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XXVIII International Conference on

Biomechanics in Sports

ISBS MARQUETTE • 2010

POLITECNICO DI MILANO

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MOTOR VARIABILITY and SKILLS MONITORING in SPORTS

MV and ISBS

DYSON AWARDS

★ Bartlett, R. (2005). *Future trends in sports biomechanics – reducing injury risk or improving performance? XXIII ISBS. Beijing, China.*

★ Hamill, J. et al. (2006). *Overuse injuries in running: do complex analysis help our understanding? XXIV ISBS. Salzburg, Austria.*

KEYNOTE LECTURES

★ Bartlett, R. (2004). *Is movement variability important for sports biomechanics? XXII ISBS. Ottawa, Canada. .*

★ Hamill, J. et al. (2005). *Using coordination measures for movement analysis. XXIII ISBS. Beijing, China.*

★ Wilson, C. (2009). *Approaches for optimising jumping performance. XXVII ISBS. Limerick, Ireland.*

APPLIED SESSION

★ (2009). *Data analysis techniques. XXVII ISBS. Limerick, Ireland*

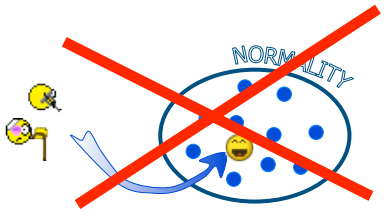
KEYWORDS

SPORTS BIOMECHANICS

SKILLS MONITORING ⟷ MOVEMENT VARIABILITY (MV)

SPORTS BIOMECHANICS

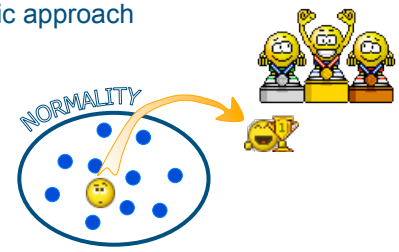
★ distinctive peculiarities, need for specific approach



CLINICS

★ "turning a pathological state into a physiological one"

★ average behaviour



SPORTS

★ no "average subject"

★ exalting individual potentialities (performance & technique)

★ maximal biomechanical demands

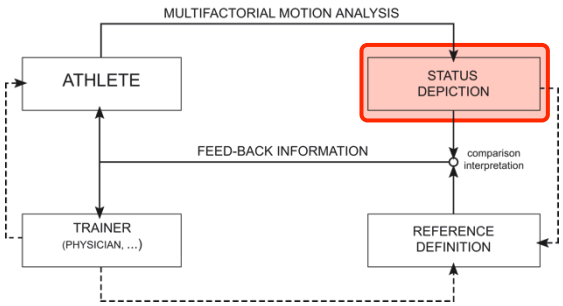
★ granting wellness & preventing injuries

★ details may be fundamental

SKILLS MONITORING

MOTOR SKILL

The ability of obtaining the desired goal with a high degree of certainty and maximum proficiency. *[Schmidt & Lee, 2004; Newell K.M. and Ranganathan R., 2009]*



MAIN ISSUES

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

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

Motor Variability and Skills Monitoring in Sports

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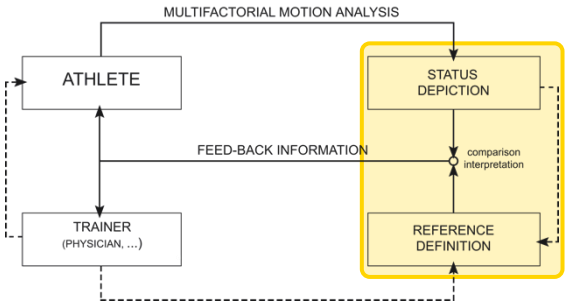

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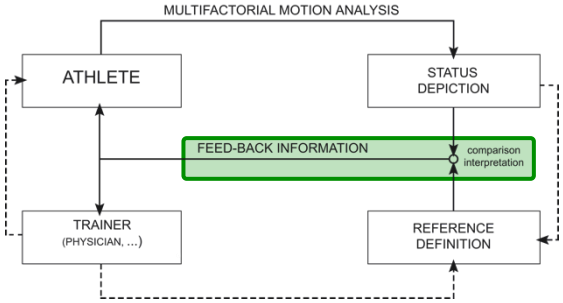
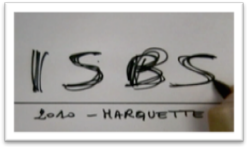


MAIN ISSUES

- ★ 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

❶ HOW MUCH? HOW TO DEAL WITH?

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

❸ WHAT MAY IT MEAN? WHAT MAY IT BE RELATED TO?

RACE WALKING (RW)

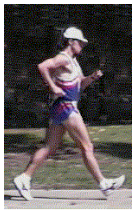
DEFINITION *(IAAF Handbook, Section 7, rule 230)*:

"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 contact❶ occurs.

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

WALKING

v > ~2.5 m/s



RUNNING

★ NO DOUBLE SUPPORT
★ "INBORN"

RACE WALKING

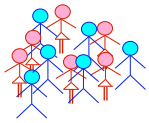
❶ NO FLIGHT PHASE
❷ NO KNEE FLEXION (supporting leg)
❸ "FORCED"

WHY RW?

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

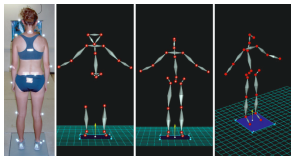
EXPERIMENTAL SETTINGS

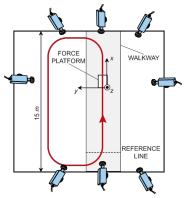
POPULATION:

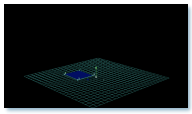


★ 7 (INTER)NATIONAL RACE WALKERS
(4M + 3F: 19.7±2.1 y; 1.75±0.10 m; 58.3±8.3 kg)
★ PB over 10 Km: 40'56" ÷ 48'34"
(→ 3.77±0.24 m/s)

INSTRUMENTATION & EXPERIMENTAL DESIGN



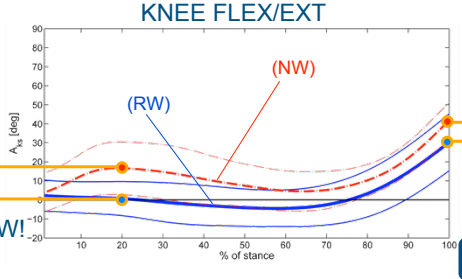




★ 8 TVC optoelectronic sys. *(ELITE – 100 Hz)*
★ FORCE platform *(AMTI – 500 Hz)*
★ SAFLo marker set
★ 20 suitable trials (for each subject's side) @ self-selected training pace
★ controls (trainer, velocity, GRF_{ap})
★ focus on kinematic/kinetic variables of lower limbs and pelvis

RW BIOMECH CHARACTERISATION

KNEE FLEX/EXT

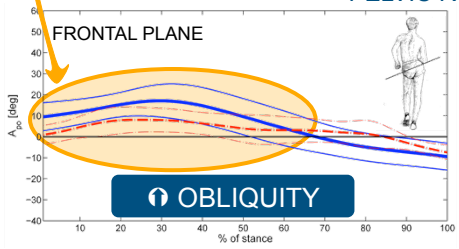


FLEX. in RW

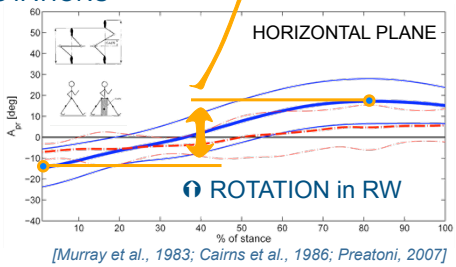
NO KNEE FLEX in RW!

STEP LENGTH

PELVIC ROTATIONS



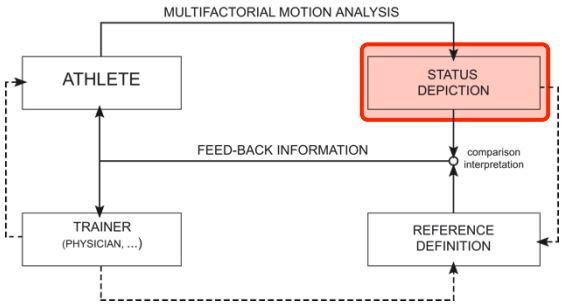
OBLIQUITY



ROTATION in RW

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

QUANTIFICATION OF MV



❶ HOW MUCH? HOW TO DEAL WITH?

