sports Medicine, 2013. *ACSM's guidelines for exercise testing and prescription*. Lippincott Williams & Wilkins.


Gebel, K., Ding, D., Chey, T., Stamatakis, E., Brown, W.J. & Bauman A.E. 2015, Effect of Moderate to Vigorous Physical Activity on All-Cause Mortality in Middle-aged and Older Australians. *JAMA Internal Medicine*, 175(6), pp. 970-977.


Khan, K.M. & Tunaiji, H.A., 2011. As different as Venus and Mars: time to distinguish efficacy (can it work?) from effectiveness (does it work?). *British Journal of Sports Medicine*, 45(10), pp. 759-760.


Rowsell, A., Muller, I., Murray, E., Little, P., Byrne, D.C., Ganahl, K., Müller, G., Gibney, S., Lyles, R.C., Lucas, A., Nutbeam, D. & Yardley, L., 2015. Views of People With High and Low Levels of Health Literacy About a Digital Intervention to Promote Physical Activity for


Williams, S.L. & French, D.P., 2011. What are the most effective intervention techniques for changing physical activity self-efficacy and physical activity behaviour--and are they the same? *Health Education Research, 26*(2), pp. 308-22.


APPENDICES

APPENDIX A. LETTER OF ETHICAL APPROVAL GRANTED FOR CHAPTER 3

10 October 2012

Dear Oliver,

Full title of study: Energy expenditure estimation in adults using multisensor activity monitors

REACH reference number: EP 12/13 3

The Research Ethics Approval Committee for Health (REACH) reviewed the amendments to the above application following its meeting held on 26th September 2012.

On behalf of the Committee, I am pleased to confirm a favourable ethical opinion of the above research on the basis described in the application form and supporting documentation.

Please inform REACH about any substantial amendments made to the study if they have ethical implications.

Kind Regards

James Friedlander-Boss
Department Co-ordinator
APPENDIX B. CASE FOR OMITTING PARTICIPANTS (N=3) IN CHAPTER 3.

In chapter 3, Section 3.3 the inflated energy expenditure estimations observed in three participants for the Actiheart™ device is described. These participants were excluded from all analysis involving the Actiheart™ device as they had unfeasibly high energy expenditure values as shown below. The line graphs present a 24-hour energy expenditure from the three participants in question to exemplify the dramatic discrepancy between the energy expenditure estimates of the Actiheart™ and Bodymedia.

In the table, the magnitude of this effect can be seen in both the large change in SD for the Actiheart™ device when the participants are removed and the typical difference between estimates from the two devices is 181 (± 382) Kcal/day compared to 368 (± 731) Kcal/day if participants 5, 13 and 29 are included. It is acknowledged that this effect may have been improved with individual calibration of the Actiheart™ device (Brage et al., 2005) however we decided not to do this for the present investigation as this process would not be feasible for large studies conducted in primary care.
### Mean free-living energy expenditure

<table>
<thead>
<tr>
<th>Participant</th>
<th>Energy expenditure (Kcal/day)</th>
<th>Actiheart</th>
<th>Bodymedia</th>
<th>Difference</th>
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<td>3498</td>
<td>2700</td>
<td>798</td>
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</tbody>
</table>

\[ M^1 = \text{Mean (SD) of all participants} \]

\[ M^2 = \text{Mean (SD) with highlighted participants excluded} \]
Appendix C. Wear Instructions for the Actiheart™

Actiheart Operating Instructions

How is the Actiheart worn?

- The Actiheart monitor is held to the skin by two sticky pads placed on the left side of the chest.
- Before fitting sticky pads, please clean and dry the area thoroughly and avoid using lotion or moisturiser. Removal of excess hair from the area using a shaver can also improve contact to the skin.
- To attach the main piece and small piece, you will need to press down on the little buttons on the edges of the Actiheart and place them firmly onto the metal parts of the sticky pads.
- The ActiHeart can be worn on the upper or lower chest as shown...

![](image)

- The wire should be straight (horizontal) but not too stretched
- We recommend changing the pads every 1-3 days (and alternating between the upper and lower attachment sites if needed) to help prevent itching and to minimise any skin irritation.

When should the Actiheart be worn?

- Wear the ActiHeart all day, every day (including while sleeping) but remove for showing or water-based activities.
- The pads themselves do not need to be removed for showing etc.
- If the monitor is removed (e.g. for water-based activities) please put it back on as soon as possible afterwards.
Bodymedia Armband Operating Instructions

Wear your Armband on the back of the upper left arm (the tricep). To work properly, the Armband logo must face upward towards the shoulder and the silver sensors on the underside of the Armband will be in contact with your skin.

1. Be sure the upper left arm is clean, dry, and free of lotion or oil then slide the Armband onto your left arm.

2. Adjust the strap so that it fits comfortably, and then secure the Velcro pull-tab. Ensure that the sensors on the underside of the Armband maintain continuous contact with your skin and that the Armband does not slide off your arm.

3. Do not secure the strap too tightly. You should be able to place two fingers beneath the strap. Once the strap is adjusted to a comfortable fit, there is no need to readjust the Velcro tab. Slide the Armband on and off your arm by stretching the strap.

4. Wear the Armband continuously (including while sleeping) but please remove the monitor briefly for showers or water activities as it is not waterproof.

