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Motor Variability and Skills Monitoring in Sports

DYSON AWARDS


KEYNOTE LECTURES


APPLIED SESSION
★ (2009). Data analysis techniques. XXVII ISBS. Limerick, Ireland
Motor Variability and Skills Monitoring in Sports

E. PREATONI

SPORTS BIOMECHANICS

KEYWORDS

SKILLS MONITORING

MOVEMENT VARIABILITY (MV)

SPORTS BIOMECHANICS

- distinctive peculiarities, need for specific approach

CLINICS
- “turning a pathological state into a physiological one”
- average behaviour

SPORTS
- no "average subject"
- exalting individual potentialities (performance & technique)
- maximal biomechanical demands
- granting wellness & preventing injuries
- details may be fundamental
Motor Variability and Skills Monitoring in Sports

SKILLS MONITORING

MOTOR SKILL

The ability of obtaining the desired goal with a high degree of certainty and maximum proficiency. 


MAIN ISSUES

★ ROBUST DESCRIPTION (variability, exp. design, data reduction, …)

[Preatoni, 2007; Preatoni et al., in press]
SKILLS MONITORING

MOTOR SKILL

The ability of obtaining the desired goal with a high degree of certainty and maximum proficiency.


MAIN ISSUES
★ ROBUST DESCRIPTION (variability, exp. design, data reduction, …)
★ REFERENCE DEFINITION (data evaluation: population, skill level, individual)
★ SUITABLE AIDS FOR TRAINING (“translation”) [Preatoni, 2007; Preatoni et al., in press]

MOVEMENT VARIABILITY (MV)

Variability is pervasive throughout the multiple levels of movement organization and occurs not only between but also within individuals

[Bartlett, 1997; Bartlett et al., 2007; Bates et al., 2004; Hatze, 1986; James, 2004; Newell et al., 2006; + many others]

ISSUES
1. HOW MUCH? HOW TO DEAL WITH?
2. WHY? WHAT IS IT? WHERE DOES IT COME FROM?
3. WHAT MAY IT MEAN? WHAT MAY IT BE RELATED TO?
**RACE WALKING (RW)**

**DEFINITION** (IAAF Handbook, Section 7, rule 230):

"RACE WALKING is a progression of steps so taken that the walker makes contact with the ground, so that no visible (to the human eye) loss of contact occurs.

The advancing leg shall be straightened (i.e. not bent at the knee) from the moment of first contact with the ground until the vertical upright position."

**WHY RW?**

- SPECIFIC BIOMECHANICAL and COORDINATIVE DEMANDS
- HIGHLY TECHNICAL MOTOR TASK
- APPARENTLY STEREOTYPED
- MOST SIMILAR TO NORMAL WALKING

---

**EXPERIMENTAL SETTINGS**

**POPULATION:**

- 7 (INTER)NATIONAL RACE WALKERS
  - (4M + 3F: 19.7±2.1 y; 1.75±0.10 m; 58.3±8.3 kg)
  - PB over 10 Km: 40'56" - 48'34"
    - 3.77±0.24 m/s

**INSTRUMENTATION & EXPERIMENTAL DESIGN:**

- 8 TVC optoelectronic sys. (ELITE – 100 Hz)
- FORCE platform (AMTI – 500 Hz)
- SAFLo marker set
- 20 suitable trials (for each subject’s side)
  - @ self-selected training pace
- controls (trainer, velocity, GRFap)
- focus on kinematic/kinetic variables of lower limbs and pelvis
RW BIOMECH CHARACTERISATION

KNEE FLEX/EXT

○ FLEX. in RW

NO KNEE FLEX in RW!

