MUSCLE ACTIVATION PATTERNS AT THE KNEE JOINT DURING UNANTICIPATED SIDESTEPPING TASKS

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The purpose of this paper was to investigate the muscle activation patterns during pre-planned (PP) and unanticipated (UN) sidestepping tasks, with respect to the external moments applied to the joint. Ten healthy male subjects performed running and sidestepping tasks under PP and UN conditions. Activation from ten knee muscles was estimated using surface EMG and averaged across stages of the stance phase. Selective activation of medial and lateral muscles and co-contraction of flexors and extensors were used to stabilise the joint under PP conditions, whereas only generalised co-contraction strategies were employed during the UN condition. Net muscle activation during the UN sidestepping tasks only increased by 10-20%, compared with the 200% increase in external joint load. This study has implications for the prevention of ligament injuries.

KEY WORDS: knee, muscle activation, ligament injury, sidestepping

INTRODUCTION: Unanticipated (UN) sidestepping tasks have been shown to increase the valgus and internal rotation moments at the knee as much as 200% compared with sidestepping manoeuvres that are pre-planned (PP) (Besier et al., 2001). These loads, coupled with an external flexion moment during stance phase, are hypothesised to be responsible for non-contact anterior cruciate ligament injury. Muscles have the ability to support these applied loads and reduce the potential for ligament loading, owing to their anatomical moment arms. Whether they are activated to do so during dynamic PP and UN sidestepping tasks remains to be seen.

When destabilising forces are anticipated during standing, the central nervous system (CNS) is capable of adjusting muscle activation patterns to oppose these forces, supporting the notion that anticipatory postural adjustments are planned in detail (Benvenuti et al., 1997). However, the pre-programmed nature of these postural adjustments suggests there may be insufficient time for the CNS to plan appropriate activation strategies to account for large increases in joint loads during UN sidestepping tasks. Indeed, lack of appropriate postural adjustments are hypothesised to be responsible for the large increase in externally applied joint loads during UN sidestepping tasks (Besier et al., 2001).

The CNS adopts two neural strategies to counter the external loads applied to the knee joint. The first strategy involves ‘selective activation’ of muscles with moment arms that counter the external load (e.g. increased quadriceps activation to counter an external flexion moment). The second strategy involves the activation of flexor and extensor muscles in concert, or ‘co-contraction’, to counter any external load applied to the joint. Both strategies stabilise the knee joint during static/isometric varus/valgus (VV) tasks (Buchanan et al., 1996; Lloyd and Buchanan, 1996, 2001). It is hypothesised that different neural strategies will be employed during the PP and UN sidestepping tasks, based upon the anticipation of the forth-coming movement.

Joint mechanics may also play a role in the selection of muscle activation patterns. The condylar joint, for example, is suited to co-contraction strategies to support external loads in the frontal plane, as the axis of rotation can shift between condyles depending on the external VV load applied (Figure 1). This simplifies the task of the CNS to stabilise the joint in the frontal plane, as muscle forces do not have to be adjusted according to the predicted VV moment at the joint. Rather, the CNS can employ a more general strategy of co-contraction, with joint stability maintained by changes in VV moment arm alone.

The purpose of this paper was to investigate two fundamental questions. Firstly, can the CNS anticipate the external VV loads and adjust the activation of medial or lateral muscle groups accordingly, or does the CNS use a general co-contraction strategy to counter the large increase in joint loads? Secondly, does the CNS have time to adjust muscle activation patterns during sidestepping tasks that are unanticipated?

