EFFECT OF FATIGUE ON TRUNK- AND HIP-KNEE COORDINATION DURING SIDESTEP CUTTING MANEUVER IN HANDBALL ATHLETES

Dayanne R. Pereira[1], Renato Moraes[2], Ana Luiza Lopes[3], Ronaldo D. Assis[1], Paulo R. P. Santiago[2], Bruno L. S. Bedo[1].

[1]School of Physical Education and Sport, University of São Paulo, São Paulo, Brazil
[2]School of Physical Education and Sport of Ribeirão Preto, University of São Paulo, Ribeirão Preto, Brazil
[3]Faculty of Physical Education, Universidade Estadual de Campinas, Campinas, Brazil

This study investigated how fatigue impacts trunk-hip and hip-knee coordination in female handball athletes during the sidestep cutting maneuver (SCM). Twenty participants performed three trials of the SCM task under pre- and post-fatigue conditions. An eight-camera motion capture system tracked reflective markers attached to their skin to compute the trunk, hip, and knee angles. A vector coding technique evaluated coordination patterns. Results indicated that while trunk-knee coordination remained unaffected by fatigue, significant changes were observed in the hip-knee coordination within the transversal plane post-fatigue. These findings highlight the need for customized training that considers possible joint changes caused by fatigue.

KEYWORDS: COORDINATION, SIDESTEP CUTTING, FATIGUE.

INTRODUCTION: The knee joint is prone to injury among team sports athletes, including those who play handball. These injuries are predominantly non-contact, as in the case of anterior cruciate ligament (ACL) ruptures, generally occurring during landing or lateral cutting maneuvers (SCM). Given the significant incidence of athletic injuries observed during SCM, different groups have investigated the joint kinematics of the lower limbs (LL) in these tasks and the effect of extrinsic and intrinsic factors on knee biomechanics. Previous studies have linked muscle fatigue to an increased likelihood of ACL rupture risk, indicating that fatigue can affect LL kinematics during dynamic movements (Bedo et al., 2022; Hollman et al., 2020). These assumptions are supported by research suggesting that fatigue results in proprioceptive deficits and delayed muscular response (Hiemstra et al., 2001), increasing the risk of injury. Thus, knowing that coordination is an organizational pattern between multiple joints or segments and that presents variability within their movement patterns, it is possible that changes in variability can be caused by fatigue and be directly related to the appearance of injuries in the LL (Dutaillis et al., 2021).

For example, Brown et al., (2014) demonstrated a decrease in the knee flexion angle, an increase in the knee abductor angle and moment, and changes in trunk movement during SCM; similar findings in fatigued runners were found (Möhler et al., 2019). However, most studies have investigated joints individually, presenting a disadvantage in understanding movement coordination and the influence of distal joints, like the trunk, in interarticular control (Briani et al., 2022; Chang et al., 2008).

Different techniques have been used to understand intersegmental coordination and its relationship with injuries, such as relative motion graphs (Chang et al., 2008) and continuous relative phases (Hamill et al., 1999); however, these techniques have certain limitations (Tepavac & Field-Fote, 2001). In this way, vector coding has become an analysis technique in providing a more sensitive measure of subtle changes in joint coordination (Sparrow et al., 1987). Therefore, this study investigated how a handball-specific fatigue protocol impacts coordination patterns for trunk-knee and hip-knee pairs.

METHODS: Twenty female handball athletes (1.76 ± 0.07 m, 63.5 ± 9.1 kg, 21.9 ± 3.4 years) with no reported knee injuries were recruited. All participants provided written consent. They performed three SCM before and after a handball-specific fatigue protocol, designed as a circuit and conducted in a laboratory setting to replicate movements commonly performed in handball practice (Bedo et al., 2020). For the SCM task, athletes sprinted 5 meters as quickly as possible and executed the cutting maneuver at a 45º angle from the runway's longitudinal axis. A motion capture system with eight cameras (MX-T40S, Vicon, Oxford, UK) recorded the movements of the reflective markers placed on the participants' skin as defined by the marker set (Mantovani & Lamontagne, 2017). The data were reconstructed, labeled, and filtered with a zero-lag 4th order Butterworth filter set at 6 Hz using Nexus 2.8 software (Vicon, Oxford, UK). The trunk, knee, and hip angles were determined, with the x-axis representing the mediolateral direction, the y-axis denoting the anterior-posterior direction, and the z-axis indicating the superior-inferior direction. All angles were time-normalized, covering the stance phase (between foot-contact and foot-off).

