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Neuromechanical adaptations to slippery sport shoes

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ABSTRACT

Although shoe friction has been widely studied in occupational ergonomics, information was lacking about friction in sport shoes. The purpose of the study was to examine the neuromechanical adaptations to different shoe-surface interface in an aerobic-gym specific movement. Sixteen females performed 10 change of direction movements in two shoe conditions differing by their outsoles (ethyl-vinyl-acetate: EVA and rubber: RB) to ensure significant differences in mechanical coefficients of friction (EVA = 0.73 ± 0.07 and RB = 1.46 ± 0.15). The kinematics, kinetics and muscle activities of the right lower-limb were analysed. Statistical parametric mapping was used to investigate the kinematics and kinetics adaptation to the different shoe-surface coefficients of friction. The participants had a longer stance duration in the EVA compared to the RB condition (526 ± 160 ms vs. 430 ± 151 ms, $p < .001$). The ankle and knee joints powers and works were lower during both the braking and the push-off phases in the EVA as compared to the RB condition. Preactivation of the agonist muscles (soleus, gastrocnemius medialis and vastus medialis) decreased in the EVA compared to the RB condition (−28.5%, −26.5% and −49.0%, respectively). Performing a change of direction movement with slippery shoes reduced the ankle and knee joints loadings, but impaired the stretch-shortening cycle performance. Participants demonstrated thus a different neuromechanical strategy to control their movement which was associated with a reduced performance.

1. Introduction

Footwear friction is an important factor for both sports performance (Starbuck et al., 2016; Sterzing, Müller, Hennig, & Milani, 2009) and reduction of the injury risk (Dixon, Fleming, James, & Carré, 2015). In sports, two main cases of friction phenomenon can be distinguished. The first one is the traction between shoes and an outdoor loose soil or a deformable surface, like soccer shoes into natural grass or an artificial turf field, tennis shoes on a clay court, or sprint spikes into a tartan running track. In this case, there is interpenetration between the shoe and the surface, generally when shoe studs penetrate into the surface. The second one is the friction between shoes and a hard surface, like tennis shoes on a hard court, basketball or aerobic shoes on an indoor gymnasium/wooden surface or running shoes on asphalt. In this second case, the friction surface is limited to the contact surface of the shoe outsole onto the surface, without interpenetration. In both cases the footwear friction/traction "is considered to be the propulsive or braking force generated on the sport surface by an athlete or machine to achieve a chosen manoeuvre" (Barry & Milburn, 2013). It can be quantified using the coefficient of friction (CoF).

The CoF corresponds to the ratio between shear and normal forces acting at the shoe-surface interface. From this ratio measured during the stance duration of a sport-like step, two specific CoF have been proposed to describe the global phenomenon of friction at the macro level of the shoe-surface interface (Barry & Milburn, 2013; Morio, Sissler, & Guéguen, 2015). The static CoF corresponds to

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the ratio of forces needed to initiate the movement of the shoe relative to the surface (slip) whereas the dynamic or kinetic CoF corresponds to the ratio of forces needed to sustain this sliding regardless of the sliding magnitude (Barry & Milburn, 2013).

Although several studies already investigated shoe traction, they mainly focused on shoes-surface interaction in case of slight to strong penetration of shoes into the soil, like tennis shoes on clay courts (Damm et al., 2013; Starbuck et al., 2016) or football boots on grass fields (Sterzing et al., 2009; Wannop, Luo, & Stefanyshyn, 2013). Regarding hard surfaces, stiffness and roughness were found to influence the shoe-surface friction (Clarke, Carré, Damm, & Dixon, 2012; Clarke et al., 2011). In the absence of any large slide or slip, the static CoF was considered a better descriptor of the shoe-surface interface than the dynamic CoF (Morio et al., 2015). Some authors hypothesized the existence of friction thresholds specific to each playing skill or playing surface (Damm, Clarke, Carré, & Dixon, 2013). A recent study compared multiple shoe-surface combinations (Morio, Bourrelly, Sissler, & Guéguen, 2017) and determined a friction threshold for a change of direction movement on hard surfaces. The authors found that above this threshold, the additional available friction was not used by participants (i.e. participants utilized less friction than the shoe-surface interface could provide). On the one hand, this suggests that adaptation may allow the task to be continued without enough friction. On the other hand, participants reduced their utilized friction as the available friction decreased. This could indicate that they maintained a safety margin to prevent slip. In this previous experiment, the participants continued to perform the task although they reported that the shoes did not provide enough friction. They had to adapt their movement to manage this lack of friction in a manner which has not been described yet in the literature.

