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THE EFFECTS OF BALANCE TRAINING ON NEUROMODULATION OF CUTTING MANOEUVRES

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SUMMARY
Unexpected changes in the environment, as well as overloading during specific movements such as landing and cutting manoeuvres account for a high number of lower limb injuries during sports. Balance training has been proven to reduce injury incidence, however, the underlying mechanisms behind the improvements are poorly addressed.

In this study we investigated the effects of 6 weeks of balance training on balance recovery during perturbed cutting manoeuvres. Subjects performed cutting manoeuvres and suddenly a last trial was perturbed at initial contact by using a moveable platform. Surface electromyography (EMG) was recorded from 16 muscles of the lower limbs and trunk for the extraction of motor modules.

No alterations to motor module organization during the unperturbed cutting manoeuvres were imposed by the training. On the other hand, when perturbations were elicited, the motor modules especially related to the recruitment of trunk and proximal hip muscles were altered in both their temporal and spatial properties. In conclusion, balance training may adapt neural control of trunk muscles so that perturbations have reduced effect on balance and the task can be performed with more safety.

INTRODUCTION
Sudden changes in joint loading may represent a potential risk to the lower limb joints during environmental changes such as slippery surfaces. Recent studies have shown that when perturbations to balance are elicited during cutting manoeuvres, knee and hip muscles change their activation shortly after the event, which might reduce potential joint stability [1]. Moreover, the neural control of the main muscles from the lower limb and trunk was altered by perturbations [2].

Balance training can reduce knee joint loading during cutting manoeuvres [3], being an essential component of team sports. Although already proven as effective in reducing joint loading, the underlying neural mechanisms which allow balance training to improve motor gesture remains unknown. Therefore, the aim of this study was to verify whether balance training can influence the neural control of cutting manoeuvres – investigating by extracting muscle synergies or motor modules – performed with and without perturbations to balance.

METHODS
Twenty-three healthy men volunteered for the experiment. These subjects were randomly assigned to a training group (TG, n=13, age: 28±4 yrs; body mass: 69±8 kg; body height: 173±5 cm) or a control group (CG, n=10, age: 25±3 yrs; body mass: 72±8 kg; body height: 172±3 cm).

Pre-training and post-training measurements consisted of a single session each during which the subjects were asked to perform repeated 90° cutting manoeuvres. Subjects performed 11 cutting trials instructed to accelerate in a straight path towards the force platform, stepping with the right foot over it and turn as fast as possible to the left. Without any warning, a perturbation to the moveable force platform was elicited at initial contact during the 11th trial. The perturbation consisted of 10 cm translation lasting 150 ms (average speed 66.6 cm/s) in the original running direction. The training protocol consisted of six weeks (24 sessions) of balance exercises for the right limb exclusively. A detailed description of the training protocol is provided elsewhere [4].

Pre- and post-training surface EMG signals were recorded from the following muscles of the right side: tibialis anterior (TA), peroneus longus (PER), soleus (SOL), gastrocnemius medialis (GM), vastus medialis (VM), vastus lateralis (VL), rectus femoris (RF), biceps femoris (BF), semitendinosus (ST), adductor muscles (ADD), gluteus medius (GME), gluteus maximus (GMA), tensor fascia latae (TFL), erector spinae at L1 (ESP), rectus abdominis (RAB) and external obliquus (EOB). The EMG signals were amplified with a gain of 2,000 (EMG-USB, LISiN; OT Bioelettronica, Turin, Italy), sampled at 2,048 Hz (12 bits per sample), band-pass filtered (second-order, zero lag Butterworth, bandwidth 10–500 Hz).

The segmentation for EMG factorization was defined from the left initial contact prior the right foot step onto the force platform to the end of the stance phase on the force platform. For each subject, non-negative matrix factorization (NMF) [5,6] was applied for each trial in order to identify motor modules and activation signals as detailed in previous studies [2,6].

The number of necessary motor modules to reconstruct the original EMG signals was defined by dimensionality analysis [5,6,7]. Motor modules and activation signals from unperturbed (UPT) and perturbed cutting manoeuvres (PTB) were compared pre- and post-training by similarity analysis, defined by scalar products between the two compared vectors [5,6,7]. In addition, the burst duration (defined as the period in which the activation signals remains higher than 50% of its peak) for each activation signal was determined and compared between UPT and PTB.

