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Study highlights

- The effect of helmet-wearing on cognitive performance under demanding conditions, so that small effects would become more detectible.
- One out of nine cognitive parameters showed a significant effect of helmet-wearing, disappearing in a post-hoc comparison.
- These results resolve previous disparate studies to suggest that, although helmets can be uncomfortable, any effect of wearing a helmet on cognitive performance is at worst marginal.

1 1. Introduction

2 The head is one of the most vulnerable parts of the body. Therefore, head protection
3 is recommended, and often mandatory, for many professional and leisure activities. A
4 helmet's main purpose is to protect against mechanical impact, e.g., for bicyclists,
5 soldiers, and firefighters. Consequently, most scientific attention is spent on optimizing
6 helmets to protect against mechanical impact (Aare et al., 2004; Cui et al., 2009; Deck
7 and Willinger, 2006; Mills and Gilchrist, 2008). However, protective headgear is often
8 associated with elevated local skin temperatures, unfavorable temperature perception,
9 and discomfort (De Bruyne et al., 2008; Hsu et al., 2000; Li et al., 2008; Liu et al., 2008;
10 Patel and Mohan, 1993; Skalkidou et al., 1999). This motivated several studies on the
11 ergonomics of helmets, mainly focused on ventilation (Abeysekera et al., 1991; Bogerd
12 and Brühwiler, 2009; Brühwiler et al., 2006; Reischl, 1986; Van Brecht et al., 2008).
13 These studies started to take our understanding beyond the simple mechanics of impact
14 protection to the wider issue of how a helmet affects its wearer.

15 A helmet is typically worn in situations with a higher likelihood for an accident
16 and/or larger consequences if an accident occurs. Therefore, any tendency for a helmet
17 to distract or otherwise reduce the performance of its wearer is undesirable, and could
18 potentially obviate its protective effect by making potentially injurious incidents more
19 likely to occur. Hancock and Warm (1989) have suggested a relationship between
20 attention performance and stress. The stress in their model can be psychological as well
21 as physiological in nature. This model explains several studies showing negative effects
22 of fabric discomfort (Bell et al., 2003; Bell et al., 2005) and whole-body thermal
23 discomfort on cognitive performance (Gaoua et al., 2012). Since helmets cause
24 disturbances to the wearer, and affect the temperature of the scalp's surface, this raises
25 the question whether a helmet might negatively affect cognitive performance.

26 Four studies have evaluated the effect of passive headgear on cognitive performance.
27 Three of these studies used the same helmet that covered the scalp and ears but left the
28 face uncovered (Hancock, 1983; Hancock and Dirkin, 1982; Holt and Brainard, 1976).
29 One of these studies found increased reaction times on a dual task while wearing the
30 helmet (Hancock and Dirkin, 1982). A more recent study found a negative effect on
31 cognitive performance of wearing a cricket helmet during cricket practice (Neave et al.,
32 2004). In contrast to these two studies, which showed an effect of headgear, on at least
33 one of the cognitive parameters investigated, the other two found no effect of helmet

1 wearing (Hancock, 1983; Holt and Brainard, 1976). This discrepancy might indicate that
2 wearing a helmet has a minor effect of cognitive performance. In fact, the effect size (r^2)
3 calculated from these publications is .02 ($\pm .02$), which is small in magnitude (Cohen,
4 1988).

5 The present study revisits the effect of a helmet on cognitive performance with a
6 view to clarifying this contradictory literature. Since the effect of a helmet on cognitive
7 performance is expected to be small, the present study aims at saturating the
8 participants' attention capacity (Hancock and Warm, 1989), so that small effects cannot
9 be buffered, and thus become more likely detectible. More specifically, 19 participants
10 carried out a demanding cognitive test battery for 30 min in a repeated-measures study
11 whilst wearing no helmet on one occasion and a helmet on the other. Unlike the open-
12 faced helmets used in earlier studies, a full-face motorcycle helmet was employed for the
13 present study representing a helmet design that covers the whole face, scalp and ears.
14 This was to make the thermal and comfort effects of the helmet more extreme for the
15 wearer. The measurements were carried out under warm (27.2 ± 0.6 °C) and wind-still
16 conditions. One out of nine cognitive parameters showed a significant effect of helmet-
17 wearing, and this effect was marginal, disappearing in a post-hoc comparison.