We used a vector coding technique to evaluate coordination patterns. For this, the time series of the joint angles of interest were initially obtained. The subsequent step captured the relative movement between the two joints/segments. These movements were visualized in angle-angle diagrams, and the coupling angle (γ) was derived from the diagrams. The evaluation of coordination patterns was then based on this coupling angle, determined by the angle formed by a vector connecting two consecutive points in time and the horizontal axis to the right. The coupling angle captured the immediate spatial relationship, from which four specific coordination patterns were discerned: i) anti-phase, ii) in-phase, iii) primary phase (Trunk or Hip), and iv) secondary phase (Knee) (Chang et al., 2008). Subsequently, histograms were generated to classify the identified coordination patterns. Using 45° bins for classification (Chang et al., 2008), a γ of 45° or 225° denotes an in-phase joint movement where both joint/segments (trunk-knee and hip-knee) rotate synchronously. On the other hand, a γ of 135° or 315° means anti-phase movement, indicating that they rotate in opposite directions. Coupling angles of 0°, 90°, 180° and 270° highlight the predominant movement of a singular joint/segment.

For each experimental condition, we calculated the frequency of each coordination pattern in flexion/extension, adduction/abduction, and internal/external rotation. The normality of the data was evaluated using the Shapiro-Wilk test. To address the non-normal distribution, we applied the arcsine transformation. Subsequently, we used the repeated measure ANOVA with two factors: experimental condition and phase coordination. If significant F-ratios were detected, a Bonferroni post-hoc comparison was applied to determine where the differences occurred.

RESULTS: There were no significant differences in coordination patterns between the trunk and knee in baseline and fatigue conditions across all planes of movement during the SCM task (Figure 1). Regarding hip-knee coupling angles, significant differences were observed in the transversal plane between baseline and fatigue (F=3.09, p=0.034), showing a significant increase in the frequency of the anti-phase (p=0.028) and a significant decrease in the in-phase (p=0.008).

DISCUSSION: The main result was that the fatigue affected only the transverse plane (internal and external rotation), where an increase of about 8% in the anti-phase patterns and a decrease in the in-phase pattern were found in the fatigue condition, which means that all segments are moving in opposite directions. However, it is impossible to affirm which way each segment moves based on this analysis alone.

A vital characteristic of the neuromuscular system is its adaptability. In situations of fatigue, the system can use compensatory strategies at different levels to mitigate the impact of fatigue (Enoka & Duchateau, 2016). This supports the prevailing notion that adjustments in intersegmental coordination are necessary. Our results may have occurred due to familiarisation and adaptation of the task. For instance, a repeated task makes its characteristics predictable; the musculoskeletal and neuromuscular systems already have previous responses to executing the same task, making it less complex (Dutaillis et al., 2021).

After the first task performance, the second repetition becomes more accessible, as the systems have already adapted to perform that task (Krakauer et al., 2019). Furthermore, the results highlight that the neuromuscular system shifts to alternative motor coordination strategies in response to fatigue. However, these adaptations might risk joint health by inducing changes in joint mechanics that lead to increased stiffness, potentially increasing the risk of injuries (Hamill et al., 1999); however, we cannot assume that there is consistent evidence that fatigue increases the risk of LL injuries.