The Armband will turn on and begin collecting data within 10 minutes. Activation is indicated by a series of audio tones. Please note that there is no power button on the Armband.
## APPENDIX E. MONITOR RATING SCALE USED IN CHAPTER 3 AND USER FEEDBACK.

User feedback (n = 24) of the Actiheart™ and BodyMedia devices based on six comfort and wearability items and overall preference following one week of wear. Each statement had a 20 point scale upon which to record the scores.

<table>
<thead>
<tr>
<th>Item</th>
<th>Statement</th>
<th>Actiheart™ Mean (SD) of scores</th>
<th>Count if preferred</th>
<th>BodyMedia Mean (SD) of scores</th>
<th>Count if preferred</th>
<th>No Preference Count if preferred</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emotion</td>
<td>I feel self-conscious having people see me wear this device</td>
<td>4.5 (4.4)</td>
<td>13</td>
<td>6.6 (4.6)</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attachment</td>
<td>I feel the device moving on my body</td>
<td>4.0 (4.7)</td>
<td>13</td>
<td>5.9 (4.3)</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>I feel some pain or discomfort wearing the device</td>
<td>7.8 (6.1)</td>
<td>6</td>
<td>4.4 (3.9)</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>Harm</td>
<td>I feel awkward or different wearing the device</td>
<td>4.9 (4.8)</td>
<td>10</td>
<td>5.8 (4.6)</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>Perceived Change</td>
<td>I feel the device affects the way I move</td>
<td>3.6 (4.1)</td>
<td>9</td>
<td>4.3 (3.5)</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>Movement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anxiety</td>
<td>I feel secure wearing the device</td>
<td>12.4 (7.1)</td>
<td>9</td>
<td>11.8 (6.6)</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>Preferred Device</td>
<td>Please indicate below which device you preferred to wear</td>
<td>11</td>
<td></td>
<td>12</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

* Reverse scored, higher mean is considered favourable for this Item
APPENDIX F. LETTER OF ETHICAL APPROVAL GRANTED FOR CHAPTERS 5 AND 6

04 February 2013

Dr Oliver J Peacock
Research Officer
University of Bath
Eastwood 22-23, 3.2
Department for Health
University of Bath, Bath
BA2 7AY

Dear Dr Peacock:

Study title: Patient preferences and understanding of personalised physical activity profiles
REC reference: 12/SW/0374
IRAS project ID: 118027

Thank you for your letter of 01 February 2013, responding to the Committee's request for further information on the above research and submitting revised documentation.

The further information has been considered on behalf of the Committee by the Vice-Chair.

We plan to publish your research summary wording for the above study on the NRES website, together with your contact details, unless you expressly withhold permission to do so. Publication will be no earlier than three months from the date of this favourable opinion letter. Should you wish to provide a substitute contact point, require further information, or wish to withhold permission to publish, please contact the Co-ordinator Miss Christine Hobson, nrescommittee.southwest-frenchay@nhs.net.

Confirmation of ethical opinion

On behalf of the Committee, I am pleased to confirm a favourable ethical opinion for the above research on the basis described in the application form, protocol and supporting documentation as revised, subject to the conditions specified below.
Ethical review of research sites

NHS sites

The favourable opinion applies to all NHS sites taking part in the study, subject to management permission being obtained from the NHS/MRC R&D office prior to the start of the study (see "Conditions of the favourable opinion" below).

Non-NHS sites

Conditions of the favourable opinion

The favourable opinion is subject to the following conditions being met prior to the start of the study.

Management permission or approval must be obtained from each host organisation prior to the start of the study at the site concerned.

Management permission ("R&D approval") should be sought from all NHS organisations involved in the study in accordance with NHS research governance arrangements.

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Approved documents

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Reporting requirements

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- Notifying substantial amendments
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- Progress and safety reports
- Notifying the end of the study

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Further information is available at National Research Ethics Service website > After Review
We are pleased to welcome researchers and R & D staff at our NRES committee members’ training days – see details at http://www.hra.nhs.uk/hra-training/

With the Committee’s best wishes for the success of the project.

Yours sincerely

[Signature]

Dr Mike Shercliff
Chair

Email: nrescommittee.southwest-franchay@nhs.net

Enclosures: “After ethical review – guidance for researchers”

Copy to: Dr Oliver J Peacock
Ms Irene Blair, University of Bath
APPENDIX G. EXAMPLE OF PERSONALISED PHYSICAL ACTIVITY FEEDBACK SHOWN TO PARTICIPANTS WHO WERE INTERVIEWED FOR QUALITATIVE WORK

MiPACT PROJECT

Physical Activity Profile Portfolio
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Section 1 – Energy Expenditure

We have measured your 24-h daily energy expenditure (i.e. the number of calories you burn per day).

For each day we have collected 1440 minutes of data!

There are a variety of ways of presenting such a large amount of information.

In this section, we will present your individual data (for one 24-h day) in a number of different ways.

After a brief introduction to each graphic we will ask you a few questions regarding your thoughts, opinions and preferences.
Key to Intensity Thresholds

Very vigorous
- High-intensity exercise
- Sports
- Basketball

Vigorous
- Brisk walking
- Yoga
- Cycling
- Mowing lawn

Moderate
- Walking
- Shopping
- Gardening

Light
- Light home-based activities
- Cleaning

Sedentary
- Sitting
- Reading
- Computer work
Saturday 23/03/2013
Total Calories: 2614
B - 24 hour Radial

Saturday 23/03/2013
Total Calories: 2614
Section 2 – Summary Data

We have shown you various ways of displaying your daily or weekly activity patterns, we can now pick out key summary information.