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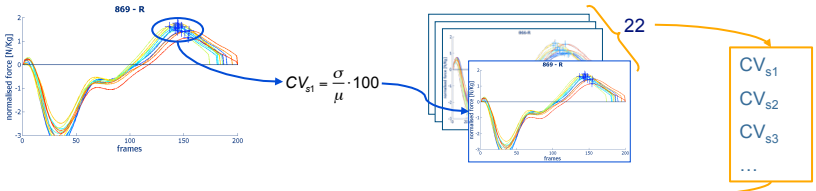
PARAMETER VARIABILITY



	"global" variables					kinematic/kinetic/technique variables			
subj	***Δt***	***v_x***	***Δx***	***$R_{v\text{-}MAX}$***	***…***	***$A_{ks}ROM$***	***$t@R_{v\text{-}MAX}$***	***$M_{ks\text{-}MAX}$***	***Δz_{COM}***
s1(L)	4.8%	2.1%	4.1%	3.4%	…	18.9%	7.7%	35.7%	26.1%
s1(R)	7.0%	2.4%	6.6%	2.5%	…	29.4%	16.7%	41.6%	17.6%
s2(L)	2.0%	1.9%	1.4%	2.3%	…	5.4%	6.7%	18.4%	9.9%
…	…	…	…	…	…	…	…	…	…
med	3.0%	2.6%	2.4%	3.3%	**…**	10.5%	6.1%	16.9%	24.6%
95th %le	6.5%	4.6%	9.6%	4.8%	**…**	28.8%	55.9%	35.3%	56.0%

★ intra-individual CV distributions

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

PARAMETER VARIABILITY

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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]

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Motor Variability and Skills Monitoring in Sports

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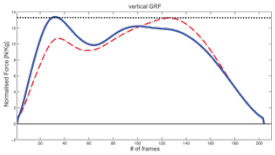
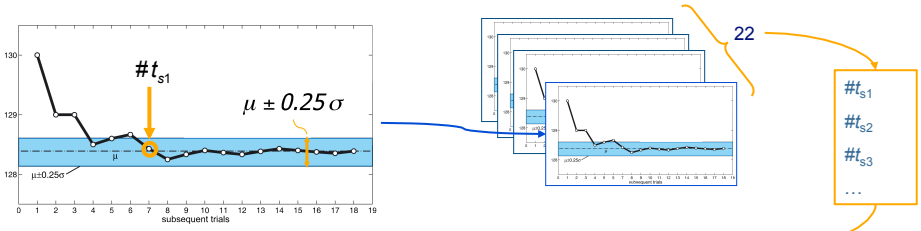


[Preatoni, 2007; Preatoni et al., in press]

PARAMETER STABILITY

★ sequential estimation procedure *[Hamill & McNiven, 1990; Rodano & Squadrone, 2002]*

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



subj	**Δt**	**v_x**	**Δx**	**$A_{po}ROM$**	**…**
s1(L)	4	4	4	4	…
s1(R)	4	12	7	4	…
s2(L)	13	9	11	11	…
…	…	…	…	…	…
med	11	9	8.5	8.5	**…**
95th %le	14.7	14	15	11	**…**

PARAMETER STABILITY

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med_{tot}	min_{tot}	max_{tot}
8.0	5.5	11.0
14.0	10.5	16.4

★ need for a "proper" number of trials

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

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

★ sensitivity to stability band definition?

★ what about curve variability and stability?

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

Motor Variability and Skills Monitoring in Sports

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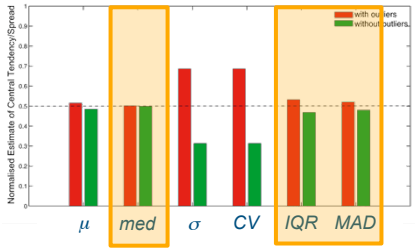
[Preatoni, 2007; Preatoni et al., in press]

ROBUSTNESS OF ESTIMATORS

★ intra/inter-individual parameter distributions often not Gaussian

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

CONSISTENCY TO OUTLIERS



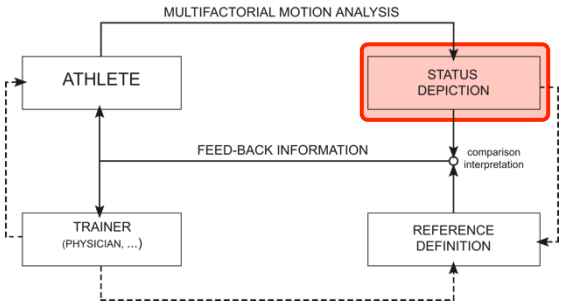
CENTRAL TENDENCY	% ROBUST Wilcoxon (α=0.05)
μ	87%
med	94%
SPREAD	**% ROBUST Wilcoxon (α=0.05)**
σ	11%
CV	11%
IQR	41%
MAD	39%

★ 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



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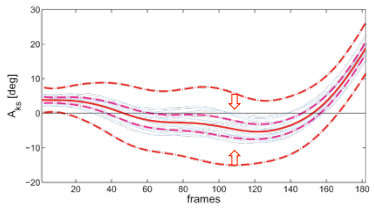
DUAL NATURE OF MV

MV_{tot}

MV_{ε} (noise)

$MV_{\varepsilon B}$ (bio.) | $MV_{\varepsilon M}$ (meas.) | $MV_{\varepsilon E}$ (env.) | …



DUAL NATURE OF MV

MV_{tot}

MV_{ε} (noise)

$MV_{\varepsilon B}$ (bio.) | $MV_{\varepsilon M}$ (meas.) | $MV_{\varepsilon E}$ (env.) | …

MV_{m} (n-m-s intrinsic dynamics)

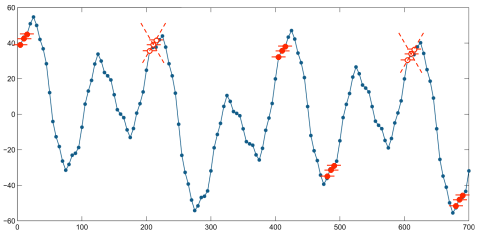
MV_{mS} (skill) | M_{mP} (pathol.) | …

★ 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

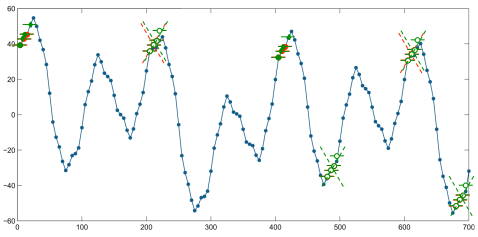
SAMPLE ENTROPY (*SampEn*)



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

e.g.: $C_{1,m}$ (**m=** 3 length of sequence)
(**r=** preset tolerance)

SAMPLE ENTROPY (*SampEn*)



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

e.g.: $C_{1,m+1}$ (**m+1=** 4 length of sequence)
(**r=** preset tolerance)

★ *SampEn* measures the t-series REGULARITY *[Richman & Moorman, 2000]*

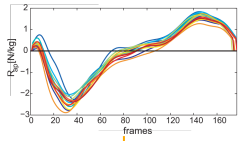
★ regularity has some relations with the complexity of the system generating the signal *[Pincus, 1995]*

***SampEn* = 0**

★⇧ regularity, ⇧ predictability
★indicates loss of system complexity
★may be a sign of anomalies
[e.g. cardiovascular - Richman & Moorman, 2000]

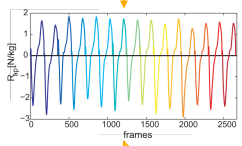
★⇩ regularity, ⇩ predictability
★indicates random behaviour

INFORMATIVE MV vs. NOISY MV



★ extraction of stance phase

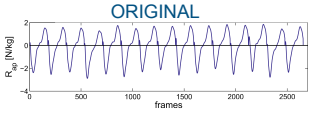
★ NO time normalisation!



★ t-series: continuous sequence of RW stance phases

★ entropy estimation (for each subj, var and side)

ORIGINAL

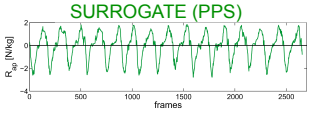


SampEn= 0.235

(m=1, r=0.1)

VS.

