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Anticipation of direction and time of perturbation modulates the onset latency of trunk muscle responses during sitting perturbations

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ABSTRACT

Trunk muscles are responsible for maintaining trunk stability during sitting. However, the effects of anticipation of perturbation on trunk muscle responses are not well understood. The objectives of this study were to identify the responses of trunk muscles to sudden support surface translations and quantify the effects of anticipation of direction and time of perturbation on the trunk neuromuscular responses. Twelve able-bodied individuals participated in the study. Participants were seated on a kneeling chair and support surface translations were applied in the forward and backward directions with and without direction and time of perturbation cues. The trunk started moving on average approximately 40 ms after the perturbation. During unanticipated perturbations, average latencies of the trunk muscle contractions were in the range between 103.4 and 117.4 ms. When participants anticipated the perturbations, trunk muscle latencies were reduced by 16.8 ± 10.0 ms and the time it took the trunk to reach maximum velocity was also reduced, suggesting a biomechanical advantage caused by faster muscle responses. These results suggested that trunk muscles have medium latency responses and use reflexive mechanisms. Moreover, anticipation of perturbation decreased trunk muscles latencies, suggesting that the central nervous system modulated readiness of the trunk based on anticipatory information.

1. Introduction

The neuromuscular system of the trunk is mainly responsible for maintaining trunk stability during sitting and standing (Preuss and Fung, 2008). Muscle activations following disruption of quiet sitting (Masani et al., 2009; Milosevic et al., 2012; Preuss and Fung, 2008; Shahvarpour et al., 2015) and standing (Carpenter et al., 2008; Cresswell et al., 1994; Preuss and Fung, 2008; Stokes et al., 2000; Wilder et al., 1996) have previously been studied with the objective to better understand the neural mechanisms responsible for trunk stability. Perturbations were delivered in the form of direct perturbation to the trunk (i.e., pushing or pulling of the trunk) (Masani et al., 2009; Milosevic et al., 2012; Shahvarpour et al., 2015; Stokes et al., 2000; Wilder et al., 1996) or by perturbing the surface on which the individual was sitting or standing (Carpenter et al., 2008; Preuss and Fung, 2008). During such experiments, the type of perturbation (Carpenter et al., 2008), the direction of perturbation and the posture of the participant prior to the perturbation (i.e., sitting or standing posture) (Preuss and Fung, 2008) play a critical role in the response to the perturbation. The latencies of the trunk muscle activations with respect to the onset of perturbation were reported in the range between 24–55 ms (Cresswell et al., 1994) and 25–150 ms (Stokes et al., 2000) during standing trunk loading, and 100–200 ms during standing and 70–250 ms during sitting support surface translations (Preuss and Fung, 2008). Muscle response latencies in the range between 30–50 ms are generally classified as monosynaptic stretch reflexes (M1); 50–80 ms are classified as functional polysynaptic stretch reflexes (M2); 80–120 ms are classified as triggered reactions; and 120–180 ms are classified as voluntary reactions (M3) (Schmidt and Lee, 2011; Wilder et al., 1996). Previously, it has been suggested that that the trunk neuromuscular system, in response to

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sudden perturbations, has short latency responses based on monosynaptic reflexes (Granata et al., 2004) or medium latency responses based simple polysynaptic reflexes (Stokes et al., 2000).

Complexity of the central nervous system control of the trunk is revealed in situations when perturbations can be anticipated. Anticipatory postural adjustments are often investigated during internal perturbations, and those studies revealed that anticipation can lead to stiffening of the joints and adjustment of the initial posture before the onset of rapid limb movements (Allison, 2003) or self-loading perturbations (Cresswell et al., 1994) since the subjects prepare for the upcoming perturbation. In case of external perturbations, such as those delivered by direct perturbations of the trunk or by perturbing the surface on which the subject is standing or sitting, neuromuscular responses can be studied with and without the anticipation of perturbation to investigate the effects of anticipating a perturbation. During such perturbations, there are two types of anticipation: (i) spatial anticipation – which is the prediction of typo of perturbation or direction of perturbation; and (ii) temporal anticipation – which is the prediction of the time of perturbation (Wilder et al., 1996). Wilder et al. (1996) reported that the trunk muscle onset response times were affected by temporal anticipation during standing balance, but they did not investigate the effects of spatial and temporal anticipation systematically. Others have reported increased trunk muscle (Aleksiev et al., 1996) and neck muscle (Kuramochi et al., 2004) activations when timing of the external perturbations could be anticipated. However, the effect of anticipation of the perturbation on the trunk neuromuscular responses during sitting is still not well understood. To our knowledge no study has investigated the effect of anticipation of direction and time of perturbation on the neuromuscular responses during sitting support surface translations. Therefore, a systematic investigation of the neuromuscular responses during sitting balance support surface translations, with and without anticipation of direction and time of the perturbation, is required.