18 **2. Materials and methods**

19 **2.1. Participants**

20 Nineteen healthy male participants aged 28.3 (± 4.7) years (mean \pm standard
21 deviation) completed the study. The participants' head circumferences ranged from 53
22 cm to 62 cm. The exclusion criteria were the use of medications on a regular basis, or
23 suffering from claustrophobia or an attention disorder. All participants were instructed
24 to refrain from alcohol, drugs and caffeine 12 hours prior to each session. During
25 familiarization sessions the participants were instructed to adjust their clothing in order
26 to be thermally comfortable. As a result the participants wore jeans in combination with
27 a long sleeved shirt or a T-shirt. The participants wore the same clothing during both
28 experimental sessions. All participants gave informed consent before participation. This
29 study was approved by the Cantonal Ethics Committee of St. Gallen (Switzerland).

30 **2.2. Setup**

31 The participants sat at the exit of a wind tunnel. A 19" LCD screen of 1280×1024
32 pixels was positioned just below the exit of the wind tunnel, allowing the participant to

1 see the screen clearly (Fig. 1). A conventional keyboard and joystick (Attack 3, Logitech,
2 Fremont, USA) were positioned in front of the screen. The vertical distance from the
3 participant's head to the top of the wind tunnel was $5 (\pm 1)$ cm, and the horizontal
4 distance from the end of the housing of the wind tunnel to the forehead was $8 (\pm 6)$ cm.
5 This resulted in a viewing distance of $53 (\pm 6)$ cm from the eyes of the participant to the
6 screen. During the sessions the participant was the only person occupying the chamber
7 and did not have contact with the outside, nor had he any reference to time. All
8 measurements were conducted in a climate chamber maintained at an ambient
9 temperature of $27.2 (\pm 0.6)$ °C, and relative humidity of $41 (\pm 1)\%$. The wind speed (v_w)
10 was $0.5 (\pm 0.1)$ m s⁻¹ in order to have a minimal, but well-controlled v_w .

11

12 *** Fig. 1 somewhere here ***

13

14 **2.3. Protocol**

15 Each participant underwent five sessions. The time of day was kept constant to avoid
16 any influences of the circadian rhythm. In order to reduce learning effects on the results,
17 participants carried out three familiarization sessions. Subsequently, each participant
18 underwent two experimental sessions in a balanced order. The first and last sessions
19 occurred within two weeks, in order to prevent loss of familiarization. Before the start of
20 each session the participant completed a mood questionnaire (Monk, 1989), and
21 indicated the quality and quantity of their sleep during the previous two nights on two
22 visual analogue scales. Finally, each session was finished with the assessment of whole
23 body temperature perception on a nine-point scale (-4: very cold, to 0: neutral, to 4: very
24 hot) and a five-point thermal comfort scale (0: comfortable, to -4: extremely
25 uncomfortable). Both scales are detailed elsewhere (ISO10551, 2001).

26 The first 10 min of each experimental session were a familiarization session (Fig. 2).
27 Each participant donned safety goggles (control: CON) or a helmet (intervention: HEL)
28 at the start of this period and kept these on until the session was completed. More
29 details concerning the helmets and goggles are given under Section 2.5. Following the
30 familiarization, a 20 min equilibration phase started, the purpose of which was to
31 achieve a thermal steady state. This period was previously found to be sufficient for this
32 purpose (Bogerd et al., 2011). During this phase the participant read or carried out
33 unrelated computer work. Finally, each participant completed the cognitive test battery.

1 The three separate familiarization sessions, preceding the experimental sessions,
2 consisted of the first 10 min of an experimental session, and did not take place on the
3 same day as an experimental condition.

4

5 *** Fig. 2 somewhere here ***

6

7 **2.4. Cognitive tests**

8 **Visual vigilance and tracking test (VTT)**

9 The visual vigilance and tracking test (VTT) consisted of a tracking and a vigilance
10 task in parallel. The tracking task involved a red annulus that was presented in the
11 middle of the computer screen, and a moving blue ball (Fig. 1). The ball received random
12 impulses from the software, and the participant was instructed to keep it in the middle
13 of the annulus, using the joystick to control the acceleration, direction, and amplitude.
14 On the screen, the outer diameters of the annulus and ball were 4.3 cm and 2.6 cm,
15 respectively. The vigilance component required continual observation of a black square
16 in the center of the annulus which appeared to rotate 45° every 1 s. At random intervals
17 the square was replaced by a black circle of similar size (diameter 1.1 cm); upon
18 perceiving this change, the participant had to press the 'fire' button of the joystick as
19 soon as possible. A random number of 125 (± 14) such circles were presented to the
20 participant during a 30 min period. The following parameters were obtained from the
21 VTT: (i) the mean absolute distance of the center of the ball to the center of the annulus,
22 (ii) the mean reaction time to the appearance of the circular target, (iii) the number of
23 correct detections of this target (defined as a response within 2 s of its appearance), and
24 (iv) the number of false alarms (responses when the target had not appeared).