SURROGATE (PPS)



PPS: Pseudo Periodic Surrogate

[Small et al., 2001]

★ destroys nonlinear structure

★ preserves periodic features

SampEn= 0.476

(m=1, r=0.1)

INFORMATIVE MV vs. NOISY MV

$SampEn_{ORIG}$ ≅ $SampEn_{SURR}$

MV_{tot}

MV_{ε} (noise)

MV_{m} (n-m-s intrinsic dynamics)

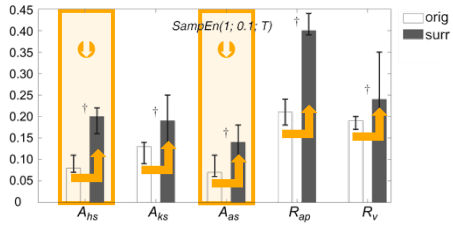
$SampEn_{ORIG}$ < $SampEn_{SURR}$

MV_{tot}

MV_{ε} (noise)

MV_{m} (n-m-s intrinsic dynamics)

INFORMATIVE MV vs. NOISY MV



P always < .002

Cohen's *d* always >.80

★ low *SampEn* values for every considered variable (→RW very stereotyped!!)

★ $SampEn_{ORIG}$ significantly lower than $SampEn_{SURR}$ (Δ= 16% – 59%)

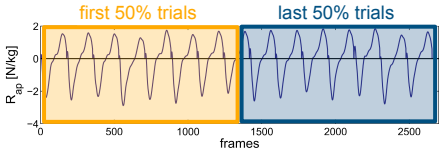
★ MV may be functionally related to the n-m-s system organisation

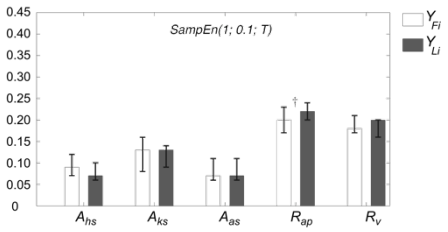
★ increased regularity @ hip and ankle compared with knee

★ increased control to compensate unnatural knee flex-extension in RW

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

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

[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]*

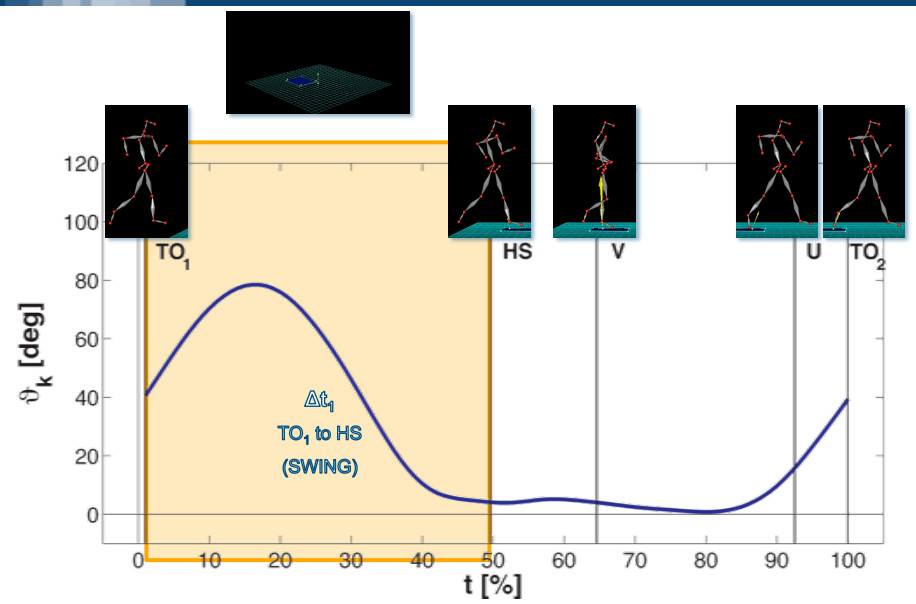
DYNAMIC SYSTEMS THEORY (DST) APPROACH

★ limbs as systems of coupled pendulums

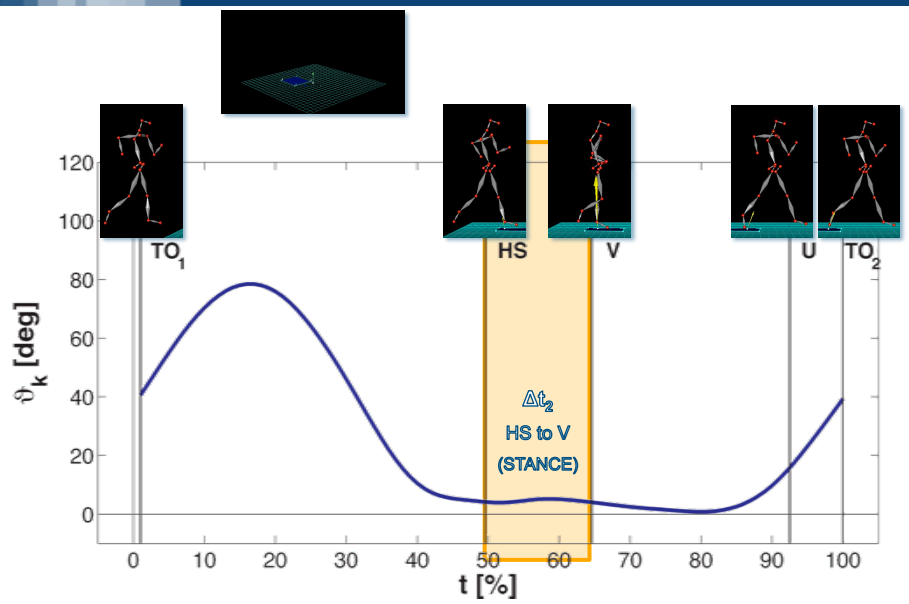
★ observation of Continuous Relative Phase (CRP)

