11. Biomechanical Movement Synergies

synergy ≡ collaboration towards a

11.0 Introduction

The neuro-musculo-skeletal system is interconnected and integrated.

ex. §1.2 neuro-musculo integration

to generate the moment-of-force profile at a given

- how the muscles at all joints contribute to the
- more than one simultaneous subtask of individual group of

biomechanics = major discipline that measures and analyses the total body in 3D

⇒ identify total body movement

1. total balance control in the plane during normal walking (§11.3)
2. total body responses to total arm voluntary movements in the plane (§11.3)
3. total body recovery mechanisms during standing (§11.2)

major examples of synergistic motor patterns, kinetic & EMG profiles

11.1 The Support Moment Synergy

§5.2.6 (Fig. 5.14) $M_s = M_k(\text{ext.}) - M_a(\text{flex.}) - M_h(\text{flex.})$

Fig. 11.1 Ensemble averaged moment profiles (same subject, 9 days)

$M_s = M_h(\text{ext.}) + M_k(\text{ext.}) + M_a(\text{ext.})$

$CV_h = 68\%$, $CV_k = 60\%$ (CV = coefficient of variation §2.3.3)

$CV_{h+k} = 21\%$, $CV_s = 20\%$

⇒ "trading off" between the

ex. The hip becomes more , while the knee becomes more

mean covariance between hip and knee over

$$\sigma_{hk}^2 = \sigma_h^2 + \sigma_k^2 - \sigma_{h+k}^2 \tag{11.1}$$

σ_h^2, σ_k^2 : mean variance of hip, knee

σ_{h+k}^2 : mean variance of

maximum $\sigma_{hk}^2 = \sigma_h^2 + \sigma_k^2$ when $\sigma_{h+k}^2 =$

M_h and M_k change out of phase, cancel each other out completely

$$\%\text{ covariance}\quad COV = \frac{\sigma_{hk}^2}{\sigma_h^2 + \sigma_k^2} \times 100\% \tag{11.2}$$

ex. Fig. 11.2

day-to-day repeat COV_{hk} = 89%, COV_{ak} = 76%

trial-to-trial repeat COV_{hk} = 72%, COV_{ak} = 49%

11.1.1 relationship between M_s and vertical ground reaction force

support moment M_s = summation of the moments at all three joints

: how much the total limb is pushing away from the

~ vertical ground reaction force

ex. Fig. 11.3 average F_y and average M_s for 19 adult subjects

correlation coefficient r = 0.97

11.2 Medial/Lateral and Anterior/Posterior Balance in Standing

standing = (§11.2.1)

in the medial-lateral ( ) direction (§11.2.2)

and anterior-posterior ( ) direction

11.2.1 quiet standing

inverted pendulum model (§5.2.9)

$W(COM - COP) = I\alpha$, $d\alpha =$

$$\Rightarrow \quad COP - COM = -\frac{I}{Wd}\ddot{x} = -K\ddot{x} \tag{11.3}$$

$COP - COM$: error signal for controlling $\ddot{x}$ (horizontal of the COM)

⇒ focus on how the CNS(?) controls the COP to achieve a stable balance

quiet standing : COP is controlled by

ankle dorsiflexors/plantorflexors in the direction

hip abductors/adductors in the direction

bilateral synergy :

Fig. 11.4 left and right vertical ground reaction forces

Fluctuations are virtually equal in and out of

⇒ Left (or right) hip moment is with the left (or right) vertical reaction force.

hip abductor and adductor moments

exactly equal in magnitude, 180° phase

⇒ accomplish load/unload mechanism

$COP - COM \Rightarrow -\ddot{x}$: accelerating the COM toward a position

The CNS has to keep the left and right hip abductors/adductors

at a small level of muscle tone

so that the minuscule M/L sway results in small synchronized fluctuations

in hip frontal-plane moments sufficiently large to maintain

11.2.2 medial lateral balance control during workplace tasks

Anterior/posterior ( ) balance is controlled by the plantarflexors/dorsiflexors,

medial/lateral ( ) balance is controlled by the hip abductors/adductors.

M/L balance (= load/unload mechanism)

increased abductor forces on one side

⇒ abductor forces on the contralateral side

lift the pelvis/HAT mass (loading the ipsilateral side)

⇒ the contralateral side

move COP toward the ipsilateral foot

⇒ of COM toward the contralateral side

11.3 Dynamic Balancing during Walking

11.3.1 the human inverted pendulum in steady state walking

gait cycle (steady state walking)

RHC - double support - LTO - single support - LHC - double support - RTO - single support - RHC

trajectories of COP and COM (Fig. 11.7)

- COP under the , COM of the
- COM never passes within the base of the
- COM moves forward passing just medial of the inside of each

inverted pendulum model (§5.2.9)

during each 40% -support period

(11.3) $COP - COM =$

$COP > COM \quad \Rightarrow \quad \ddot{x} \quad 0$:

$COP < COM \quad \Rightarrow \quad \ddot{x} \quad 0$:

trajectory of the swinging foot decides

its future and

its for the next single-support period.

11.3.2 initiation of gait

from a stable balance condition during quiet

to a state in about two steps

requires coordination of the A/P (plantarflexors/dorsiflexors)

and the M/L (hip abductrs/adductors)

Fig. 11.8

11.3.3 gait termination

from a steady state

to a stable within two steps

requires balance control

- forward of the body must be removed
- COP must be controlled to a position slightly ahead of the
  as the COM comes to a near stop.

Fig. 11.9