25 **Auditory vigilance test (AVT)**

26 The AVT presented the participants with a random sequence of two tones (2.5 kHz or
27 2.0 kHz) at 0.8 s intervals. At a random point in each 20 s interval, a sequence of three
28 the same tones was presented. The participants were instructed to respond to these
29 triplets as quickly as possible by pressing the spacebar on the keyboard. The following
30 parameters were obtained: (i) reaction time, (ii) the number of correct responses
31 (defined as a response within 2 s of the triplet), and (iii) the number of false alarms
32 (responses when the target had not appeared). The tones were presented via in-ear

1 phones (CX300, Sennheiser Electronic, Wedemark, Germany) which occupied little
2 space outside the ear, in order to minimize problems fitting the helmet. Each participant
3 chose the volume with which the tones were presented during the first familiarization
4 session, and this was then kept constant over the remaining sessions. The AVT software
5 was written in Matlab R2006b with use of the Psychtoolbox, version 3.0.8 (Brainard,
6 1997).

7 **Letter cancellation test (LCT)**

8 The letter cancellation test (LCT) consisted of six lines of 52 characters each, printed
9 in 10 point Courier New type in landscape orientation over the full width of a white A4
10 page, with a 1 cm margin to the left and right of the text. Each line held nine 'K' and nine
11 'N' characters, randomly placed amongst other letters chosen at random. The task was to
12 highlight all characters 'K' and 'N' using a marker, as quickly and accurately as possible.
13 The time to completion and the number of correct responses were registered.

14 **2.5. Intervention**

15 During one experimental session the participant wore a helmet, while the other
16 session served as a control condition in which the participant wore only goggles, as
17 indicated in Fig. 2. In preparation for the first familiarization session, the participant was
18 presented with the helmet size (as indicated by the manufacturer) corresponding to his
19 head circumference, which was measured according to ISO8559 (1989). In addition, the
20 participants chose the most comfortable model out of three comparable full-face
21 motorcycle helmet models. These helmets have previously been characterized for their
22 effect on heat loss (Bogerd and Brühwiler, 2008; Bogerd and Brühwiler, 2009), in those
23 two studies, these helmets were coded as 130, 201, and 250. The helmets facilitate a
24 similar heat transfer under the present wind still conditions. Furthermore, if the
25 participant judged a given helmet to be uncomfortably tight or loose, the next
26 appropriate size was used. During the sessions, the visor and vents of the helmet
27 remained closed. During CON, the participant wore clear standard safety goggles
28 (Astrospec 3000, Uvex, Fürth, Germany), in order to match the visual conditions
29 experienced when looking through a motorcycle visor. The visor and goggles were
30 cleaned before each use.

31 **2.6. Statistics and data processing**

32 The data collected during the 30 min VTT+AVT were evaluated as averages of six 5-
33 min intervals for VTT and AVT. Repeated-measures multivariate analysis of variance
34 (MANOVA) and generalized linear mixed models were employed for analyses as

1 appropriate (further details below). Perception of comfort and temperature were
2 compared using a paired t-test. Initial data processing was carried out with Matlab
3 R2006b and analyses were carried out with SPSS 20.0.

4 **3. Results**

5 Mood, sleep quality and sleep quantity were indistinguishable between conditions.
6 Generally, the cognitive parameters did not show an effect for the helmet intervention,
7 whereas most parameters showed worsening performance with increasing time.
8 Comfort was less favorable for HEL compared to CON ($t_{18} = 3.92, p = .001, d = 2.10$), with
9 mean ratings of $-1.7 (\pm 1.0)$ and $-0.8 (\pm 0.6)$, respectively. In addition, temperature was
10 perceived as warmer for HEL than CON ($t_{18} = -5.29, p < .001, d = -1.21$), with mean
11 ratings of $1.9 (\pm 0.7)$ and $1.1 (\pm 0.8)$, respectively. Additional details are given below.