★ variability in phase relationships

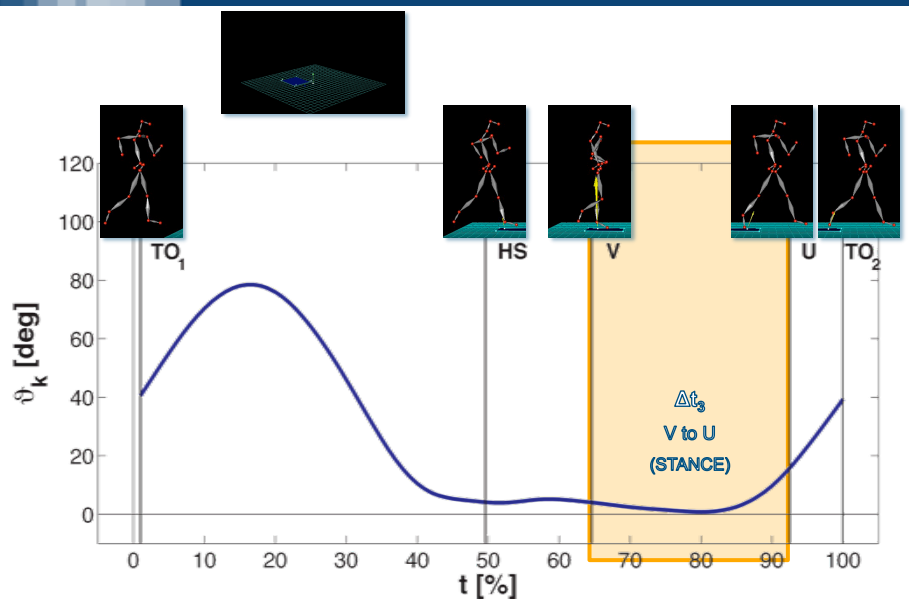
FUNCTIONAL PHASES OF RW



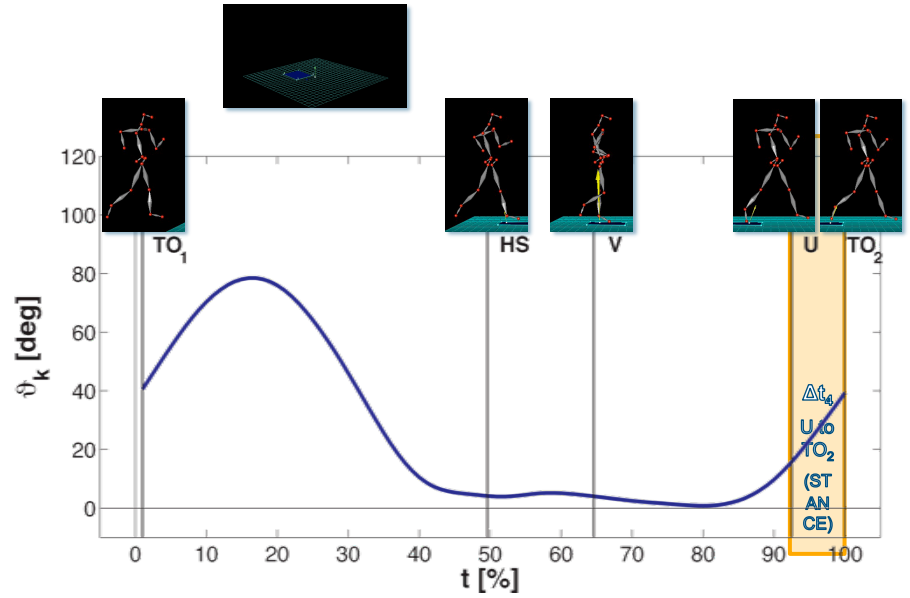
FUNCTIONAL PHASES OF RW



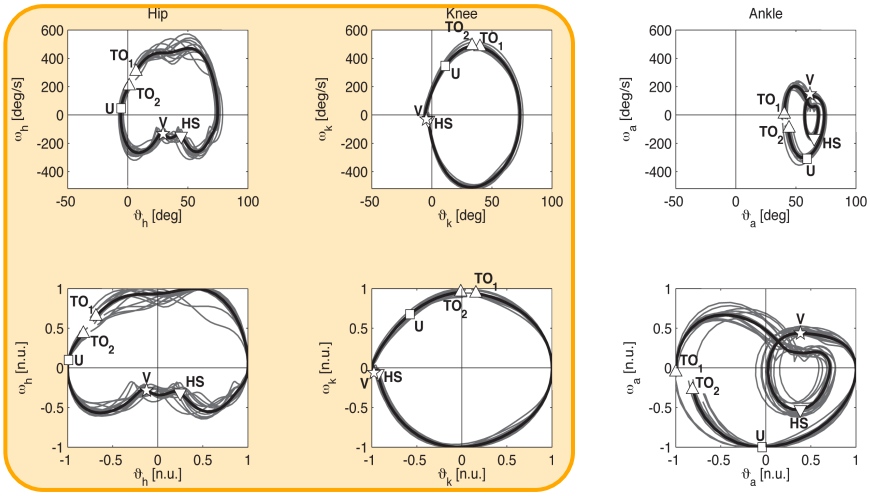
FUNCTIONAL PHASES OF RW



FUNCTIONAL PHASES OF RW

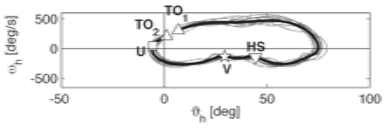


DST: PHASE PLOTS

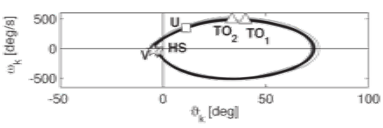


DST: CRP

Hip

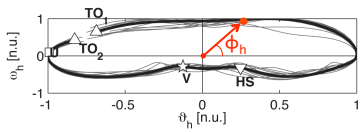


Knee

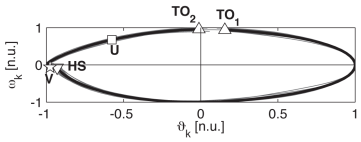


DST: CRP

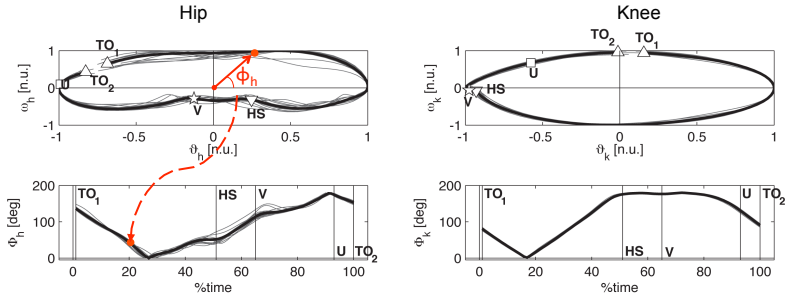
Hip



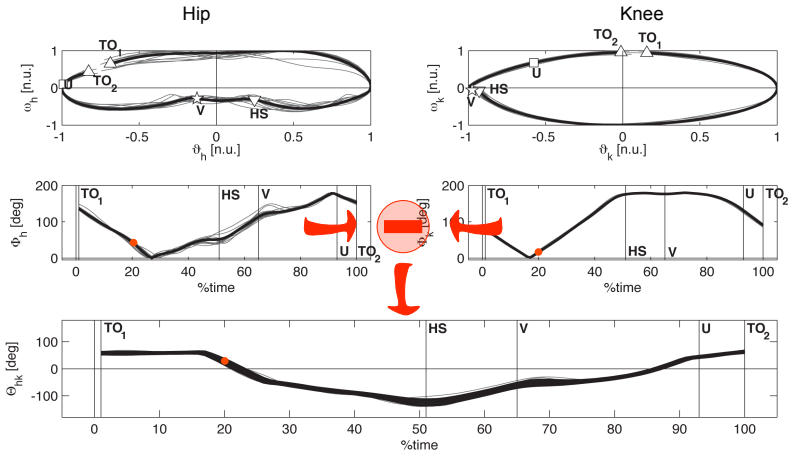
Knee



DST: CRP

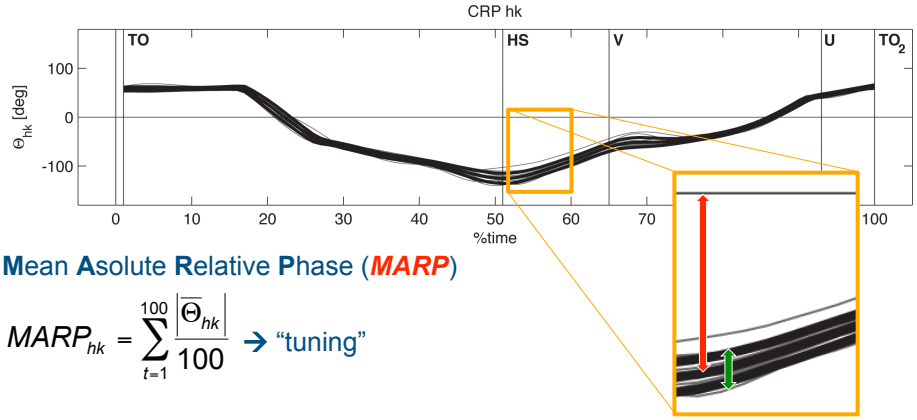


DST: CRP



$$CRP(t) = \Theta_{hk}(t) = \phi_h(t) - \phi_k(t)$$

DST: CRP MEASURES



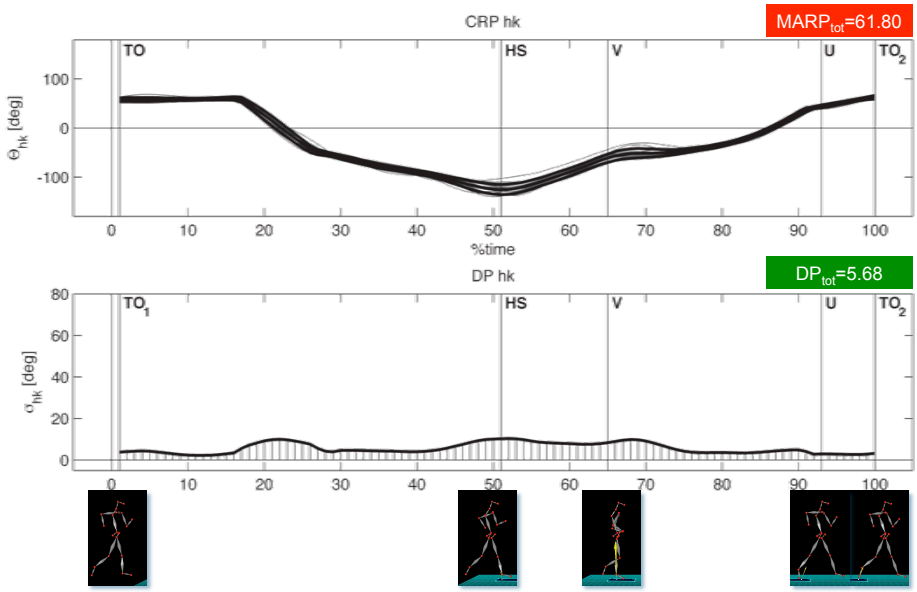
Mean Asolute Relative Phase (*MARP*)