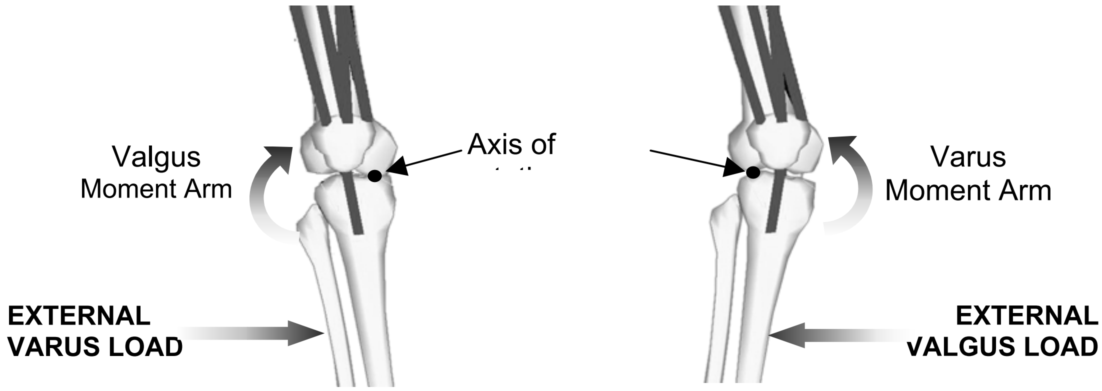

Figure 1 - Change in varus/valgus axis of rotation with applied varus/valgus moments. Note the ability of quadriceps to produce varus AND valgus moments, depending on the external load applied to the joint. Images courtesy of Musculographics Inc.

METHODS: Ten male subjects performed five PP and five UN running and sidestepping manoeuvres at 3 m/s in our gait laboratory. Sidestepping tasks were performed at 30º and 60º from the direction of travel (S30 and S60, respectively). The UN condition was simulated using a set of target LED's, such that the subjects had to make a split-second decision regarding which direction to move. Joint kinematics and kinetics were collected using a VICON motion analysis system (Oxford Metrics) in conjunction with an AMTI force plate. Activation of ten muscles surrounding the right knee were estimated using surface EMG collected at 2000 Hz. Raw EMG were high pass filtered (30Hz), then full-wave rectified and low pass filtered (6Hz) to obtain a 'linear envelope'. Maximum activation for each muscle during the PP running task was used to normalise the data.

Mean activation from each muscle were then calculated at the following periods around stance phase: Pre-Contact (PC) – 50 ms prior to heel-strike up to heel-strike; Weight-Acceptance (WA) – from heel-strike to first trough in ground reaction force; and Peak Push Off (PPO) – 10% either side of peak resultant ground reaction force. Net muscle activation was also determined as the mean activation of all muscles at each stage of stance.

To determine if medial or lateral muscles were selectively activated to counter the VV applied to the joint, muscles were grouped according to their respective varus or valgus moment arms. Average 'medial' and 'lateral' muscle activation were then determined.

Co-contraction ratio's (CCR's) were calculated at each stage of stance, using the mean activation of flexor and extensor muscles, with a ratio of 1.0 equivalent to pure co-contraction. As the CCR does not take into account the overall activation of the muscles', co-contraction indices (CCI's) were calculated as the product of the CCR and mean activation of flexor and extensor muscles. Mean muscle activation and CCI's during PP and UN conditions were compared using a three-way ANOVA (task $\times$ condition $\times$ stage of stance).

RESULTS AND DISCUSSION: Compared to the running (RUN) task, the sidestepping tasks had significantly greater muscle activation during the PP condition (~46% and 35% increase across all stages for S60 and S30, respectively, $p < 0.05$). These increases in activation were proportional to the magnitude of the applied joint moments, and were evident prior to initial foot contact, supporting the notion that muscle activation patterns are pre-programmed.

Selected activation of medial muscles occurred during the PP sidestepping tasks, with an average of 25% more activation than the lateral muscles at PC and WA compared to the RUN ($p<0.05$). This increase in activation is likely to provide support for the increased external valgus load applied to the joint during the sidestepping tasks compared to the RUN. Toussaint et al.

(1998) showed that previous experience in performing a task altered pre-programmed postural movements required to perform that skill. Previous experience in performing sidestepping tasks appears to change the muscle activation strategies in such a way as to promote the activation of medial muscles to counter the external valgus load. The ratio of flexor and extensor activation (CCR) was similar for all tasks, however, the increased activation during the sidestepping tasks meant that the CCI's during the sidestepping tasks were also significantly greater than the RUN ($p<0.05$). This indicates that when large loads are anticipated at the knee during sidestepping tasks, the CNS increases both flexor/extensor co-contraction and selected activation of medial muscles to stabilise the joint.

During the UN sidestepping tasks, the net muscle activation increased compared to the PP condition ($p < 0.05$, Figure 2), indicating that the CNS adjusted for the unanticipated nature of the task. However, these increases were small (~10-20%) compared to the 200% increase in valgus and internal rotation moments during these tasks (Besier et al., 2001) and may not be sufficient to prevent loading of ligamentous structures. Net activation during the UN RUN increased by only 5% compared to the PP condition, which was similar to the change in external joint moments. However, these changes were not significant (Figure 2).