12 **3.1. VTT+AVT**

13 MANOVA was carried out on the VTT data, combining the dependent variables of
14 displacement and reaction time into a single overall analysis of visuo-motor tracking
15 performance. This showed an effect of Time on performance (Wilks's $\lambda = .21, F_{10,9} = 3.44,$
16 $p = .038, \eta^2_p = .79$) but no effect of Helmet (Wilks's $\lambda = .96, F_{2,17} = 0.34, p = .719, \eta^2_p = .04$)
17 and no Time \times Helmet interaction (Wilks's $\lambda = .61, F_{10,9} = 0.58, p = .797, \eta^2_p = .39$).
18 Follow-up univariate tests of within-participants contrasts suggested a linear effect of
19 Time on displacement scores such that mean displacement tended uniformly to increase
20 with time spent on the task ($F_{1,18} = 12.72, \text{MSE} = 179.26, p = .002, \eta^2_p = .41$) and a
21 quadratic effect of Time on reaction time ($F_{1,18} = 5.75, \text{MSE} = 0.001, p = .028, \eta^2_p = .24$),
22 caused by a tendency for reaction times during the first and last 5-minute blocks to be
23 shorter than in the middle four. The VTT data are given in Fig. 3, with the exception of
24 the false alarms.

25 The AVT reaction time showed no effects of Time (Wilks's $\lambda = .77, F_{5,14} = 0.85, p =$
26 $.537, \eta^2_p = .23$) or Helmet (Wilks's $\lambda = .96, F_{1,18} = 0.81, p = .381, \eta^2_p = .04$) and no
27 interaction (Wilks's $\lambda = .69, F_{5,14} = 1.26, p = .333, \eta^2_p = .31$). Fig. 4 gives the AVT data.

28

29 *** Fig. 3 somewhere here ***

30

1

2 *** Fig. 4 somewhere here ***

3

4 The accuracy data from the two tasks were analyzed using generalized linear mixed
5 models with, as appropriate, Poisson error distributions and log link functions (for
6 count data) or binomial error distributions and logit link functions (for proportions).
7 Helmet use and Time were entered as fixed effects and a random effect term coded
8 which scores were contributed by individual participants. The proportion of correct
9 responses on VTT showed an effect of Time ($F_{5,216} = 11.47, p < .001$) but no effect of
10 Helmet ($F_{1,216} = 2.97, p = .086$) and no Time \times Helmet interaction ($F_{5,216} = 0.99, p = .422$).
11 The Time effect was caused by a general decline in performance across the 6 5-min time
12 blocks. Similar effects were seen for the VTT false alarms, in which the number of false
13 alarms tended to increase across the Time blocks ($F_{5,216} = 7.22, p < .001$) but showed no
14 relationship to Helmet ($F_{1,216} = 1.90, p = .169$) and no interaction ($F_{5,216} = 0.38, p = .866$).
15 The proportion of correct responses on AVT similarly showed a Time effect ($F_{5,216} = 3.59,$
16 $p = .004$), although only the first 5-min block differed from the last ($p = .035$), suggesting
17 the effect of Time on this measure is small. There was also a significant effect of Helmet
18 on the proportion of correct responses ($F_{1,216} = 4.64, p = .032$), but this too appears to be
19 a minor effect, as a post-hoc contrast showed no difference ($p = .229$). The Time \times
20 Helmet interaction was not significant ($F_{5,216} = 1.29, p = .271$). Finally, the AVT false
21 alarm count showed an effect of Time ($F_{5,216} = 4.83, p < .001$) but no effect of Helmet
22 ($F_{1,216} = 1.30, p = .255$) and no interaction ($F_{5,216} = 1.84, p = .106$). For reasons that are
23 not entirely clear, the Time effect in these data was carried by a higher number of false
24 alarms in the second five-minute block than in the rest; other than this false alarm rates
25 were comparable in each 5-min block.

