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Muscle pre-activation strategies play a role in modulating K_{vert} for change of direction manoeuvres: An observational study

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ABSTRACT

The aim of the study presented in this paper was to establish if a relationship existed between lower limb muscle pre-activation strategies and vertical stiffness (K_{vert}). Participants from a professional rugby union club all performed a multidirectional hopping task on a force platform which measured K_{vert}. Muscle activity was concurrently measured for the gluteus maximus, vastus lateralis, vastus medialis, biceps femoris, semimembranosus, and medial gastrocnemius using electromyography and the activity of those muscles in the 100 ms prior to foot contact (pre-activation) was analysed. Moderate to strong positive relationships were typically seen for K_{vert} and muscle pre-activation for each muscle when normalized to maximum voluntary contraction. Pre-activation cocontraction of the muscles surrounding the knee joint also showed a typically moderate relationship with K_{vert} and peak muscle activation of antagonist muscles at the knee joint were typically similar. Results suggest that muscle pre-activation strategies play a role in modulating K_{vert} for change of direction manoeuvre.

1. Introduction

Stiffness in the human body requires the interaction of anatomical structures such as tendons, ligaments, muscles, cartilage and bone to resist change once ground reaction forces or moments are applied (Brughelli and Cronin, 2008; Serpell et al., 2012). The ‘stiffness’ concept is derived from Hooke’s law which states that the force required to deform an object is related to a proportionality constant (spring) and the distance that object is deformed (Austin et al., 2002; Butler et al., 2003). Often the human body, or body segments, are modelled as a spring (Butler et al., 2003). For instance, vertical stiffness (K_{vert}) is considered the quotient of maximum ground reaction force (GRF) and centre of mass (COM) displacement (Serpell et al., 2012). Not surprisingly, therefore, it has been argued that stiffness increases are partly due to increased muscle tension (Farley et al., 1998; Hobara et al., 2010; Horita et al., 2002; Spurrs et al., 2003). Some have argued that the increased muscle tension is a function of increased muscle pre-activation (particularly in the calves) (Hobara et al., 2010; Kuitunen et al., 2002, 2007; Muller et al., 2010; Spurrs et al., 2003), some have argued that it is a function of changed touch down angle at foot plant which may be modulated by knee joint muscle pre-activation (Farley et al., 1998; Horita et al., 2002; Muller et al., 2010). Regardless of the exact mechanism, results from these studies combined certainly suggest that K_{vert} is affected by muscle pre-activation at some level. Pre-activation in stiffness studies has typically been measured using electromyography (EMG) and considered muscle activity in the 100 ms prior to ground contact (Farley et al., 1998; Hobara et al., 2010; Horita et al., 2002; Kuitunen et al., 2002, 2007; Muller et al., 2010). However, it is important to note that while previous literature has postulated a link between muscle pre-activation and stiffness, some has only posed the connection theoretically, sometimes without even direct measurement of muscle activity (Farley et al., 1998; Spurrs et al., 2003). Other work has been largely inconsistent in measurement methods, and task selection has varied considerably which questions ecological validity of the studies (Hobara et al.,

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2010; Horita et al., 2002; Kuitunen et al., 2002, 2007; Muller et al., 2010).

Generally speaking, muscle activation prior to foot contact (that is, during the pre-activation period) is centrally programmed (Hobara et al., 2010; Mrachacz-Kersting et al., 2006). Activity in the early part of ground contact is a continuation of that centrally programmed function and also a function of the short latency stretch reflex response with the contribution of the pre-programmed function diminishing (Hobara et al., 2010; Mrachacz-Kersting et al., 2006). Thereafter it is likely to shift toward a supraspinal response of exponentially increasing contribution (Hobara et al., 2010). The magnitude of the short latency reflex response, therefore, may be affected by the amount of pre-activation. For instance, with high pre-activation, the 'amount' of activity 'allowable' from the short latency reflex response may decline given stretch may not be as great. Previous work which has measured muscle pre-activation has typically shown that gastrocnemius and soleus activation continually increases prior to ground contact (Horita et al., 2002; Kuitunen et al., 2002); that the level of pre-activation between the four quadriceps muscles and between the three hamstrings is not uniform (Butler et al., 2003; Hobara et al., 2010; Horita et al., 2002; Kuitunen et al., 2002); and that increased net quadriceps pre-activation relative to net hamstring pre-activation (antagonistic pre-activation co-contraction) may also be observed with increased speed and stiffness (Hobara et al., 2010; Kuitunen et al., 2002). However, studies which have discussed the role of muscle pre-activation K_{vert} or leg stiffness are limited by an inconsistency in analysis methodologies; with some reporting on filtered raw data (Horita et al., 2002; Kuitunen et al., 2002, 2007) whereas others have reported on muscle activation normalized to maximum voluntary contraction (MVC) (Farley et al., 1998; Hobara et al., 2010; Muller et al., 2010). Furthermore, only one study has actually discussed in detail the role of agonist to antagonist muscle activation for reducing COM displacement and subsequently increasing stiffness (Hobara et al., 2010); most typically only discuss pre-activation of individual muscles in isolation of each other. From a theoretical standpoint pre-activation of a single muscle is likely only to be loosely related to K_{vert} or leg stiffness as it does not provide any indication of muscle tension on either side of the joint. Where tension is not close to even on either side of the joint increased flexion angles will likely be observed and large displacements of COM or large reductions in leg length will ensue (Hobara et al., 2010); suggesting low stiffness considering Hooke's law.