PELVIC ROTATIONS

○ STEP LENGTH

FRONTAL PLANE

○ OBLIQUITY

HORIZONTAL PLANE

○ ROTATION in RW

[Murray et al., 1983; Cairns et al., 1986; Preatoni, 2007]

QUANTIFICATION OF MV

1 HOW MUCH? HOW TO DEAL WITH?

2 WHY? WHAT IS IT? WHERE DOES IT COME FROM?

3 WHAT MAY IT MEAN? WHAT MAY IT BE RELATED TO?
PARAMETER VARIABILITY

<table>
<thead>
<tr>
<th>&quot;global&quot; variables</th>
<th>Kinematic/kinetic/technique variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>subj</td>
<td>$\Delta t$</td>
</tr>
<tr>
<td>s1(L)</td>
<td>4.8%</td>
</tr>
<tr>
<td>s1(R)</td>
<td>7.0%</td>
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<tr>
<td>s2(L)</td>
<td>2.0%</td>
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<td>...</td>
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<tr>
<td>med</td>
<td>3.0%</td>
</tr>
<tr>
<td>95th %ile</td>
<td>6.5%</td>
</tr>
</tbody>
</table>

★ intra-individual CV distributions

★ 70 parameters, 20 trials/side/subject, 22 samples

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RW globally repeatable... but...

★ … only 36/70 parameters had CV$_{med}$ < 10%

★ … as many as 59/70 parameters had CV$_{95\%}$ > 10%

★ … a few subject manifest very poor repeatability

[Preatoni, 2007; Preatoni et al., in press]
### PARAMETER VARIABILITY

#### "global" variables

<table>
<thead>
<tr>
<th>subj</th>
<th>( \Delta t )</th>
<th>( v_x )</th>
<th>( \Delta x )</th>
<th>( R_{v\text{-MAX}} )</th>
<th>( v_{\text{MAX}} )</th>
<th>( m_{\text{MAX}} )</th>
<th>( \Delta z_{\text{COM}} )</th>
</tr>
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<tbody>
<tr>
<td>s1(L)</td>
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<td>s1(R)</td>
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<td>2.4%</td>
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★ RW globally repeatable... but...

★ ... only 36/70 parameters had \( CV_{\text{med}} < 10\% \)

★ ... as many as 59/70 parameters had \( CV_{\text{95th \%ile}} > 10\% \)

★ ... a few subject manifest very poor repeatability

[Preatoni, 2007; Preatoni et al., in press]
PARAMETER VARIABILITY

"global" variables | kinematic/kinetic/technique variables

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★ RW globally repeatable... but...
★ ... only 36/70 parameters had $CV_{med} < 10\%$
★ ... as many as 59/70 parameters had $CV_{95\%} > 10\%$
★ ... a few subject manifest very poor repeatability

[Hamill & McNiven, 1990; Rodano & Squadrone, 2002]

PARAMETER STABILITY

★ sequential estimation procedure
★ 70 parameters, 20 trials/side/subject, 22 samples

<table>
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<tr>
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<tr>
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<td>4</td>
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<tr>
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<td>9</td>
<td>11</td>
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<tr>
<td>med</td>
<td>11</td>
<td>9</td>
<td>8.5</td>
<td>8.5</td>
<td>...</td>
</tr>
<tr>
<td>95th %ile</td>
<td>14.7</td>
<td>14</td>
<td>15</td>
<td>11</td>
<td>...</td>
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### Motor Variability and Skills Monitoring in Sports

#### PARAMETER STABILITY

<table>
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<tr>
<th>subj</th>
<th>Δt</th>
<th>ω</th>
<th>Δx</th>
<th>$A_{\text{μ-ROM}}$</th>
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<tr>
<td>s1(R)</td>
<td>4</td>
<td>12</td>
<td>7</td>
<td>4</td>
<td>...</td>
</tr>
</tbody>
</table>
| s2(L) | 13 | 9  | 11 | 11               | ...
| ... | ... | ... | ... | ... | ...|
| med  | 11 | 9  | 8.5| 8.5              | ...
| 95th %ile | 14.7 | 14 | 15 | 11               | ...|

<table>
<thead>
<tr>
<th>med_{tot}</th>
<th>min_{tot}</th>
<th>max_{tot}</th>
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<td>8.0</td>
<td>5.5</td>
<td>11.0</td>
</tr>
<tr>
<td>14.0</td>
<td>10.5</td>
<td>16.4</td>
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</table>

★ need for a “proper” number of trials

★ #t_{min} is task-, population/subject- and parameter-dependent

★ #t_{min} \geq 11 (with med) or #t_{min} \geq 16 (with max)

★ sensitivity to stability band definition?