26 3.2. LCT

27 MANOVA indicated that the combined time to completion and correct responses
28 showed an effect of Time (Wilks's $\lambda = .70, F_{2,17} = 3.72, p = .046, \eta^2_p = .30$), but no effect of
29 Helmet (Wilks's $\lambda = .89, F_{2,17} = 1.09, p = .358, \eta^2_p = .11$) and no Time \times Helmet interaction
30 (Wilks's $\lambda = .80, F_{2,17} = 2.20, p = .142, \eta^2_p = .21$). Follow-up univariate tests of within-
31 participants contrasts suggested a linear effect of Time on the time to completion,
32 indicating shorter time to completion following the VTT+AVT procedure than before
33 ($F_{1,18} = 12.72, MSE = 129.37, p = .013, \eta^2_p = .30$). Fig. 5 shows all the LCT data.

1

2 *** Fig. 5 somewhere here ***

3

4 **4. Discussion**

5 This study attempted to resolve earlier mixed findings about the cognitive
6 performance effects of wearing a helmet by using the most enclosed type of real-world
7 helmet available and by making the cognitive tasks substantially demanding. These
8 manipulations were intended to magnify any effects of wearing a helmet and so make
9 them more visible. Under these harsh but realistic conditions the results suggest there is
10 no substantial effect of a helmet on cognitive performance, even though subjectively
11 participants found the helmet warm and uncomfortable.

12 Most of the cognitive parameters that were measured indicated a reduction in
13 attentional capacity over time. Such time effects are typical (Grier et al., 2003; Taylor et
14 al., 2008) and are the motivation behind recommendations that people should not
15 attempt prolonged periods of cognitively demanding work in safety-critical situations.
16 Such time effects are likely caused by a reduction in attention capacity (Grier et al.,
17 2003; Hancock and Warm, 1989). An implication the presence of these time effects is
18 that the cognitive tests and the protocol employed in the present study were sufficiently
19 sensitive to changes in the participants' internal states. In addition, this suggests a
20 meaning full level of sensitivity on cognitive performance, also if they would be caused
21 by helmet-wearing.

22 A potential drawback of cognitive examinations in which a participant carries out
23 more than one task is the possibility of shifts in attention from one task to the other. To
24 evaluate attention shifts between VTT and AVT, for each 5-min block a single value was
25 calculated for each test. This was achieved as follows: First, the 30-min mean was
26 subtracted from each 5-min interval for each participant; second, the sign was corrected
27 for each parameter so that negative values represented worse performance relative to
28 the 30-min average, and vice versa; third, these differences were divided by the SD
29 obtained from the entire 30-min interval; finally, the mean was taken from these
30 normalized differences for all participants and parameters. For both VTT and AVT,
31 Pearson's correlations were calculated between these new measures for each

1 participant, after applying linear detrending. If participants had switched attention from
2 one task to another there should be negative correlations in these data. This analysis
3 gave $r = .21 (\pm .26)$, with a nonsignificant correlation in 17 out of 19 participants.
4 Therefore, the fluctuations in VTT are in general not related to fluctuations in AVT,
5 suggesting attention shifts did cause increased variance in the VTT and AVT data. The
6 lack of substantial correlations in these data also suggests that VTT and AVT consume a
7 different attention capacity, a common finding in the cognitive literature (Brooks, 1968;
8 Hirst and Kalmar, 1987).

9 The present results are in line with two previous studies, which did not find an effect
10 of passive headgear on cognitive performance (Hancock, 1983; Holt and Brainard,
11 1976). The former study used a simple arithmetic addition task, whereas the latter used
12 a simple reaction time task. In contrast, the two other studies mentioned in the
13 Introduction reported at least one measured cognitive parameter being affected by
14 wearing a helmet (Hancock and Dirkin, 1982; Neave et al., 2004). Hancock and Dirkin
15 (1982) used a central and peripheral visual choice reaction time, whereas Neave et al.
16 (2004) used an extensive proprietary cognitive test battery. This pattern of findings
17 across the four earlier studies could suggest that any effect of wearing a helmet is
18 sufficiently subtle that it can only be seen when people's cognitive resources are highly
19 taxed.

20 The question, then, is why the present study, which arguably taxed participants more
21 than in any previous study, found no real effect of helmet-wearing on cognitive
22 performance. The four earlier studies all used a similar type of helmet, which was more
23 open than the full-face, visored helmet used in the present study. However, it is not clear
24 why this should lead to less interference in this study than the previous studies. Neave
25 et al. (2004) used a notably different population to all the other studies (youths, with a
26 mean age of 14.3 ± 4.0 years), and had their participants undertake 30 min of physical
27 exercise, which both make their study stand out from the rest. But whilst these
28 differences could plausibly explain Neave et al. (2004) showing different results to the
29 present study, it cannot explain why Hancock and Dirkin (1982) found an effect of
30 helmet-wearing when this study did not.