For example we can display the average and total time spent in each activity intensity threshold during your week.

We can also summarise the amount of calories expended at each of these intensity thresholds.

The table below is used to describe the relationship between time and energy within each activity threshold.

You will now be shown some visual images of your summary data.

<table>
<thead>
<tr>
<th>Activity Intensity</th>
<th>Time (Minutes)</th>
<th>Calories</th>
<th>Calories</th>
<th>Time (Minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sleep</td>
<td>30</td>
<td>35</td>
<td>500</td>
<td>400</td>
</tr>
<tr>
<td>Sedentary</td>
<td>30</td>
<td>50</td>
<td>500</td>
<td>275</td>
</tr>
<tr>
<td>Light</td>
<td>30</td>
<td>100</td>
<td>500</td>
<td>150</td>
</tr>
<tr>
<td>Moderate</td>
<td>30</td>
<td>180</td>
<td>500</td>
<td>80</td>
</tr>
<tr>
<td>Vigorous</td>
<td>30</td>
<td>300</td>
<td>500</td>
<td>50</td>
</tr>
<tr>
<td>Very Vigorous</td>
<td>30</td>
<td>425</td>
<td>500</td>
<td>35</td>
</tr>
</tbody>
</table>
D – Bubble

<table>
<thead>
<tr>
<th>Time spent (hh:mm)</th>
<th>Energy spent (Kcal per day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12:50</td>
<td>1044</td>
</tr>
<tr>
<td>00:54</td>
<td>136</td>
</tr>
<tr>
<td>01:46</td>
<td>484</td>
</tr>
<tr>
<td>00:27</td>
<td>201</td>
</tr>
<tr>
<td>00:01</td>
<td>5</td>
</tr>
</tbody>
</table>
Section 3 – Health Targets

Further to summarising your activity data, we can now show how this sits with current health recommendations.

These recommendations are set based on levels of activity associated with risk for a variety of health problems.

Here we present 5 physical activity targets which have independent effects on your health risk.

There are therefore various aspects of your physical activity profile that can be altered to improve your health.

The 5 dimensions are:
- **Daily calorie burn:** PAL ≥ 1.75
- **Weekly moderate activity:** 120 accumulated minutes
- **Moderate 10 minute bouts:** 150 minutes per week
- **Vigorous activity minutes:** 75 minutes per week
- **Sedentary time:** < 60% of waking day

This section will use a traffic light colour system to indicate whether you are under, near or over the target.

<table>
<thead>
<tr>
<th>Hit Target</th>
<th>Near Target</th>
<th>Missed Target</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Green Circle" /></td>
<td><img src="image2.png" alt="Orange Circle" /></td>
<td><img src="image3.png" alt="Red Circle" /></td>
</tr>
</tbody>
</table>
H – Target Bars

- **Daily Calorie Burn (Kcal)**
  - Hit Target: 2415
  - Near Target: 2329

- **Daily Moderate Activity (Minutes)**
  - Hit Target: 120
  - Near Target: 107

- **Weekly Moderate Bouts (Minutes)**
  - Hit Target: 150
  - Near Target: 450

- **Weekly Vigorous Activity (Minutes)**
  - Missed Target: 75
  - Near Target: 195

- **Sedentary Time (% of day)**
  - Missed Target: 60
  - Near Target: 80
I – Sliding Targets

- **Daily Calorie Burn (Kcal)**: 2329 Kcal
- **Daily Moderate Activity (Minutes)**: 107 Minutes
- **Weekly Moderate Bouts (Minutes)**: 450 Minutes
- **Weekly Vigorous Activity (Minutes)**: 195 Minutes
- **Sedentary Time (% of day)**: 80%
APPENDIX H. DEMOGRAPHIC AND CLINICAL FACTORS USED TO CALCULATE 10-YEAR CARDIOVASCULAR DISEASE AND TYPE TWO DIABETES RISK AS USED IN THE NHS HEALTH CHECK.

The calculator is available at http://qintervention.org/ and the algorithms used are discussed further in Hippsley-Cox et al., (2008) and Hippsley-Cox et al., (2009).
APPENDIX I. Topic guides developed for semi-structured interviews of CHAPTER 5 AND CHAPTER 6: HEALTHCARE PROFESSIONALS

Participant Topic Guide (HCP)

1. Introduction/lifecircle
   1.1. Who are your patients or clients and what is your typical role with them?

2. Physical activity views and opinions
   2.1. What are your personal thoughts on physical activity?
       2.1.1. Are you physically active yourself?
       2.1.2. What physical activities are you involved in?
   2.2. Is physical activity something you often discuss with your patients or clients?
       2.2.1. Why? Or in what context?
   2.3. When discussing physical activity with patients, how do you approach the topic?
       2.3.1. How do you describe physical activity?
       2.3.2. What about mentioning the health risks associated with inactivity?
   2.4. How do patients react when you initiate a discussion about their physical activity levels?

3. Barriers and benefits of physical activity
   3.1. Do you think patients believe physical activity is important for their health and well-being?
   3.2. What are the key barriers or competing interests preventing patients from being active?
       3.2.1. Any examples?
   3.3. What in your opinion does or would motivate patients to be physically active?
       3.3.1. Again, do you have any examples?
   3.4. Are there any methods or techniques that you currently or would like to use to encourage a patient to be more physically active?
4. Impression and understanding of profiles
   4.1. What is your first impression of this profile? (colours; graphics; detail)
   4.1.1. Do you understand what it is showing you?
   4.2. What features of the [individual] design do you like? Why?
   4.3. Which bits do you not like? Why?