★ what about curve variability and stability?

[Preatoni, 2007; Preatoni et al., in press]
ROBUSTNESS OF ESTIMATORS

★ intra/inter-individual parameter distributions often not Gaussian
★ 70 parameters, 20 trials/side/subject, 22 samples

<table>
<thead>
<tr>
<th>CONSISTENCY TO OUTLIERS</th>
<th>med</th>
<th>µ</th>
<th>σ</th>
<th>CV</th>
<th>IQR</th>
<th>MAD</th>
</tr>
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<tbody>
<tr>
<td>µ</td>
<td></td>
<td></td>
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<tr>
<td>med</td>
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</table>

CENTRAL TENDENCY

<table>
<thead>
<tr>
<th>% ROBUST</th>
<th>µ</th>
<th>med</th>
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<tbody>
<tr>
<td></td>
<td>87%</td>
<td>94%</td>
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</table>

SPREAD

<table>
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<tr>
<th>% ROBUST</th>
<th>σ</th>
<th>CV</th>
<th>IQR</th>
<th>MAD</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>11%</td>
<td>11%</td>
<td>41%</td>
<td>39%</td>
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</table>

★ non-parametric estimators are more robustly descriptive
★ outliers elimination may be advisable

[Chau et al., 2005; Preatoni, 2007; Preatoni et al., in press]

MEANING OF MV

1. HOW MUCH? HOW TO DEAL WITH?

2. WHY? WHAT IS IT? WHERE DOES IT COME FROM?

3. WHAT MAY IT MEAN? WHAT MAY IT BE RELATED TO?
**DUAL NATURE OF MV**

\[ MV_{\text{tot}} \]

\[ MV_{\varepsilon} \]

(noise)

\[ MV_{\varepsilon B} \]

(bio.)

\[ MV_{\varepsilon M} \]

(meas.)

\[ MV_{\varepsilon E} \]

(env.)

\[ MV_{\varepsilon m} \]

(n-m-s intrinsic dynamics)

\[ MV_{\varepsilon S} \]

(skill)

\[ MV_{\varepsilon P} \]

(pathol.)

\[ \ldots \]

\[ \ldots \]

★ **MV is not (only) noise, it may be functional!**

[Bartlett et al., 2007; Chau et al., 2005; Hamill et al., 2005; James, 2004; Newell et al., 2006; Riley & Turvey, 2002]

★ conventional methods are not enough for evaluating MV
**SAMPLE ENTROPY (SampEn)**

$$\text{SampEn}(m; r) = \ln \left( \frac{C_m(r)}{C_{m+1}(r)} \right)$$

* e.g.: $C_m$ \((m=3\text{ length of sequence})\)
  \((r=\text{preset tolerance})\)

- SampEn measures the t-series REGULARITY [Richman & Moorman, 2000]
- regularity has some relations with the complexity of the system generating the signal [Pincus, 1995]

SampEn = 0
- \(\nabla\) regularity, \(\nabla\) predictability
- indicates loss of system complexity
- may be a sign of anomalies
  (e.g. cardiovascular - Richman & Moorman, 2000)
- \(\nabla\) regularity, \(\nabla\) predictability
- indicates random behaviour
INFORMATIVE MV vs. NOISY MV

- Extraction of stance phase
- NO time normalisation!