31 Most plausibly, the explanation for the overall pattern of results across these studies
32 and the present study lies in helmet-wearing having a marginal effect on cognitive
33 performance. Hancock and Dirkin (1982) measured a total of eight parameters but only
34 report an effect of helmet-wearing on one. Neave et al. (2004) only found a helmet effect

1 after their individual cognitive performance parameters were combined into composite
2 measures. Their individual cognitive parameters did not show significant effects of
3 helmet-wearing (Neave, 2008, personal communication). The present study found an
4 effect of wearing a helmet on one out of a total of nine cognitive parameters, and even
5 then, this parameter did not remain significant in a post-hoc test. Thus, it appears that if
6 a helmet does cause an impairment of cognitive performance, such effects are small, and
7 undetectable under well-controlled laboratory conditions. It is unlikely that such
8 marginal effects, if any really exist, will have real-world implications for safety. Small
9 effects, of the type we are suggesting here, are difficult to measure, and increase the risk
10 of a Type 2 error. Therefore, a power analysis was carried out to verify the sensitivity of
11 the present study in detecting small effects. The effect size for each of the cognitive
12 parameters was calculated using G*Power 3.1.2 using: $\alpha = .05$, $\beta = .20$, $N = 19$. All other
13 necessary inputs were directly derived from the data collected. The approach was to
14 quantify, for each cognitive parameter measured in this study, the smallest effect size
15 that our procedure and participant pool could detect. This analysis showed that, on
16 average, we had sufficient power to detect effect sizes of $r^2 = .03 (\pm .02)$ or above. In the
17 worst case, for the reaction time on the AVT, the present design has sufficient power to
18 detect an effect size of $r^2 = .06$ or above. Thus, the present study was able to measure
19 small effects (by the criteria of Cohen, 1988) on cognitive performance had any existed.

20 **5. Conclusions**

21 The present study assessed the effect of wearing a full-face helmet on cognitive
22 performance under realistic but demanding conditions. One out of nine cognitive
23 parameters showed a significant effect, and this effect was marginal, disappearing in a
24 post-hoc comparison. These results, together with previous studies, suggest that
25 although people find wearing helmets in warm conditions subjectively uncomfortable, if
26 wearing a helmet does impair cognitive performance, the effect is at worst marginal.

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29 **8. Figure captions**

30 Fig. 1. The setup with a participant carrying out the simultaneous visual vigilance and
31 tracking test (VTT) and auditory vigilance test (AVT). The helmet shown here was
32 not used in the study.

33 Fig. 2. The protocol and interventions in an experimental session. VTT: vigilance and
34 tracking test, AVT: auditory vigilance test, and LCT: letter cancellation test.

35 Fig. 3. The results for the vigilance and tracking test (VTT) parameters (a) displacement,
36 (b) response time, and (c) correct responses. The data is represented as averages of
37 5 min intervals, the error-bars indicate the SEM.

38 Fig. 4. The results for the auditory vigilance test (AVT) parameters (a) response time, (b)
39 correct responses, and (c) false alarms. The data is represented as averages of 5 min
40 intervals, the error-bars indicate the SEM.

41 Fig. 5. The results for the letter cancellation test (LCT) parameters (a) time to

1 completion, and (b) correct responses. The LCT was carried out before and
2 following the VTT+AVT (Fig. 2), the error-bars indicate the SEM.