-------- End of Each Section --------

4.4. How does seeing your personal activity data in this way make you feel?
4.5. Which is your favourite design(s)? Why?
4.6. Would you like to suggest some ideas of how we could improve any of these designs?
   4.6.1. How can we make them easier to understand?
   4.6.2. Do you think we should include more information? Any examples?
4.7. Do any of these profiles provide you with information you were not aware of?

-------- Put Aside Profiles---------

5. Application of profiles
5.1. Do you think that information presented in this way would be useful for patients?
   5.1.1. Do you feel that patients would understand the data being shown?
   5.1.2. Is the information presented something you feel patients could manage themselves?
   5.1.3. How much additional support might they require?
   5.1.4. Would it be valuable resource to help you initiate and conduct a discussion about physical activity?
5.2. Thinking practically, is the information presented something that might help them change their physical activity behaviour?
   5.2.1. Are there any specific strategies that you can think of that might be effective?
   5.2.2. Do you see the patients being able to use technological platforms (Web or smartphones) to monitor their profiles?
   5.2.3. Would it work in some people and not others, and if so, which subgroups?

Close
Thank you very much for taking the time to participate. If there is nothing you would like to add that is the end of the interview. Please feel free to ask any questions about anything we have discussed.
APPENDIX J. TOPIC GUIDES DEVELOPED FOR SEMI-STRUCTURED INTERVIEWS OF
CHAPTER 5 AND CHAPTER 6: PATIENTS

Participant Topic Guide (PNT)

1. Introduction/icebreaker
   1.1. Can you tell me through a typical day?
       1.1.1. What do you usually do, when do you usually wake up?

2. General health
   2.1. Very briefly, can you tell me a little bit about your health?
   2.2. Do you have any health problems? If yes, what are they? If no, do you ever get sick?

3. Physical activity views and opinions
   3.1. What is physical activity for you?
       3.1.1. Can you give me examples of physical activities?
   3.2. Is physical activity important to you? Why?
   3.3. Which physical activities are you currently and/or have you previously been involved in?
       3.3.1. How often do you do physical activity? Who do you do it with?
   3.4. What type or types of physical activity would you like to take part in?
       3.4.1. Individual or group? Sport or leisure? Walking more?
   3.5. Do you think your current level of physical activity is sufficient?
       3.5.1. Are you aware of current physical activity recommendations?

4. Barriers and benefits of physical activity
   4.1. What are the benefits of being physically active for you?
   4.2. What motivates you to be physically active?
   4.3. What stops you from being physically active?
   4.4. Is physical activity something your friends and family are involved in or support?
       4.4.1. If yes, what kind of support they offer you?
   4.5. If you wanted to, what in your opinion could make it easier for you to do physical activity?
5. Impression and understanding of profiles
   5.1. What do you think of this profile? (Prompt: colours; graphics; data)
   5.1.1. Do you understand what it is showing you?
   5.2. What features of the [individual] design do you like? Why?
   5.3. Which bits do you not like? Why?

      End of each section      

5.4. How does seeing your physical activity data in this way make you feel?
5.5. Do you think that your personal profile provided you with information you were not aware of?
   5.5.1. If yes, what was that information?
5.6. Which is your favourite design? Why?

6. Practical application of profiles
   6.1. On the whole, has seeing your personal physical activity data in these formats been useful?
   6.1.1. As a practical tool or for information?
   6.2. Can you see yourself using this data to help increase your physical activity? In what way?
   6.2.1. Do you see there are several different options to change your physical activity?
   6.2.2. Techniques such as self-monitoring, goal setting, progress tracking?
   6.3. What part of this, if any, motivates you the most?
   6.4. Is there anything else that might be useful to support the visual information or anything that is missing?

      Run through platform      

7. Platform
   7.1. Do you think that technological platforms to display and track profiles could be beneficial?
   7.2. Would you feel confident using technological devices in this way to monitor physical activity?
   7.2.1. Which, if any, technological devices do you own? (smart phone, computer, iPod)
   7.3. Does this look like something you could or would use on your own to monitor over time?
   7.3.1. What type of support would you need?
   7.4. Would you like to suggest ways that the platform could be improved?
   7.4.1. What would make it more user friendly?
   7.4.2. Can you think of anything that was missing that might be useful?

Close
Thank you very much for taking the time to participate, if there is nothing you would like to add that is the end of the interview. Please feel free to ask any questions about anything we have discussed.
APPENDIX K. LETTER OF ETHICAL APPROVAL GRANTED FOR CHAPTER 7

Health Research Authority
NRES Committee South West - Frenchay
Bristol Research Ethics Committee Centre
Level 3, Block B
Wh ferners
Law Ino Road,
Bristol
BS1 2NT

06 September 2013

Dr Dylan Thompson
Reader
University of Bath
Eastwood 22-23 3 8
Department for Health
University of Bath,
Bath
BA2 7AY

Dear Dr Thompson

Study title: Multidimensional Individualised Physical Activity Profiles for Behaviour Change using Technology

REC reference: 13/SW/0179
IRAS project ID: 133506

Thank you for your letter of 02 September 2013, responding to the Committee’s request for further information on the above research and submitting revised documentation.