- t-series: continuous sequence of RW stance phases
- Entropy estimation (for each subj, var and side)

SampEn$_{\text{ORIG}}$ = 0.235
$m=1$, $r=0.1$

SampEn$_{\text{SURR}}$ = 0.476
$m=1$, $r=0.1$

PPS: Pseudo Periodic Surrogate
[Smeal et al., 2001]
- Destroys nonlinear structure
- Preserves periodic features

MV$_\text{tot}$

MV$_\epsilon$ (noise)

MV$_m$ (n-m-s intrinsic dynamics)

SampEn$_{\text{ORIG}}$ < SampEn$_{\text{SURR}}$
**INFORMATIVE MV vs. NOISY MV**

- Low \(SampEn\) values for every considered variable (\(\rightarrow\) RW very stereotyped!!)
- \(SampEn\text{\_}\text{ORIG}\) significantly lower than \(SampEn\text{\_}\text{SURR}\) (\(\Delta = 16\% – 59\%\))
- MV may be functionally related to the n-m-s system organisation
- Increased regularity @ hip and ankle compared with knee
- Increased control to compensate unnatural knee flex-extension in RW

\[\text{P always < .002} \]
\[\text{Cohen’s d always > .80} \]

**ADAPTATION & PROTOCOL VALIDITY**

- No changes of regularity throughout the testing session
- Likely no adaptation across trials
- Racewalkers acquainted with the testing procedures from the beginning
- Validity of the experimental design

\[\text{[Preatoni, 2007; Preatoni et al., in press]} \]
MV & COORDINATION: DST APPROACH

★ MV may be functional… …but how?

MOTOR COORDINATION

“[…] the problem of mastering the very many degrees of freedom involved in a particular movement […]”  [Bernstein, 1967; Turvey, 1990]

“[…] the process by which the degrees of freedom are organized in time and in sequence to produce a functional movement pattern.”  [Stergiou et al., 2001]

“[…] the functional link between the muscles and joints used to produce the desired performance or outcome.”  [Payton & Bartlett, 2008]

DYNAMIC SYSTEMS THEORY (DST) APPROACH

★ limbs as systems of coupled pendulums

★ observation of Continuous Relative Phase (CRP)

★ variability in phase relationships

FUNCTIONAL PHASES OF RW

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FUNCTIONAL PHASES OF RW

- \( \theta_k \) [deg]
- t [%]

- \( \theta_1 \): TO
- \( \theta_2 \): HS
- \( \theta_3 \): V
- \( \theta_4 \): U

- HS to V (STANCE)
- V to U (STANCE)
FUNCTIONAL PHASES OF RW

DST: PHASE PLOTS
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DST: CRP

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\[ \text{CRP}(t) = \Theta_{hk}(t) = \phi_h(t) - \phi_k(t) \]
Mean Absolute Relative Phase (MARP)

\[ \text{MARP}_{hk} = \frac{\sum_{r=1}^{100} |\theta_{hk}|}{100} \Rightarrow \text{“tuning”} \]

Deviation Phase (DP)

\[ \text{DP}_{hk} = \frac{\sum_{r=1}^{100} |\tau_{hk}|}{100} \Rightarrow \text{variability} \Rightarrow \text{“coordinative stability”} \]
DST: CRP MEASURES

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MARP $= 66.28$

DP $= 5.42$

MARP $= 100.8$

DP $= 8.70$
DST: CRP MEASURES

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DST: CRP MEASURES

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PHASING VARIABILITY IN RW: DP

P < .001 (Friedman)

★ increased variability @ load acceptance...
...flexibility to overcome perturbations (impact+ext.knee) & redistribute load
PHASING VARIABILITY IN RW: DP

★ DP_{hk} ↑ at transitions through V

PHASING VARIABILITY IN RW: DP

★ DP_{ka} ↑ between U and TO
1. **HOW MUCH? HOW TO DEAL WITH?**

2. **WHY? WHAT IS IT? WHERE DOES IT COME FROM?**

3. **WHAT MAY IT MEAN? WHAT MAY IT BE RELATED TO?**

---

**SKILL LEVEL and SampEn**

- **POPULATION [7]**
  - LESS SKILLED (national rank) [4]
  - MORE SKILLED (Europe elite) [3]