RESULTS AND DISCUSSION

Dimensionality analysis revealed that five motor modules were sufficient to reconstruct cutting manoeuvres with high levels of variance accounted for (CG UPT = 0.92±0.02; CG PTB 0.85±0.05; TG UPT = 0.91±0.02; TG PTB = 0.86±0.04).

High levels of similarity were found between motor modules extracted before and after training for UNP in both TG and CG (average similarity = 0.92±0.03). CG similarity for PTB was also high (0.90±0.06), whereas TG similarity for PTB was reduced (Figure 1 left panel shows the five concatenated motor modules and their respective similarities. The mean similarity was 0.82±0.09).

The reduced similarity for PTB in the TG after training was related to a reduced activation of RAB after training in module 1; also, an increased weighting for the gluteus muscles (GME and GMA) and RAB after training in M2. In M4, there were increased weightings for ADD and ESP muscles, whereas the weighting for EOB was reduced. The missing activation of RAB was included in M5 after training, together with an increased weighting for EOB muscle.

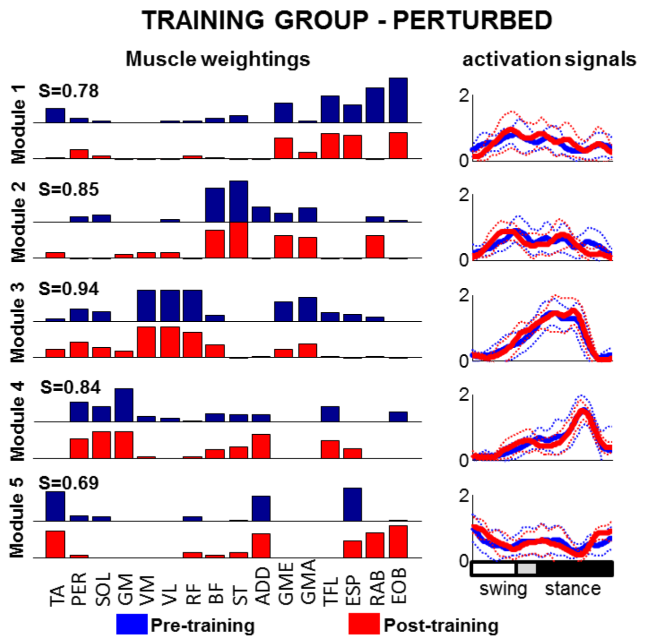

Figure 1: Muscle weightings and activation signals extracted from non-negative matrix factorization (NMF) for perturbed cutting manoeuvres before (*blue*) and after 6 weeks of balance training (*red*). Abbreviations for muscle names are described in the methods.

No significant differences in the burst duration of the activation signals between pre- and post-training were found for CG in both UPT and PTB conditions, as well as for UPT in the TG (2-way ANOVA, $p<0.05$, Figure 1, right panel). However, burst duration was increased for M2 (pre=20.3±9.4%; post=30.1±9.2%, $p<0.01$).

Balance training implemented changes in the modular organization of the task, by enhancing activation of trunk and hip stabilizers during landing and propulsion when perturbations were elicited. These results suggest that balance training is effective in altering muscle recruitment in order to optimize postural responses in an overall motor control context.

Previous investigations have suggested that improved core stability is essential to reduce injury risks [8,9]. The present results corroborate to this assumption since there were predominant changes in modulation of trunk and proximal hip muscles for both muscle weightings and activation signals. This may suggest that improvements on core stability are the main mechanism to improve balance recovery after training. In addition, motor module 2 is almost exclusively related to hamstring muscles [6], which also contribute to knee stability. Therefore the prolonged burst duration after training may suggest additional protection during perturbations for the knee joint, being a crucial adaptation to maintain joint stability in unexpected events.

CONCLUSIONS

We conclude that improvements of balance recovery from balance/neuromuscular training may be at least partially explained by adaptations on the modular control of trunk (RAB, EOB and ESP) and proximal hip muscles originating in the pelvic region (ADD, GME and GMA). Therefore, unexpected perturbations to balance are better accommodated by the recruitment of adapted motor modules, with some but minor adjustments in the timing for their activation.

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