The further information has been considered on behalf of the Committee by the Chair.

We plan to publish your research summary wording for the above study on the NRES website, together with your contact details, unless you expressly withhold permission to do so. Publication will be no earlier than three months from the date of this favourable opinion letter. Should you wish to provide a substitute contact point, require further information, or wish to withhold permission to publish, please contact the REC Manager Mrs Ruth Avery, nrescommittee.southwest-frenchay@nhs.net.

Confirmation of ethical opinion

On behalf of the Committee, I am pleased to confirm a favourable ethical opinion for the above research on the basis described in the application form, protocol and supporting documentation as revised, subject to the conditions specified below.
Ethical review of research sites

NHS sites

The favourable opinion applies to all NHS sites taking part in the study, subject to management permission being obtained from the NHS/HSC R&D office prior to the start of the study (see "Conditions of the favourable opinion" below).

Conditions of the favourable opinion

The favourable opinion is subject to the following conditions being met prior to the start of the study.

Management permission or approval must be obtained from each host organisation prior to the start of the study at the site concerned.

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<td>Other: Student Max Western CV</td>
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We are pleased to welcome researchers and R&D staff at our NRES committee members' training days – see details at http://www.hra.nhs.uk/hra-training/
With the Committee’s best wishes for the success of this project.

Yours sincerely

Dr Robert Beetham
Chair

Email: mrescommittee.southwest-frenchay@nhs.net

Enclousres: “After ethical review – guidance for researchers”

Copy to: Dr Oliver J Peacock
Ms Irene Blair, University of Bath
## Appendix L. Session outlines used to guide health trainers for the five MiPACT training sessions

**Session Outlines**

<table>
<thead>
<tr>
<th>Session</th>
<th>Aims and Objectives</th>
</tr>
</thead>
</table>
| 1A      | AIM: To provide all participants with standardised messages and links to resources on vascular disease risk, physical activity for health and general lifestyle advice.  
OBJECTIVES – by the end of the session you will want the participant to:  
➢ Recognise the project aims and understand the benefits of taking part  
➢ Understand disease risk and that things can be done to lower their risk  
➢ Have discussed their personal views and understanding of physical activity  
➢ Be aware of current physical activity guidelines, available options and the benefits of being more physically  
➢ Receive a factsheet on physical activity along with links to on-line resources for further information on vascular disease, physical activity and lifestyle advice. |
| 1B      | AIM: To help the participant to familiarise with the platform and understand their own activity data so they can begin to think about the need to change.  
OBJECTIVES – by the end of the session you will want the participant to:  
➢ Recognise the overall aims of the MiPACT programme.  
➢ Be aware of the multiple dimensions of physical activity behaviour that are good for health and that these can be captured by advanced monitoring technology.  
➢ Be able to set up and navigate through the web platform and have the confidence to use its features at home.  
➢ Begin to understand their baseline data and what it means in terms of their health and the interaction between activity patterns, time and energy and health targets.  
➢ Start to think about their individual needs, aspects of their current behaviour that they enjoy and an area of their health profile that they might wish to change. |
| 2 & 3 | AIM: To ensure that the participant understands their personal data, is comfortable with self-monitoring and using the platform, and has the confidence and motivation to start making plans towards improving at least one aspect of their physical activity behaviour.  

OBJECTIVES — By the end of sessions 2 and 3 you will want the participant to...  
➢ Understand their data in each section of the platform and be able to use it to make informed decisions about their behaviour.  
➢ Appreciate which aspects of their health profile are relevant to them and their needs and which one(s) they may wish to try and change.  
➢ Have the skills, desire and confidence to self-monitor and use their personalised feedback and the interactive aspects of the platform to review their behaviour and plan change(s).  

The content of sessions 2 and 3 will be determined to some extent by the rate of progression of the individual participant and you will need to tailor the sessions accordingly. The focus will shift from understanding the basics (and initial experimentation with different options) to more structured goal setting and action planning towards behaviour change. |
|---|---|
| 4 & 5 | AIM: Initially to ensure that the patient is comfortable self-monitoring their behaviour and goals and is taking positive steps towards increasing their physical activity, and secondly to help the patient embed changes into their routine so that the increases are sustained once the monitoring and feedback is removed.  

OBJECTIVES — By the end of sessions 4 and 5 you will want the participant to...  
➢ Have the necessary skills to review and refine their action plans and goals so that they are achievable and facilitate motivation.  
➢ Understand why changes in their behaviour have arisen and what they can do to maintain these.  
➢ Appreciate how they can further progress in one or more physical activity dimensions.  
➢ Have the intent, ability and confidence to continue making positive behavioural changes in the absence of the objective tailored feedback.  

The content of sessions 4 and 5 will need to be flexible to account for the variable rates of progression and platform usage. Due to the slightly longer time frame between sessions (i.e. 4 weeks) the amount of time spent using the platform will likely differ from participant to participant and will need to be tailored accordingly. |
APPENDIX M. SESSION 1 CONTROL CONTENT FOR ALL PARTICIPANTS IN THE MI-PACT STUDY

Physical activity guidelines for adults
From Start Active, Stay Active

FACTSHEET

Guidelines
1) Adults who participate in any amount of physical activity gain some health benefits, including maintenance of good physical and cognitive function. Some physical activity is better than none, and more physical activity provides greater health benefits.