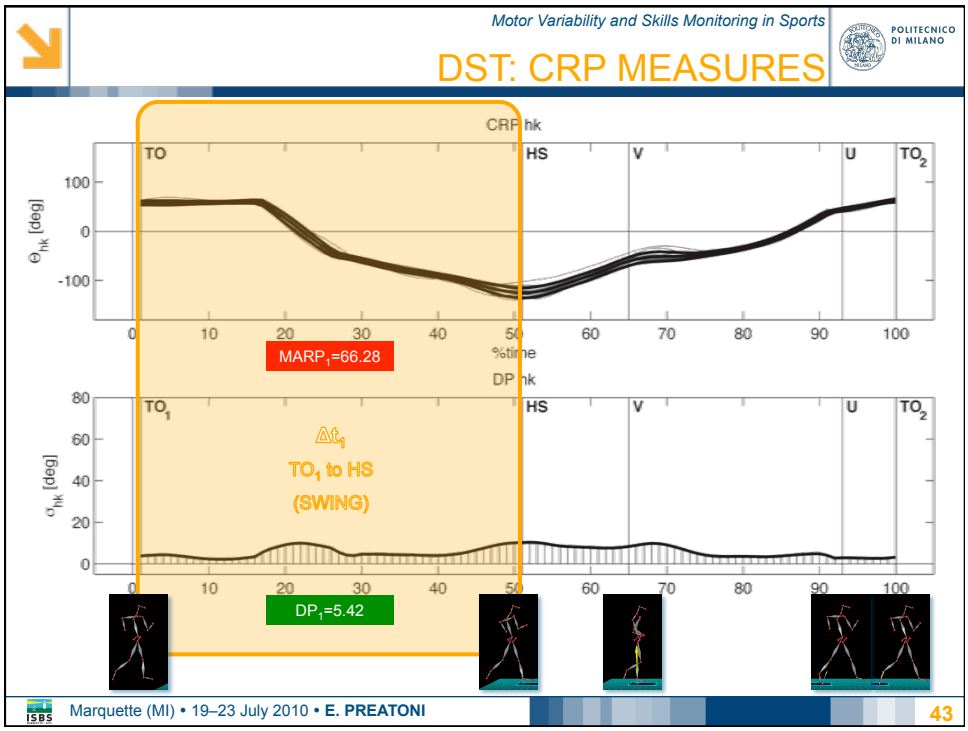
$$MARP_{hk} = \sum_{t=1}^{100} \frac{|\overline{\Theta}_{hk}|}{100}$$ → "tuning"

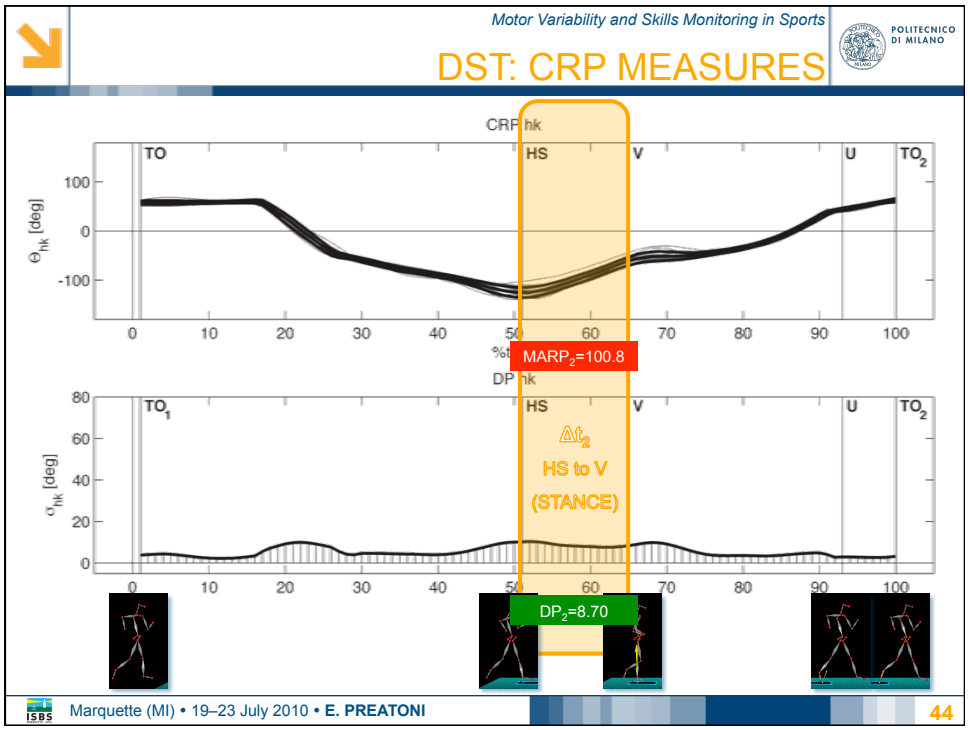
Deviation Phase (*DP*)

$$DP_{hk} = \sum_{t=1}^{100} \frac{|\sigma_{hk}|}{100}$$ → variability → "coordinative stability"

DST: CRP MEASURES




Motor Variability and Skills Monitoring in Sports
POLITECNICO DI MILANO
DST: CRP MEASURES
CRP hk
TO
HS
V
U
TO2
100
0
-100
Θhk [deg]
0 10 20 30 40 50 60 70 80 90 100
%time
MARP1=66.28
DP hk
TO1
HS
V
U
TO2
80
60
40
20
0
σhk [deg]
Δt1
TO1 to HS
(SWING)
DP1=5.42
Marquette (MI) • 19–23 July 2010 • E. PREATONI
43


Motor Variability and Skills Monitoring in Sports
POLITECNICO DI MILANO
DST: CRP MEASURES
CRP hk
TO
HS
V
U
TO2
100
0
-100
Θhk [deg]
0 10 20 30 40 50 60 70 80 90 100
MARP2=100.8
DP hk
TO1
HS
V
U
TO2
80
60
40
20
0
σhk [deg]
Δt2
HS to V
(STANCE)
DP2=8.70
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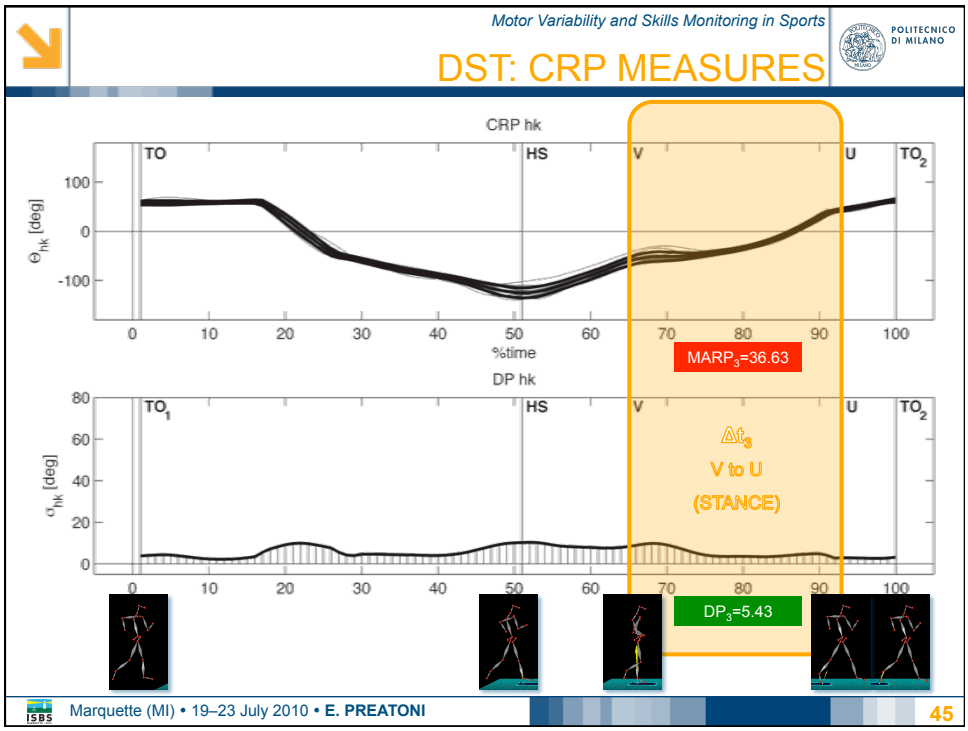
44