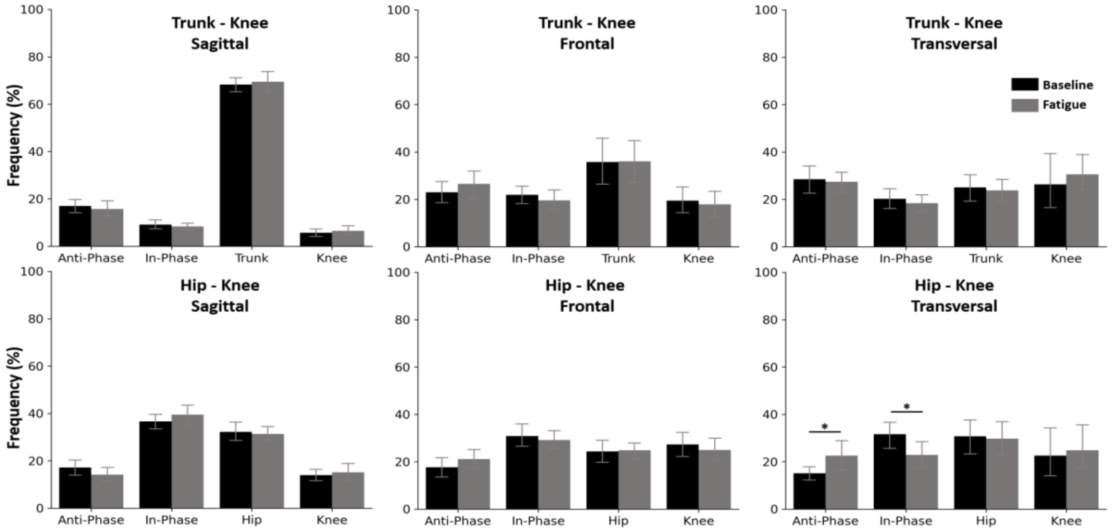

Figure 1: Histograms of trunk-knee and hip-knee coordination patterns during the SCM, under baseline and fatigue conditions (group means ± confidence interval). Graphs from left to right show sagittal, frontal, and transversal planes. The * indicates differences between Baseline and Fatigue Conditions ($p<0.05$).

Fatigue-induced kinematic changes are influenced by neuromuscular control originating from neural factors. During fatigue, the build-up of metabolic by-products in muscles impairs the function of muscle fibers, leading to compromised force generation. Additionally, fatigue can degrade sensory feedback crucial for proprioception, affecting spatial awareness. The diminished focus and delayed response times also influence the precision and timing of movements. The comprehensive impact of fatigue, encompassing neural, metabolic, sensory, compensatory, and cognitive aspects, highlights its significant influence on interlimb coordination (Cortis et al., 2013). Therefore, the changes in hip-knee coordination in the transverse plane may have occurred due to several factors. Firstly, as muscles tire, their ability to produce force and regulate movement decreases. The primary stabilizing muscles around the knee can fatigue more quickly than others, causing dependence on auxiliary muscles.

Moreover, it is known that in an anticipated task, as hypothesized in the SCM, the body requires more control and use of the trunk than the LL, unlike the unforeseen task (Weir et al., 2019); therefore, the findings support that the absence or minimal change in joint movement patterns may be due to familiarization and learning of the task. Additionally, as the SCM was performed on only one side, it was easier for the systems to prepare and respond appropriately. If the direction change had been random, changes in joint patterns might have been observed due to the increased complexity of the task and greater demand on the LL (Dutaillis et al., 2021).

The study has some limitations. The protocol was conducted in a laboratory environment, so future investigations must be performed on an actual handball court. Another potential limitation is the inability to differentiate between central and peripheral causes of fatigue. Future studies should consider incorporating methods to identify the causes of fatigue in this type of protocol.

CONCLUSION: Fatigue significantly influenced coordination patterns, particularly in the transverse plane, during SCM tasks, indicating that athletes can adjust their movement strategies in response to fatigue. Even so, these adaptations aim to compensate for the effects caused by fatigue, highlighting the need for customized training that considers possible joint changes in fatigue situations.

REFERENCES

Bedo, B. L. S., Catelli, D. S., Lamontagne, M., Moraes, R., Pereira, D. R., Graça, J. B., & Santiago, P. R. P. (2022). Fatigue modifies hip and knee kinematics during single- and double-leg dynamic tasks: An investigation with female handball players. *Journal of Sports Sciences*, *40*(17), 1964–1972. https://doi.org/10.1080/02640414.2022.2123506

Bedo, B. L. S., Pereira, D. R., Moraes, R., Kalva-Filho, C. A., Will-de-Lemos, T., & Santiago, P. R. P. (2020). The rapid recovery of vertical force propulsion production and postural sway after a specific fatigue protocol in female handball athletes. *Gait and Posture*, *77*, 52–58. https://doi.org/10.1016/j.gaitpost.2020.01.017

Briani, R. V., Cannon, J., Ducatti, M. H. M., Priore, L. B. D., Botta, A. F. B., Magalhães, F. H., & Azevedo, F. M. (2022). Exacerbating patellofemoral pain alters trunk and lower limb coordination patterns and hip-knee mechanics. *Journal of Biomechanics*, *141*, 111215. https://doi.org/10.1016/j.jbiomech.2022.111215