2) Adults should aim to be active daily. Over a week, activity should add up to at least 150 minutes (2½ hours) of moderate intensity activity in bouts of 10 minutes or more – one way to approach this is to do 30 minutes on at least 5 days a week.

3) Alternatively, comparable benefits can be achieved through 75 minutes of vigorous intensity activity spread across the week or combinations of moderate and vigorous intensity activity.

4) Adults should also undertake physical activity to improve muscle strength on at least two days a week.

5) Older adults (65 + years) at risk of falls should incorporate physical activity to improve balance and co-ordination on at least two days a week.

6) All adults should minimise the amount of time spent being sedentary (sitting) for extended periods.

Examples of physical activity that meet current guidelines:
Moderate intensity physical activities will cause adults to get warmer and breathe harder and their hearts to beat faster, but they should still be able to carry on a conversation. Examples include:
- Brisk walking
- Ballroom dancing
- Cycling

Vigorous intensity physical activity will cause adults to get warmer and breathe much harder and their hearts to beat rapidly, making it more difficult to carry on a conversation. Examples include:
- Climbing stairs
- Running, swimming or team sports

Physical activities that strengthen muscles involve using body weight or working against a resistance. This should involve using all the major muscle groups. Examples include:

- Carrying or moving heavy loads such as groceries
- Activities that involve stepping and jumping such as dancing or chair aerobics
- Exercising with weights

Activities to improve balance/co-ordination include:

- Tai chi or Yoga

Minimising sedentary behaviour may include:

- Reducing time spent watching TV
- Taking regular walk breaks around the garden or street (including breaks at work)
- Breaking up sedentary time such as swapping a long bus or car journey for walking part of the way

What are the benefits of being active daily?

- Reduces risk of a range of diseases, e.g. coronary heart disease, stroke and type 2 diabetes
- Helps maintain a healthy weight
- Helps maintain the ability to perform everyday tasks and activities of daily living
- Improves mood and self-esteem and helps maintain cognitive function with aging
- Reduces symptoms of depression and anxiety
- Reduces the risk of falls in older adults

For further information:

Start Active, Stay Active: A report on physical activity for health from the four home countries' Chief Medical Officers (2011)

NHS Choices Website: http://www.nhs.uk/Livewell
Change 4 Life: http://www.nhs.uk/Change4Life
Intervention evaluation

Participant Code........................................ Date........................................

1. How did you find the last 3 months overall? □ □ □ □ □

What did you like about the programme?

What did you dislike about the programme?

2. Were the training sessions helpful? □ □ □ □ □

What in particular did you like/dislike?

What would improve the training sessions?

3. How useful was the monitoring? □ □ □ □ □

What in particular did you like/dislike?

What could improve the monitoring?
4. How useful did you find the **Health** and **Activity** sections of the platform?

<table>
<thead>
<tr>
<th>Not useful</th>
<th>Somewhat useful</th>
<th>Very useful</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

*What in particular did you like/dislike?*

*What would improve this section(s) of the platform?*

5. How useful did you find the **Review** and **Planning** sections of the platform?

<table>
<thead>
<tr>
<th>Not useful</th>
<th>Somewhat useful</th>
<th>Very useful</th>
</tr>
</thead>
<tbody>
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<td>3</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

*What in particular did you like/dislike?*

*What would improve this section(s) of the platform?*

5. Have you got any further comments for any of the platform sections, the monitoring process or the training you received?
### APPENDIX O. PSYCHOSOCIAL DATA FOR ALL PARTICIPANTS IN CHAPTER 7

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Sub-scale</th>
<th>Control (n=70)</th>
<th>Intervention (n=134)</th>
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<tr>
<td>Autonomy</td>
<td>5.2</td>
<td>0.8</td>
<td>5.3</td>
</tr>
<tr>
<td>Competence</td>
<td>4.1</td>
<td>1.1</td>
<td>4.4</td>
</tr>
<tr>
<td>Relatedness</td>
<td>4.0</td>
<td>1.6</td>
<td>4.0</td>
</tr>
<tr>
<td>Overall need support</td>
<td>4.4</td>
<td>1.3</td>
<td>4.6</td>
</tr>
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<td><strong>BREQ-2</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amotivation</td>
<td>0.6</td>
<td>0.8</td>
<td>0.5</td>
</tr>
<tr>
<td>External</td>
<td>0.9</td>
<td>0.7</td>
<td>0.9</td>
</tr>
<tr>
<td>Introjected</td>
<td>1.7</td>
<td>0.9</td>
<td>1.7</td>
</tr>
<tr>
<td>Identified</td>
<td>2.7</td>
<td>0.9</td>
<td>2.8</td>
</tr>
<tr>
<td>Intrinsic</td>
<td>2.6</td>
<td>0.9</td>
<td>2.8</td>
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<tr>
<td>Controlled motivation</td>
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<td>0.7</td>
<td>1.3</td>
</tr>
<tr>
<td>Autonomous motivation</td>
<td>2.6</td>
<td>0.9</td>
<td>2.8</td>
</tr>
<tr>
<td><strong>SRHI</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Autonomy</td>
<td>1.8</td>
<td>1.1</td>
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<tr>
<td>Identity</td>
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<td>1.8</td>
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<td>Frequency</td>
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<td>1.1</td>
<td>2.4</td>
</tr>
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<td><strong>PCPA</strong></td>
<td>Overall</td>
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<td><strong>BSE</strong></td>
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<td>Overall (less item 2)</td>
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<tr>
<td><strong>EQ-5D</strong></td>
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<td></td>
<td></td>
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<tr>
<td>Overall health</td>
<td>72.9</td>
<td>18.3</td>
<td>76.4</td>
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<td>Mobility</td>
<td>1.1</td>
<td>0.3</td>
<td>1.2</td>
</tr>
<tr>
<td>Self-care</td>
<td>1.0</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Activities</td>
<td>1.1</td>
<td>0.3</td>
<td>1.3</td>
</tr>
<tr>
<td>Pain</td>
<td>1.4</td>
<td>0.5</td>
<td>1.4</td>
</tr>
<tr>
<td>Anxiety</td>
<td>1.3</td>
<td>0.4</td>
<td>1.3</td>
</tr>
<tr>
<td><strong>MOS-SF36</strong></td>
<td>Physical functioning</td>
<td>86.6</td>
<td>12.7</td>
</tr>
<tr>
<td></td>
<td>Limitations physical</td>
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<td></td>
<td>Limitations emotional</td>
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<td>Energy fatigue</td>
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<td>Emotional well-being</td>
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<tr>
<td></td>
<td>General health</td>
<td>66.2</td>
<td>17.4</td>
</tr>
</tbody>
</table>