Motor Variability and Skills Monitoring in Sports
POLITECNICO DI MILANO
DST: CRP MEASURES
CRP hk
TO
HS
V
U
TO2
100
0
-100
Θhk [deg]
0 10 20 30 40 50 60 70 80 90 100
%time
MARP3=36.63
DP hk
TO1
HS
V
U
TO2
Δt3
V to U
(STANCE)
80
60
40
20
0
σhk [deg]
0 10 20 30 40 50 60 70 80 90 100
DP3=5.43
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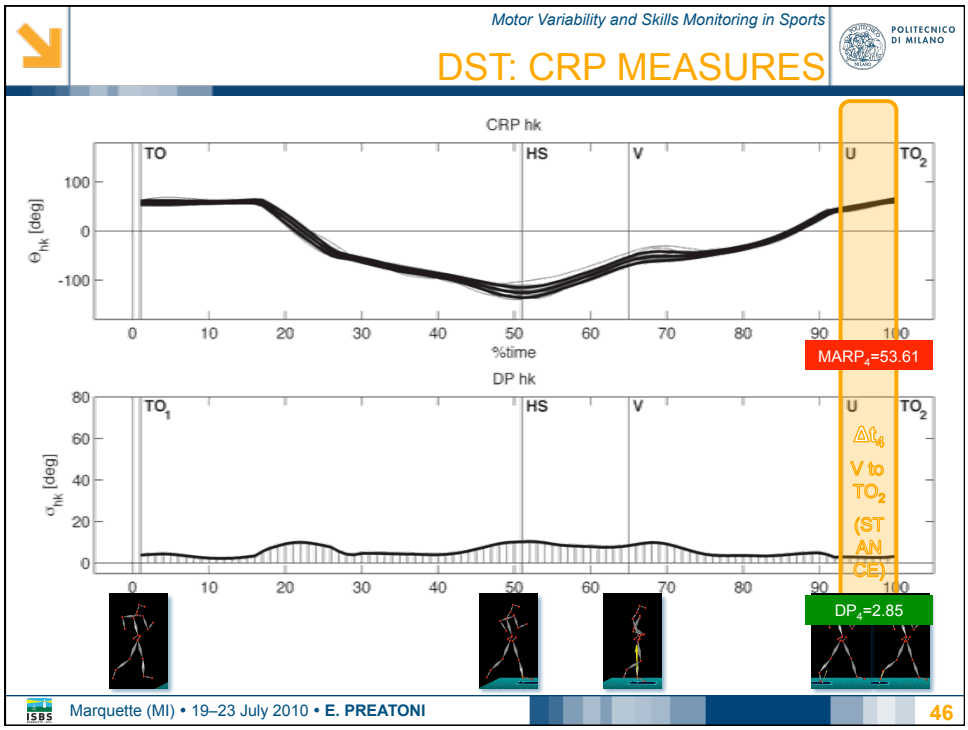
45


Motor Variability and Skills Monitoring in Sports
POLITECNICO DI MILANO
DST: CRP MEASURES
CRP hk
TO
HS
V
U
TO2
100
0
-100
Θhk [deg]
0 10 20 30 40 50 60 70 80 90 100
%time
MARP4=53.61
DP hk
TO1
HS
V
U
TO2
Δt4
V to TO2
(STANCE)
80
60
40
20
0
σhk [deg]
0 10 20 30 40 50 60 70 80 90 100
DP4=2.85
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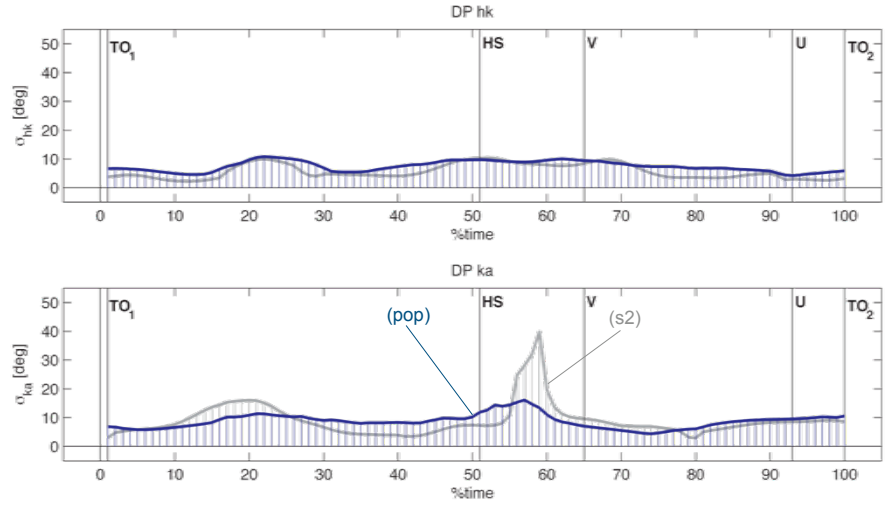
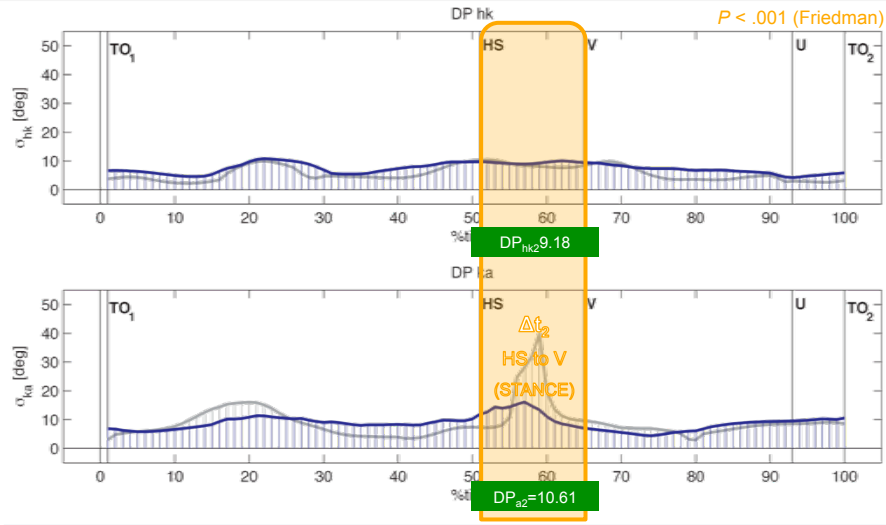
PHASING VARIABILITY IN RW: DP