There is, to our knowledge, limited information about the human adaptation to different shoe-surface friction levels with hard surfaces in sports. Some studies combined mechanical and biomechanical variables to better understand shoe-surface interaction (Clarke, Damm, Dixon, & Carré, 2013; Damm & Low et al., 2013; Starbuck et al., 2016). For example, comparing clay court (low friction) to acrylic court (high friction) in tennis, Starbuck et al. (2016) found that on clay, participants attack the ground with a more flexed knee but with a reduced overstride angle (more vertical hip relative to the foot at ground contact). Another study of the same research group presented the kinematic adaptation to clay and hard court shoes on both clay and hard court surfaces (Damm & Low et al., 2013). They found an increased knee flexion and a reduced ankle inversion on hard court compared with clay to perform a tennis-specific movement, but no effect of the different shoe friction properties. They also found higher horizontal forces showing higher utilized dynamic CoF on clay court.

Few studies have investigated the neuromuscular aspects of the participants' adaptations to slippery conditions. During walking under slippery as compared to dry surface conditions, the activity of the tibialis anterior was found to be reduced whereas the activity of the gastrocnemius was increased (Chander, Wade, Garner, & Knight, 2017). On a slippery hard surface during a tennis movement, Pavailler and Horvais (2015) reported increased vastus lateralis activity for both limbs. It may allow the tennis player to control the sliding with the non-support limb (opposite to the racket side) and to push-off with the support limb after the ball strike (racket side). There is a lack of information about the neuromechanical adaptations to slippery conditions in other sport activities.

Most of the previous studies which investigated the interaction between sports shoes and hard surfaces focused on tennis. However, each sport activity played on a hard surface requires a specific level of friction with regard to surface properties and specific movements of the activity (e.g. running, cutting, stop and go, shuffle running, change of direction). In line with this, indoor sports are of particular interest, especially gym and aerobic classes. Gym and aerobic have been defined as highly multidirectional activities (Caspersen, Powell, & Christenson, 1985). A recent survey of Apps, Liu, Pykett, and Sterzing (2015) highlighted that friction was one of the five most important shoe features for gym activities. Rapid changes of direction observed in aerobic classes could thus be an interesting and simple task to reproduce in a laboratory environment to study the adaptation to different shoe-floor friction levels.

Previous studies only investigated simple kinematic variables at key time points (touchdown and maximum during stance). The movement control, however, might be more complex and the neuromechanical adaptations to slide have not yet been studied, neither for specific aerobic movements nor for general sports movements. Therefore, the purpose of the present study was to examine the neuromechanical adaptations to two different shoe-surface interfaces, one with a standard non-slippery outsole and one more slippery, in a change of direction task (see details in the method section) corresponding to a classic movement in aerobics. It was hypothesized that, similarly to previous walking or tennis cutting movement, slippery shoes would induce a greater agonist muscle activation prior to impact and during the braking phase. It was also hypothesized that slippery shoes would induce a longer stance phase and thus a reduction of the ankle and knee power curve amplitudes, resulting in an impaired stretch-shortening cycle (SSC) performance.

2. Material and methods

2.1. Participants

Sixteen healthy active females (26.7 ± 7.3 years, 168 ± 3 cm, 64.1 ± 9.0 kg) volunteered to participate in this study. They were all regularly involved in gym classes, between 1 and 3 h per week. They were free from lower-limb injury and wore a shoe size of 39 EU (foot length 24.5 ± 0.6 cm and foot width 9.4 ± 0.5 cm). All the participants gave informed consent, in compliance with the ethical rules and laws which regulate human experimentation in France.

2.2. Procedure

Every participant tested two different pairs of indoor gym shoes (modified from Domyos™ 360 Light). The shoes had similar uppers and midsoles; only the outsoles differed in their material properties, with one ethyl-vinyl-acetate outsole (EVA) and one