PNSE = Psychological Need Satisfaction in Exercise (Wilson et al., 2006); BREQ-2 = Behavioural Regulations in Exercise Questionnaire 2 (Markland and Tobin, 2004). SRHI = Self-Report Habit Index (Verplanken and Orbell, 2003); SVS = Subjective Vitality Scale (Ryan and Frederick, 1997); PCPA = Perceived Competence Scale in Physical Activity (Williams et al., 1998). EQ-5D = EuroQol-5 dimensions (EuroQol, 1996); MOS-SF-36 = Medical Outcomes Short Form Health Survey (Brazier et al., 1992).
APPENDIX P. LETTER OF ETHICAL APPROVAL GRANTED FOR CHAPTER 8

23/09/2014

Dear Max,

Full title of study: Providing combined instantaneous and multi-dimensional feedback to support a change in physical activity behaviour and motivation.


The Research Ethics Approval Committee for Health (REACH) reviewed the above application at its meeting held on the 17th September.

The Committee requested confirmation on where the blood samples are being taken and what steps are being carried out to ensure that the Human Tissue Act is not breached.

The Committee also requested clarification on whether GP medical records are being accessed and also how the recruitment process is being carried out.

Please address these issues at your earliest convenience.

24/09/2014

Dear Max,

Following your comments, Gordon Taylor is happy to approve your application via Chair’s action.

Kind regards,

Rachael Yates

(Department Co-ordinator)
SECTION 2: Wearing your Display

Display Overview

The Display has an LCD and four buttons:

- A MODE
- B VIEW
- C LIGHT
- D RESET TRIP

Using the display

IMPORTANT: The Armband must be configured before the Display will function properly. Refer to the Armband setup information aforementioned.

To begin using your Display, you must initially pair it with your Armband.

1. Slide the Armband onto your left arm and wait for it to power on. This may take up to 10 minutes.

2. After the Armband powers on, hold down the Display’s MODE and VIEW buttons until “Hello” is displayed on the screen.

3. The Display will read PRESS ARMBAND BUTTON TO SYNC. The Display must be within 3 feet of the Armband.

4. Press and quickly release the Armband’s Status Button (in the centre of the armband). WELCOME and your name will scroll across the Display to indicate pairing and synchronization are complete.

If the Armband is not within range of the Display or is not powered on, the Display will scroll ARMBAND NOT FOUND. In this case, try repeating the above steps.

The Armband and Display must be synchronized before the Display will function properly. Information is transmitted every 60 seconds from the Armband to the Display as long as they are in sync. If data is not received from the Armband for 5 minutes, the Display will revert to a NOT IN SYNC mode and display the TIME. They can also occasionally go out of sync due to environmental interference. Once the Armband and Display have been paired, you can re-sync the Armband and Display by simply pressing the button on the Armband, then pressing the MODE button on the display.

When the Display is in sync and you achieve one of your daily targets, the Display will notify you with a series of beeps and a scrolling message stating which target has been reached. To stop the scrolling or beeping, press the RESET TRIP button once.
Mode Functions

The Mode button, located on the top left, allows you to toggle between different data modes being transmitted from the Armband, including CALORIES, STEPS, ACTIVITY, and TIME.

• CALORIES Mode: The CALORIES mode displays your calories burned for a time period you select from the VIEW function (TODAY, YESTERDAY, or TRIP). The calories burned number includes an estimate for periods when you did not wear the Armband.

• STEPS Mode: The STEPS mode displays how many steps you have taken for the time period selected in the VIEW function. Only steps taken while wearing the Armband are counted.

• ACTIVITY Mode: The ACTIVITY mode displays your moderate and vigorous physical activity duration while wearing the Armband for the time period selected in the VIEW function.

• TIME Mode: The TIME mode displays the current time. Set your time zone within the within the software before the Armband is configured. In the TIME mode, the view button is disabled.

View Functions

• TODAY View: The TODAY view shows current values for the current day’s calories burned, steps taken, and duration of physical activity.