- **P always < .02**
- **Cohen’s d always > 1.40**

- **both MS and LS possessed mastery of the movement and...**
- ...traditional analysis failed in discriminating

- **SampEn @ ankle and hip significantly lower in LS**

- **LS need to add further control to compensate the locked knee**

- **MS have a less rigid control over the body’s degrees of freedom**

- **confirmation by knee behaviour**

[Preatoni, 2007; Preatoni et al., in press]
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## t-CHANGES and SampEn

- No changes in speed and s-t parameters but...
- Changes in SampEn → regularity
- Changes in motor organisation (kinematics) rather than in global output

## INJURY MONITORING and MV

- Clinically recovered
- No changes in competitive results
- No evident changes in speed, s-t parameters and conventional measures

<table>
<thead>
<tr>
<th>par</th>
<th>PRE</th>
<th>POST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Δt [s]</td>
<td>0.33 (0.01)</td>
<td>0.32 (0.01)</td>
</tr>
<tr>
<td>v_x [m/s]</td>
<td>2.83 (0.09)</td>
<td>2.83 (0.09)</td>
</tr>
<tr>
<td>Δx [mm]</td>
<td>963.03 (26.54)</td>
<td>956.41 (35.58)</td>
</tr>
<tr>
<td>R_{AP,MAX} [N/kg]</td>
<td>1.38 (0.16)</td>
<td>1.21 (0.42)</td>
</tr>
<tr>
<td>R_{AP,MIN} [N/kg]</td>
<td>-3.70 (0.19)</td>
<td>-3.69 (1.07)</td>
</tr>
<tr>
<td>R_{AP,MAX} [N/kg]</td>
<td>17.22 (0.73)</td>
<td>18.13 (1.07)</td>
</tr>
</tbody>
</table>
but...

MARCH
TESTING SESSION

INJURED SUBJECT
(from group)

SEPTEMBER
TESTING SESSION

★ ≠ levels of entropy from the control group
★ changes in regularity ≠ from the control group
★ asymmetries

 phase plots

PRE

POST
INJURY MONITORING and DST

★ hip – knee coupling

PRE

POST

★ smoother coupling in POST

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★ changes in coupling variability about transition phases

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FEED-BACK

Multifactorial Motion Analysis

- Athlete
- Status Definition
- Trainer (Physician...)
- Reference Definition

(Biomechanics)

Neuroscience

ICT

Motor Learning/Adaptation

Psychology

How can we return complex information??
★ from complex biomechanics to practical tools
★ “translation” efforts
★ must not be intended as in control theory
★ not too much info, not too complex, not too fast
CONCLUSION and PERSPECTIVES

☆ DUAL NATURE OF VARIABILITY
  - MV AS NOISE → NEED FOR FINDING THE ATHLETE'S SIGNATURE
  - MV AS INFO → NEED FOR UNDERSTANDING UNDERLYING FACTORS

☆ NEED FOR PROPER EXPERIMENTAL DESIGNS AND DATA ANALYSES TECHNIQUES

☆ POTENTIALITIES OF “INNOVATIVE METHODS”

✪ NEED FOR REFERENCE DATABASES AND STANDARDS

✪ NEED FOR FINDING RELATIONS BETWEEN CAUSES AND EFFECTS
  - INJURY PREVENTION
  - PERFORMANCE PREDICTION

✪ NEED FOR PROPER FEEDBACK TO COACHES, ATHLETES, …
Motor Variability and Skills Monitoring in Sports

GUIDELINES

- ROBUST DESCRIPTION
- REFERENCE DEFINITION
- QUANTITATIVE AIDS

MY SPECIAL THANKS TO...

★ prof. R. RODANO
★ prof. J. HAMILL
★ dr. M. FERRARIO
★ dr. G. DONA'
★ students…
Grazie per l’attenzione !!!
Thanks for your attention !!!

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