Brown, S. R., Brughelli, M., & Hume, P. A. (2014). Knee Mechanics During Planned and Unplanned Sidestepping: A Systematic Review and Meta-Analysis. *Sports Medicine*, *44*(11), 1573–1588. https://doi.org/10.1007/s40279-014-0225-3

Chang, R., Van Emmerik, R., & Hamill, J. (2008). Quantifying rearfoot–forefoot coordination in human walking. *Journal of Biomechanics*, *41*(14), 3101–3105. https://doi.org/10.1016/j.jbiomech.2008.07.024

Cortis, C., Tessitore, A., Lupo, C., Perroni, F., Pesce, C., & Capranica, L. (2013). Changes in Jump, Sprint, and Coordinative Performances After a Senior Soccer Match. *Journal of Strength and Conditioning Research*, *27*(11), 2989–2996. https://doi.org/10.1519/JSC.0b013e3182897a46

Dutaillis, B., Opar, D. A., Pataky, T., Timmins, R. G., Hickey, J. T., & Maniar, N. (2021). Trunk, pelvis and lower limb coordination between anticipated and unanticipated sidestep cutting in females. *Gait & Posture*, *85*, 131–137. https://doi.org/10.1016/j.gaitpost.2020.12.011

Enoka, R. M., & Duchateau, J. (2016). Translating Fatigue to Human Performance. *Medicine & Science in Sports & Exercise*, *48*(11), 2228–2238. https://doi.org/10.1249/MSS.0000000000000929

Hamill, J., Van Emmerik, R. E. A., Heiderscheit, B. C., & Li, L. (1999). A dynamical systems approach to lower extremity running injuries. *Clinical Biomechanics*, *14*(5), 297–308. https://doi.org/10.1016/S0268-0033(98)90092-4

Hiemstra, L. A., Lo, I. K. Y., & Fowler, P. J. (2001). Effect of fatigue on knee proprioception: Implications for dynamic stabilization. *Journal of Orthopaedic & Sports Physical Therapy*, *31*(10), 598–605. https://doi.org/10.2519/jospt.2001.31.10.598

Hollman, J. H., Beise, N. J., Fischer, M. L., & Stecklein, T. L. (2020). Hip extensor fatigue alters hip and knee coupling dynamics during single-limb step-downs: A randomized controlled trial. *Journal of Biomechanics*, *100*, 109583. https://doi.org/10.1016/j.jbiomech.2019.109583

Krakauer, J. W., Hadjiosif, A. M., Xu, J., Wong, A. L., & Haith, A. M. (2019). Motor Learning. Em R. Terjung (Org.), *Comprehensive Physiology* (1º ed, p. 613–663). Wiley. https://doi.org/10.1002/cphy.c170043

Mantovani, G., & Lamontagne, M. (2017). How Different Marker Sets Affect Joint Angles in Inverse Kinematics Framework. *Journal of Biomechanical Engineering*, *139*(4), 044503. https://doi.org/10.1115/1.4034708

Möhler, F., Ringhof, S., Debertin, D., & Stein, T. (2019). Influence of fatigue on running coordination: A UCM analysis with a geometric 2D model and a subject-specific anthropometric 3D model. *Human Movement Science*, *66*, 133–141. https://doi.org/10.1016/j.humov.2019.03.016

Sparrow, W. A., Donovan, E., Van Emmerik, R., & Barry, E. B. (1987). Using Relative Motion Plots to Measure Changes in Intra-Limb and Inter-Limb Coordination. *Journal of Motor Behavior*, *19*(1), 115–129. https://doi.org/10.1080/00222895.1987.10735403

Tepavac, D., & Field-Fote, E. C. (2001). Vector Coding: A Technique for Quantification of Intersegmental Coupling in Multicyclic Behaviors. *Journal of Applied Biomechanics*, *17*(3), 259–270. https://doi.org/10.1123/jab.17.3.259

Weir, G., Van Emmerik, R., Jewell, C., & Hamill, J. (2019). Coordination and variability during anticipated and unanticipated sidestepping. *Gait & Posture*, *67*, 1–8. https://doi.org/10.1016/j.gaitpost.2018.09.007

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