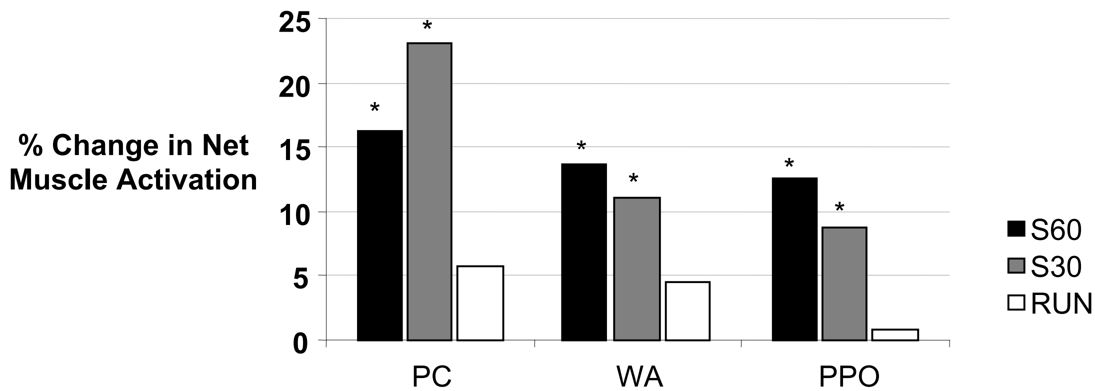

Figure 2 - Percentage change in muscle activation during unanticipated conditions compared to pre-planned conditions. * indicates significant difference to pre-planned condition ($p < 0.05$). S60 – 60º sidestep, S30 -30º sidestep, PC – Pre-Contact, WA – Weight Acceptance, PPO – Peak Push Off.

In terms of the neural strategy to perform the UN sidestepping tasks, there was no evidence of selected muscle activation patterns between medial and lateral muscle groups. Instead, a generalised co-contraction strategy was adopted to perform the tasks. The ratio of flexor/extensor muscle activation (CCR) was similar between PP and UN sidestepping tasks but the general increase in net activation accounted for an increase in the CCI's (19% and 15% at PC and WA, respectively during the UN S60, $p < 0.05$). There was also an increase in the CCI for the UN S30 task at PC of 28% ($p < 0.001$).

These findings support previous research showing increased lower limb co-contraction with tasks that require high levels of stability (Llewellyn et al., 1990). Lloyd and Buchanan (2001) suggested dual goals of the neuromotor system to support isometric VV loads at the knee, one of which was to provide joint stability using combinations of selected muscle activation strategies and co-contraction. There is no doubt that the combined loads applied to the knee joint during PP and UN sidestepping tasks challenged the stability of the joint (Besier et al., 2001), and it also appears that the CNS endeavours to optimise neural strategies to maintain joint stability during dynamic tasks, but maybe less effective in UN tasks.

Ultimately, the goal of this research is to reduce the incidence of knee ligament injury in sport. Altering the pre-programmed activation patterns of muscle surrounding the knee joint to optimise stability is one way in which this goal can be achieved. The question must then be asked: can activation strategies be 'trained' or optimised to protect knee joint ligaments, and if so, what is the best form of training?

Although co-contraction appears to be centrally controlled as a feed-forward neural strategy, the level of co-contraction can also be modulated by proprioceptive afferent feedback (Levin et al., 1995). Selected muscle activation strategies can also be adopted by stimulation of ligament-based mechanoreceptors in the knee (Kim et al., 1995). These findings suggest that pre-programmed activation strategies can be altered to provide joint stability via afferent feedback.
As co-contraction was the dominant neural strategy adopted to stabilise the knee joint during UN sidestepping tasks, a training modality should focus on improving co-contraction at the knee joint during these dynamic tasks. The potential to adjust pre-programmed activation patterns has been shown recently in a three-week wobble board training programme administered to soccer players (Besier et al., 2000). Following this training intervention, CCI's increased by as much as 20% at PC during UN sidestepping tasks (Besier et al., 2000). Further research is still required to determine the most appropriate form of training to maintain knee joint stability and to understand the mechanisms underlying these neural adaptations.

CONCLUSION: Selected activation of medial muscles and co-contraction of flexor and extensor muscles were used to stabilise the knee joint during PP sidestepping manoeuvres, whereas a generalised co-contraction strategy was evident when the tasks were unanticipated. Training modalities should concentrate on altering these pre-programmed activation strategies to provide knee joint stability and reduce the potential load placed on ligaments during unanticipated tasks.

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