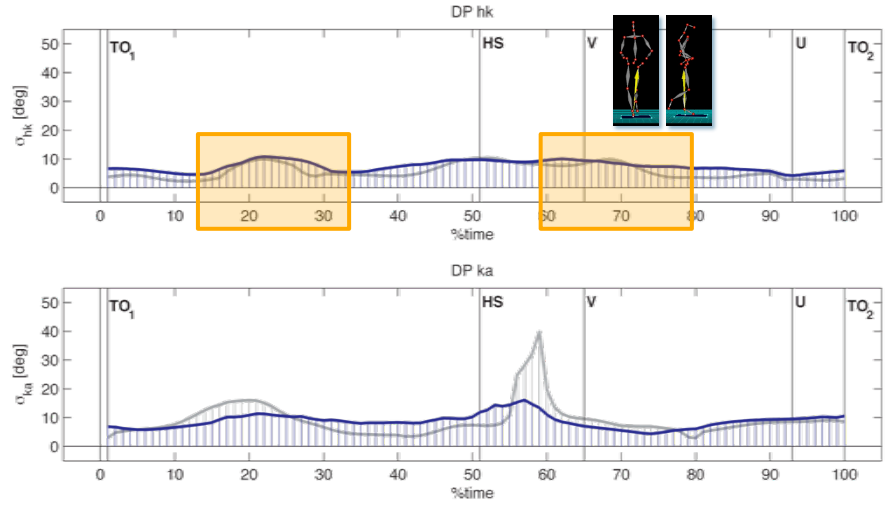


PHASING VARIABILITY IN RW: DP



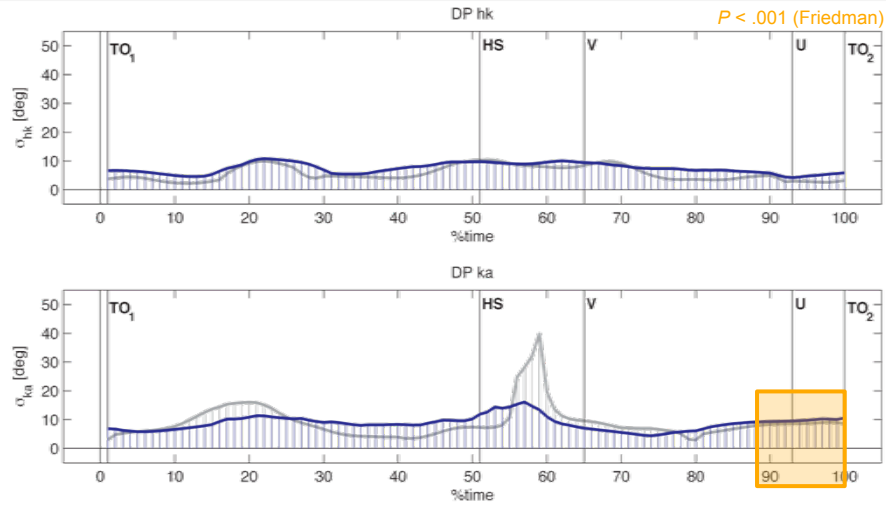
★ increased variability @load acceptance…
…flexibility to overcome perturbations (impact+ext.knee) & redistribute load

PHASING VARIABILITY IN RW: DP



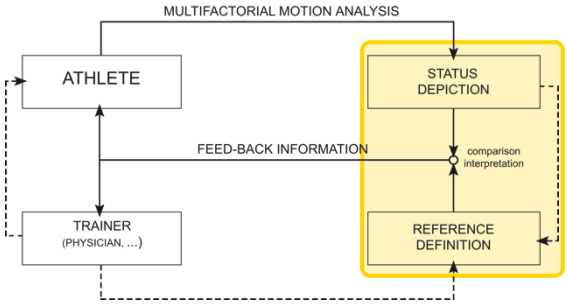
★ DP_{hk} ⇧ at transitions through V

PHASING VARIABILITY IN RW: DP



★ DP_{ka} ⇧ between U and TO

MV & MOTOR SKILLS



❶ HOW MUCH? HOW TO DEAL WITH?

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

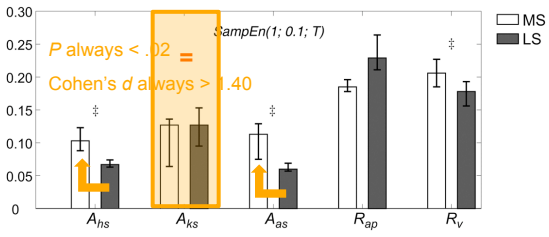
❸ WHAT MAY IT MEAN? WHAT MAY IT BE RELATED TO?

SKILL LEVEL and *SampEn*

POPULATION [7]

LESS SKILLED **LS** (national rank) [4]

MORE SKILLED **MS** (Europe elite) [3]



★ 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

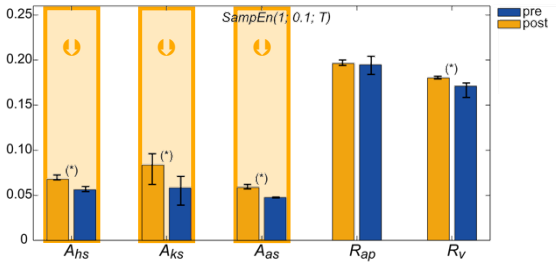
[Preatoni, 2007; Preatoni et al., in press]

t-CHANGES and *SampEn*

MARCH
TESTING SESSION

COMPETITIVE SEASON

SEPTEMBER
TESTING SESSION



★ 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

MARCH
TESTING SESSION
PRE

→

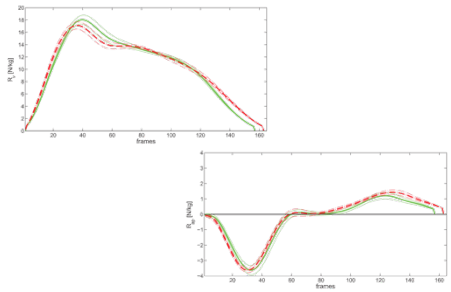
SEPTEMBER
TESTING SESSION
POST

INJURED SUBJECT
(from MS group)

★ clinically recovered

★ no changes in competitive results

★ no evident changes in speed, s-t parameters and conventional measures



par	*PRE*	*POST*
Δt [s]	0.33 (0.01)	0.32 (0.01)
v_x [m/s]	2.83 (0.09)	2.83 (0.09)
Δx [mm]	963.03 (26.54)	956.41 (35.58)
$R_{ap\text{-}MAX}$ [N/kg]	1.38 (0.16)	1.21 (0.42)
$R_{ap\text{-}MIN}$ [N/kg]	-3.70 (0.19)	-3.69 (1.07)
$R_{V\text{-}MAX}$ [N/kg]	17.22 (0.73)	18.13 (1.07)

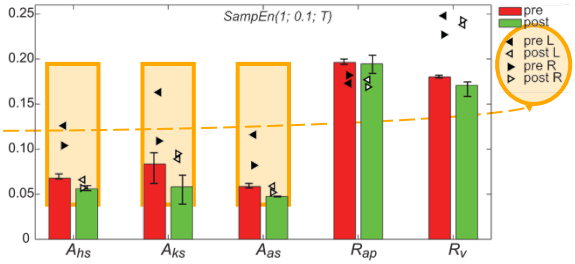
INJURY MONITORING and *SampEn*

★ but…

MARCH
TESTING SESSION

INJURED SUBJECT
(from MS group)

SEPTEMBER
TESTING SESSION



★ ≠ levels of entropy from the control group

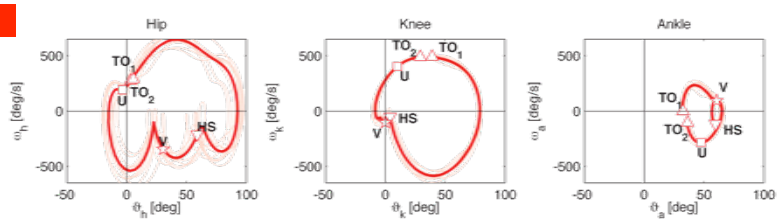
★ changes in regularity ≠ from the control group