Figure 1
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Figure 2

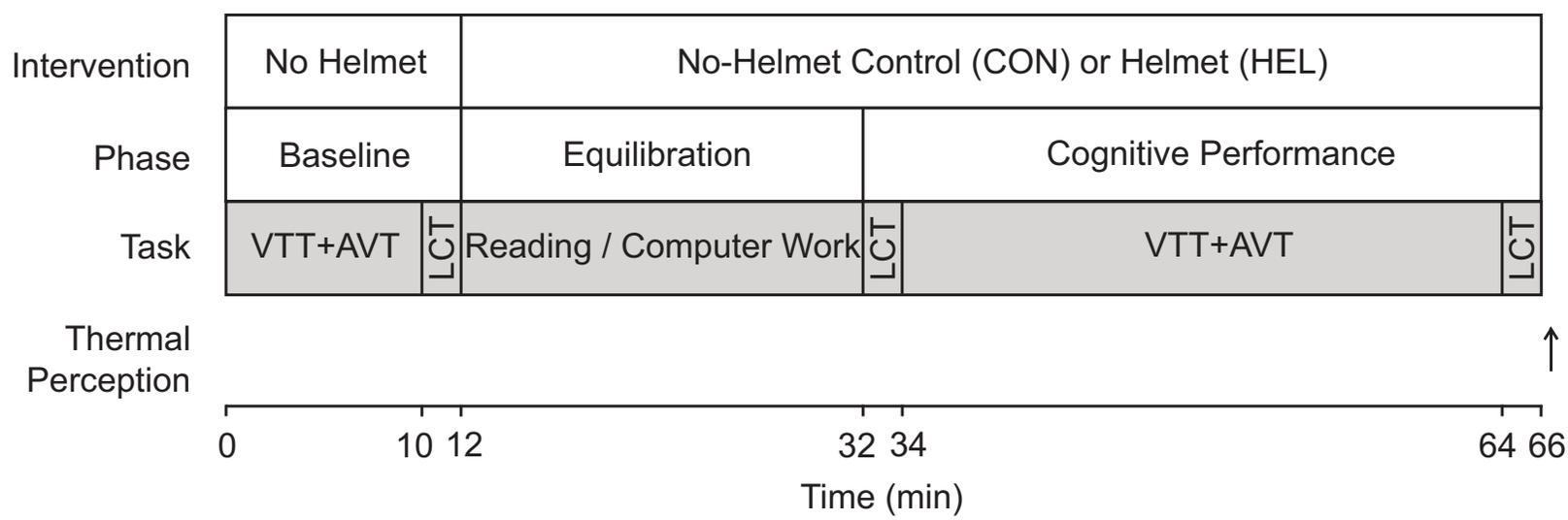


Figure 3
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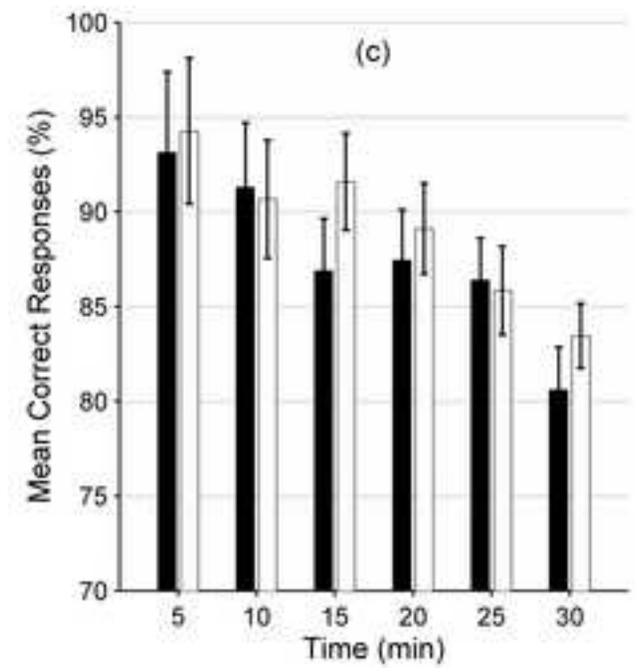
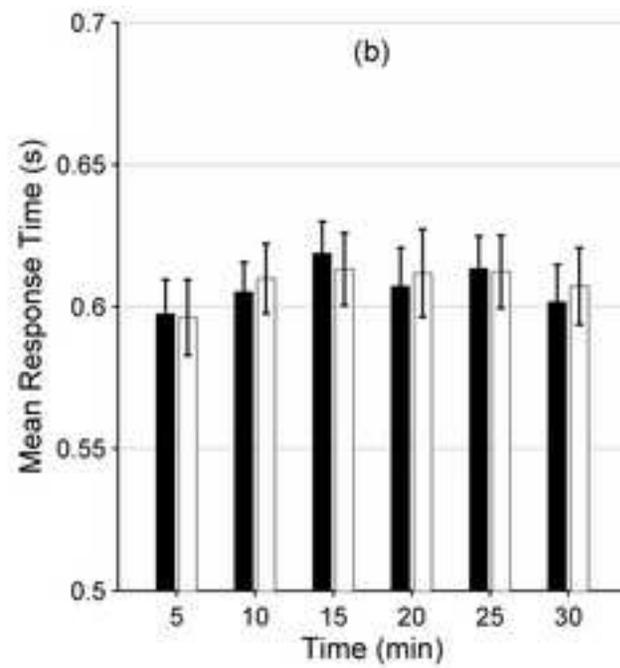
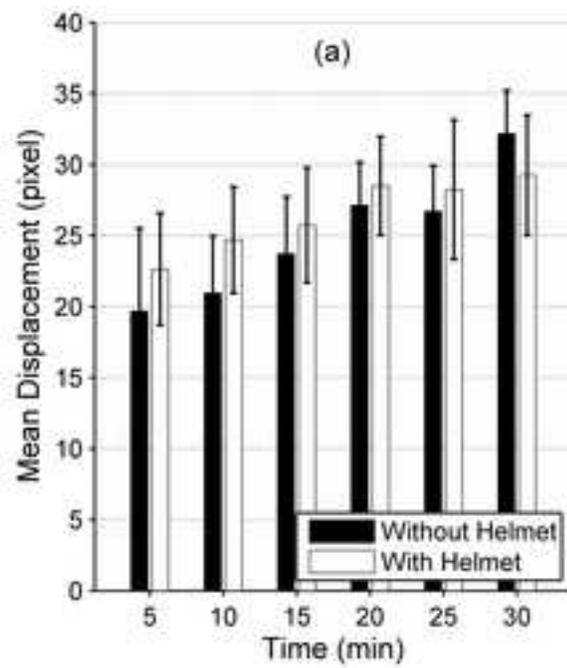