A gap in the research also exists when it concerns task selection for measuring muscle pre-activation and stiffness. The relationship between stiffness and muscle activation has only been measured from straight line running tasks or hopping tasks, sometimes at controlled frequencies (Farley et al., 1998; Hobara et al., 2010; Horita et al., 2002; Kuitunen et al., 2002, 2007; Muller et al., 2010). Running tasks should be preferred due to their ecological validity, however it is understandable that hopping tasks are used in stiffness research as equipment and logistical constraints make it difficult to measure ground reaction force for over-ground running. If hopping tasks are used then hopping frequency should not be controlled as it is known that the natural frequency of the spring-mass system while hopping is equal to step frequency for slow gait tasks, but not for fast gaits (Cavagna et al., 1988). Therefore, controlling hopping frequency could slow the system from its natural running frequency, and consequently absolute stiffness of the spring mass system will not be measured rather just stiffness at submaximal pace. This is likely due to thigh muscle activation being able to modulate K_{vert} (Hobara et al., 2009). As such, athletes can consciously alter their vertical stiffness by increasing knee flexion (Butler et al., 2003). An argument for controlling hop frequency may be that by doing so athletes give less thought to altering pre-activation strategies; however this is yet to be proven. Provided good reliability can be observed, it should be preferable to reduce conscious alteration of stiffness by simply requiring participants to hop with maximal effort with as little ground contact as possible.

Finally, as noted earlier, all work to date has examined stiffness and muscle pre-activation for straight line/sagittal plane tasks only. However, in sports where agility is a key performance indicator (e.g. the football codes and other field and court sports), stiffness while changing direction is important and therefore deserves more attention.

The aims of this project were firstly to establish if a relationship between muscle pre-activation strategies and K_{vert} for a single leg multidirectional hopping task existed which stressed the lower limbs similarly to change of direction running; and secondly, to determine if peak activation in the pre-activation period and the timing of that peak activation for each muscle was the same as that for their respective agonist muscles.

2. Methods

2.1. Experimental approach

The study presented in this paper was a cross-sectional correlational study with participants all from a single professional rugby club. They were asked to complete a 90 degree power-cut hop on and off a force platform at varying distances from the centre of the force platform, all bare foot. A power-cut hop was a single leg exercise requiring a jump at an angle of 45 degrees in the ipsilateral direction onto a designated point on the force platform, landing on the ipsilateral leg and hopping off as quick as possible at an angle of 90 degrees to land on the same leg at the set distance (see Fig. 1). Hops were performed at three distances to simulate change of direction at different speed. The test procedures were completed twice; the first occasion was for familiarisation. On the second testing occasion muscle activity was measured using EMG. The leg participants chose to hop on was self-selected.

2.2. Participants

Twenty males, all from a single professional rugby union club, agreed to participate in this study. Participant age, stature and body mass was 24.0 ± 4.4 years, 185.3 ± 11.9 cm and 100.6 ± 18.5 kg (mean ± SD) respectively. All were healthy with no history of lower limb injury in the 12 months prior to data collection.

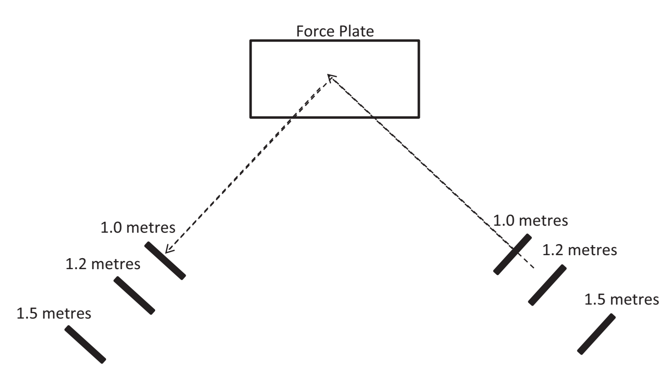

Fig. 1. Power-cut hop test. In the above diagram the participant would be completing a right foot 1.0 m power-cut hop. That is, off their right foot they would leave the 1.0 m mark on the right of the diagram and land on, and jump off, their right foot on the force plate as quick as possible before landing past the 1.0 m mark on the left of the diagram on their right foot.