★ asymmetries

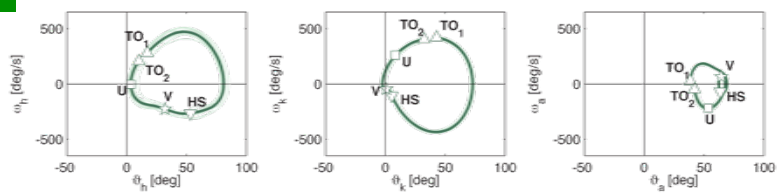
INJURY MONITORING and DST

★ phase plots

PRE

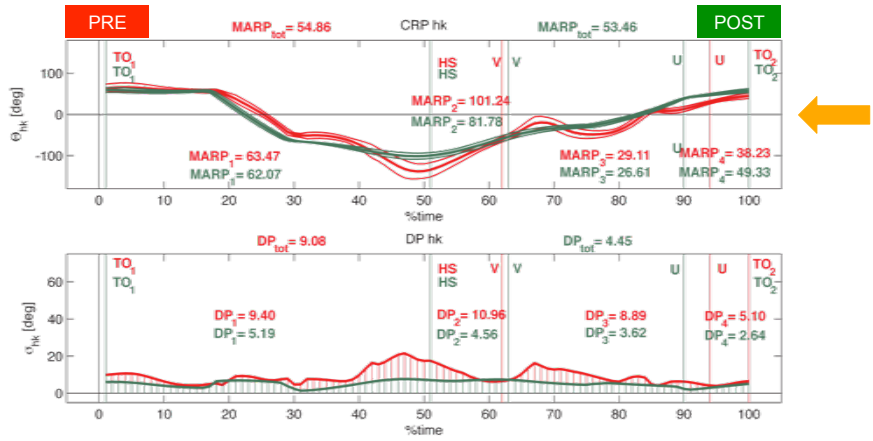


POST



INJURY MONITORING and DST

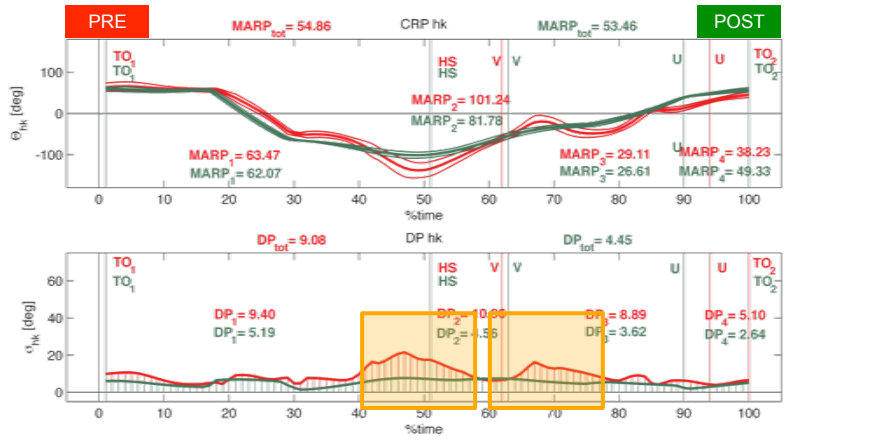
★ hip – knee coupling



★ smoother coupling in POST

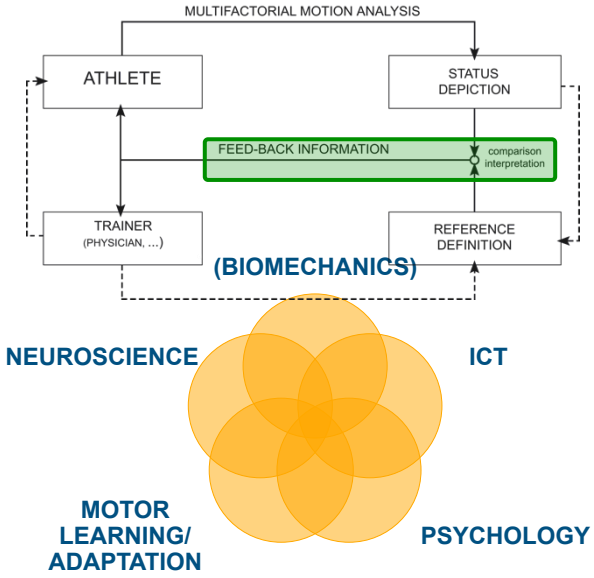
INJURY MONITORING and DST

★ hip – knee coupling

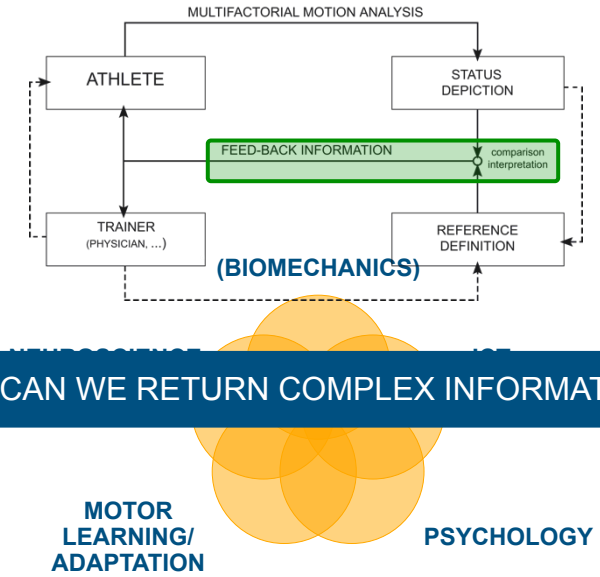


★ changes in coupling variability about transition phases

FEED-BACK

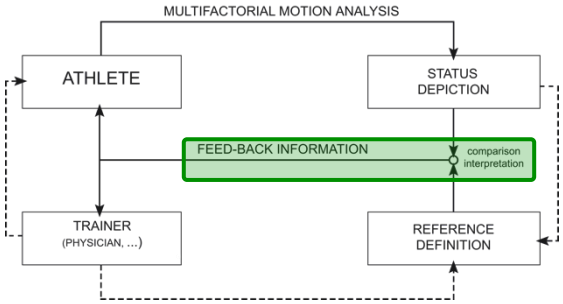


FEED-BACK



HOW CAN WE RETURN COMPLEX INFORMATION??

FEED-BACK



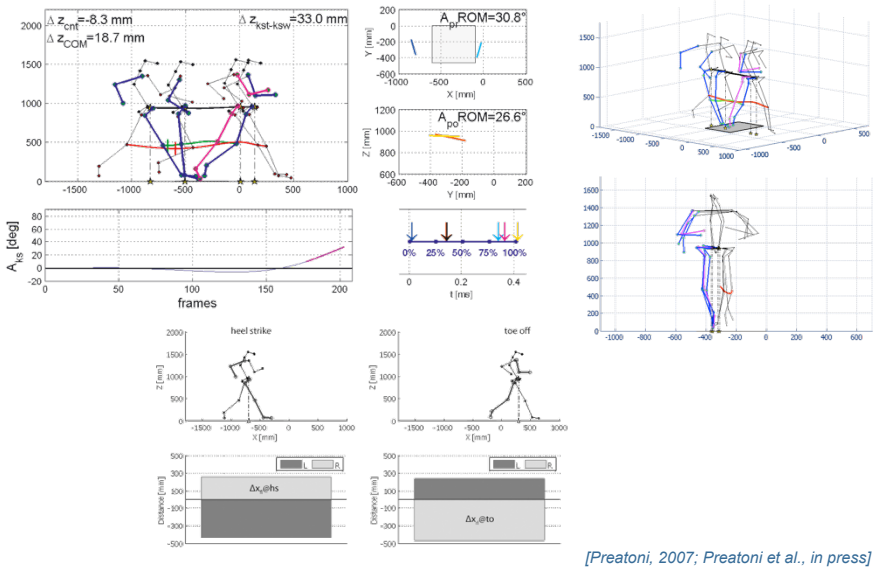
★ from complex biomechanics to practical tools

★ "translation" efforts

★ must not be intended as in control theory

★ not too much info, not too complex, not too fast

RETURNING BIOMECH INFORMATION



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

RETURNING BIOMECH INFORMATION

…BUT FOR INNOVATIVE MEASURES??

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"

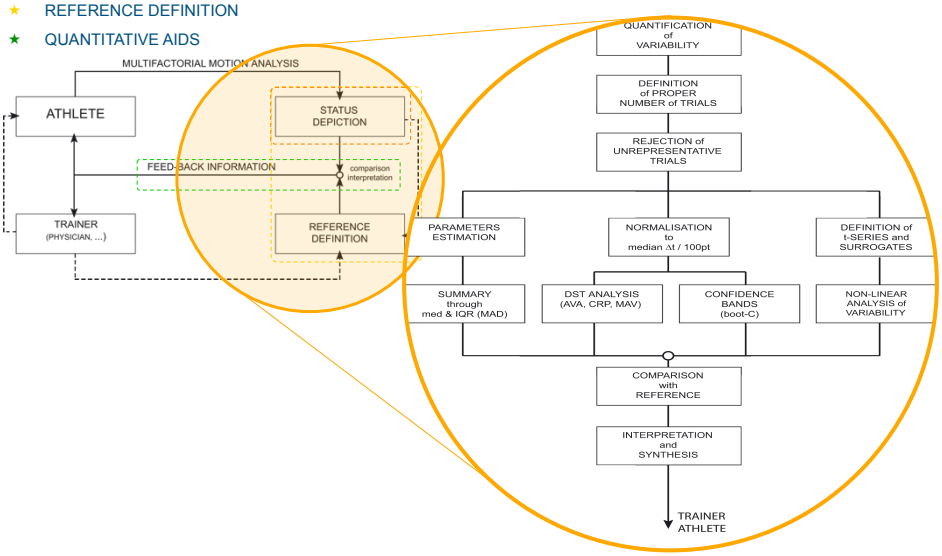
✪ NEED FOR REFERENCE DATABASES AND STANDARDS

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

✪ NEED FOR PROPER FEEDBACK TO COACHES, ATHLETES, …

GUIDELINES

- ★ ROBUST DESCRIPTION
- ★ REFERENCE DEFINITION
- ★ QUANTITATIVE AIDS



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CONTACT

Grazie per l'attenzione !!!

Thanks for your attention !!!

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