Figure 4
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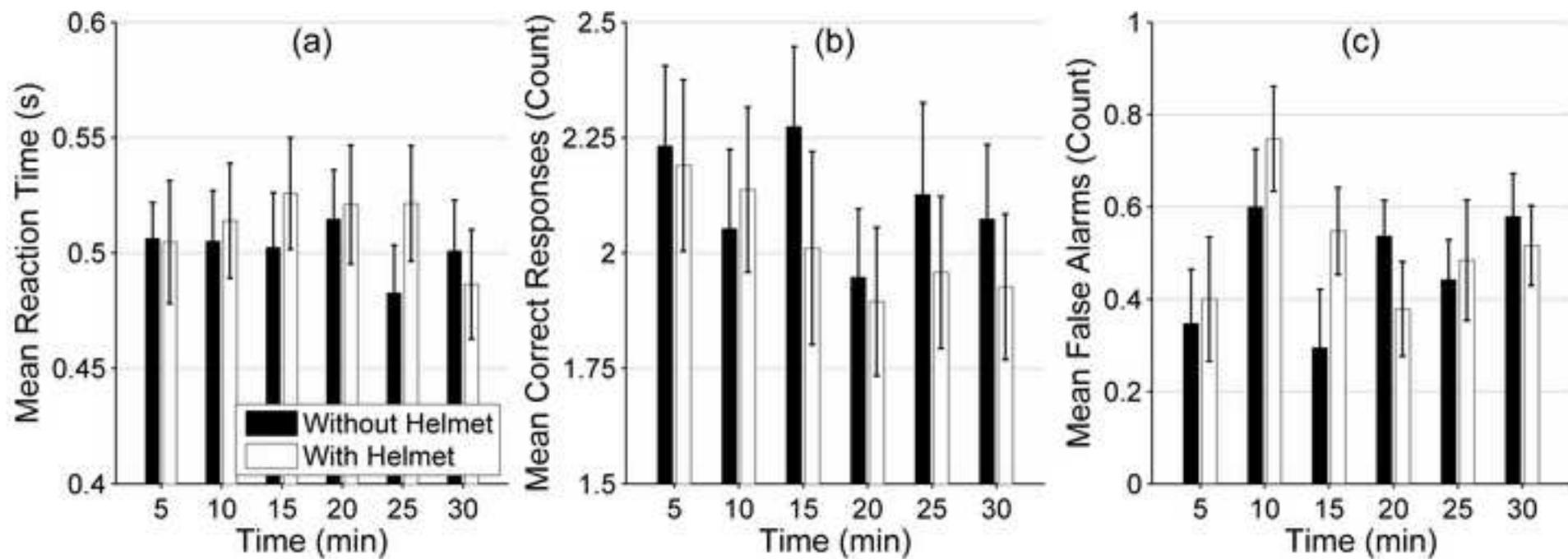


Figure 5
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