• YESTERDAY View: The YESTERDAY view shows the previous day’s total number of calories burned, steps taken, and duration of physical activity.

• TARGET View: The TARGET view shows the total daily targets for calories burned, steps taken, and physical activity duration.

• TRIP View: The TRIP view, like a car’s trip odometer, enables you to measure your calories burned, steps, and physical activity duration over a time period that you choose. To reset the TRIP, see instructions in RESET TRIP section.

Reset TRIP

To set your trip, navigate to the TRIP view then hold down the RESET TRIP button for 3 seconds. The Display will beep and reset all of the current trip values to 0.

Light

Pressing the LIGHT button will turn on the Display’s backlight for a few seconds so you may view the Display information in low-light or no-light conditions.

Standardly a beep occurs when you press any button on the Display. You can mute these beeps by holding down the light button until “beep off” is displayed. However you will still receive audio notification when you achieve your targets. You can un-mute by following the same process.
**APPENDIX R. PSYCHOSOCIAL DATA FOR ALL PARTICIPANTS IN CHAPTER 8**

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Sub-scale</th>
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<td>SD</td>
</tr>
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<td>Autonomy</td>
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<td>0.2</td>
</tr>
<tr>
<td></td>
<td>Competence</td>
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<td>1.2</td>
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<tr>
<td></td>
<td>Relatedness</td>
<td>4.0</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>Overall need support</td>
<td>4.7</td>
<td>0.8</td>
</tr>
<tr>
<td>BREQ-2</td>
<td>Amotivation</td>
<td>0.1</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>External</td>
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<td>0.6</td>
</tr>
<tr>
<td></td>
<td>Introjected</td>
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<td>Intrinsic</td>
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<td>Controlled motivation</td>
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<td>0.7</td>
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<td>Autonomous motivation</td>
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<td>0.6</td>
</tr>
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<td>Activities</td>
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<tr>
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<td>Pain</td>
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<td>Anxiety</td>
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<td>0.4</td>
</tr>
<tr>
<td>MOS-SF 36</td>
<td>Physical functioning</td>
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<td>Limitations physical</td>
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<td>Pain</td>
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</table>

PNSE = Psychological Need Satisfaction in Exercise (Wilson et al., 2006); BREQ-2 = Behavioural Regulations in Exercise Questionnaire 2 (Markland and Tobin, 2004). SRHI = Self-Report Habit Index (Verplanken and Orbell, 2003); SVS = Subjective Vitality Scale (Ryan and Frederick, 1997); PCPA = Perceived Competence Scale in Physical Activity (Williams et al., 1998). EQ-5D = EuroQol-5 dimensions (EuroQol, 1996); MOS-SF-36 = Medical Outcomes Short Form Health Survey (Brazier et al., 1992).
APPENDIX S. EVALUATION FORM USED TO RATE THE MI-PACT WEBSITE AND REAL-TIME FEEDBACK DISPLAY USED BY THE INTERVENTION GROUP OF CHAPTER 8.

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<td>4</td>
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<tr>
<td>Step Counter feedback</td>
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<td>3</td>
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</tr>
<tr>
<td>Mod/vig activity feedback</td>
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<td>3</td>
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<td>Use of personal targets</td>
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<td>The web platform</td>
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</tbody>
</table>
APPENDIX T. TOPIC GUIDE USED FOR SEMI-STRUCTURED INTERVIEWS TO EVALUATE THE INTERVENTION IN CHAPTER 8.

Activity Monitoring Study - Interview Topic Guide

Introduction
Thank you for taking part in my study and for coming in today. I am going to ask you a handful of questions about your involvement in the study but firstly as a quick reminder of the journey we have taken: you had an initial assessment followed by a 6-week self-monitoring period that involved daily instant feedback and targets on the small real-time display and the more comprehensive feedback on the web platform with information about the different aspects of your behaviour that we uploaded every 2-weeks. We then had 2 further assessments separated by 6-weeks without any of the feedback.

1. So how have you found the programme overall?
   1.1. What in particular have you enjoyed about taking part?
   1.2. Was there anything you disliked about taking part?

2. Which aspect of the intervention did you particularly find most useful?
   2.1. Online platform or instant display?
   2.2. Which parts of the online platform did you use?

3. How was it useful?
   3.1. What impact did it have on you? (Education? Motivating? Goal-focused? Feelings? Etc.)
   3.2. Is there anything you have learned about yourself as a result of taking part?

4. Has taking part in the programme changed the way you think about physical activity?
   4.1. Has there been a change in how important it is to you? How about the enjoyment or satisfaction?
   4.2. Do you feel any more aware and in control of your activity behaviour as a result of the intervention?

5. What has been the biggest change or changes you have made behaviourally, if any?
   5.1. How easy was it to make this change?
   5.2. How did taking part in the intervention make you feel about your ability to change?

6. How have you found the 6 weeks without the instant feedback?
   6.1. Was it easy to maintain activity levels?
   6.2. What did you find challenging?

7. Would you change anything about the intervention if you could?
   7.1. … such as duration, format, sessions with me?
   7.2. Is there anything that was missing or you would add to improve it?

8. What are your thoughts or plans going forward having been through the programme?
   8.1. How confident are you that you can keep up the new (or planned) levels of activity?
   8.2. Is there any further support (technological or person-based) you would need to help you?

Close
Thank you very much for taking the time to chat with me today, unless there is anything you would like to add or any further questions for me than that is the end of the interview.