We hypothesized that amplitude of the trunk muscle responses will be larger during anticipated perturbations compared to unanticipated perturbations. The objectives of this study were to identify the responses of the trunk muscles to sudden support surface translations during sitting and to quantify the effects of anticipation of direction of perturbation and time of perturbation on modulation of the trunk neuromuscular responses.

2. Methods

2.1. Participants

Twelve healthy, male individuals participated in this study. The age, body mass and height of participants were 26.8 ± 3.3 years, 64.7 ± 7.8 kg, and 171.6 ± 7.8 cm (mean ± SD), respectively. None of the participants had history of neurological or musculoskeletal impairments. Informed consent was obtained from all individual participants included in the study in accordance with the principles of the Declaration of Helsinki. The experimental procedures were approved by the local institutional ethics committee.

2.2. Experimental protocol

Participants were seated on a kneeling chair and were instructed to maintain a relaxed upright posture of the trunk while keeping their arms crossed on their chest. Perturbations in the forward or backward direction were applied as support surface translations using an instrumented treadmill FIT (Bertec, USA). Perturbations were delivered with or without spatial and temporal cues (i.e., direction and time of perturbation, respectively) in the following conditions: (i) both direction and time of the perturbation could not be anticipated ($D^- T^-$); (ii) the direction could not be anticipated, but the time of the perturbation could be anticipated ($D^- T^+$); (iii) the direction could be anticipated, but the time of perturbation could not be anticipated ($D^+ T^-$); and (iv) both direction and time of the perturbation could be anticipated ($D^+ T^+$). In order to examine if the subjects contracted their trunk muscles before the perturbation when the perturbation could be anticipated or if the anticipation only affected the reactive responses, two catch trial conditions were also incorporated: (v) the direction could not be anticipated and the time of perturbation could be anticipated, but the perturbation was not delivered ($Catch^-$); and (vi) both direction and time of perturbation could be anticipated but the perturbation was not delivered ($Catch^+$). In total, 192 randomly ordered trials were recorded for each participant, including 16 repeated trials for each of the six conditions for the forward and backward perturbation direction (i.e., 16 trials × 6 conditions × 2 directions).

Before recording the experimental data, participants were given an opportunity to become familiarized with the experimental procedure. They were perturbed six times in different directions, and these data were not used in the analysis. This was done to ensure that the initial learning of a new task is not contaminating the experimental results.

To prevent fatigue, data was collected in four sessions (48 trials per session) with a 5 min break between sessions. Each of the four sessions lasted approximately 15 min. The session order was randomized between participants.

The direction of perturbation (i.e., spatial cue) was indicated to the participant prior to delivering perturbations using verbal instructions. During two of the four sessions participant could anticipate the perturbation direction. In these sessions, perturbations were always delivered as either forward or backward perturbations during the entire session. In the remaining two sessions, the perturbations were delivered in the forward and backward direction such that the participant could not anticipate which perturbation will be next.

The time of perturbation (i.e., temporal cue) was indicated to the participant in all four sessions, during the conditions with anticipated perturbation time, using an audio signal. The audio signal was a brief tone that occurred 1–3 s before the perturbation, such that the participants would be ready for the perturbations but wouldn't use preparatory actions before the perturbation occurred. The triangle-shaped velocity perturbation was applied over a period of 120 ms. The resultant average perturbation displacement during all trials was 7.3 ± 0.3 cm and the peak acceleration was 12.3 ± 2.7 m/s^2 (mean ± SD). The perturbations displacement and accelerations were equal across experimental conditions. After each perturbation was delivered, the treadmill was slowly returned to the starting position and the next perturbation trial was started after 5–7 s, such that the participants could not anticipate the next perturbations.

2.3. Data acquisition

2.3.1. Trunk muscle electromyography and force signal measurements

Trunk muscle activity was recorded using surface electromyography (EMG) unilaterally on the right side of the body, assuming that the participant has symmetric responses (Masani et al., 2009). Disposable EMG electrodes (Ag–AgCl) with 1 cm separation were placed between the electrodes on the abdominal muscles: rectus abdominis, 3 cm right and 1 cm superior to the umbilicus (RA-1) and rectus abdominis, 3 cm right and 1 cm inferior to the umbilicus (RA-2); as well as erector muscles: thoracic erector spinae, 5 cm right of the T9 spinous process (T9) and lumbar erector spinae, 3 cm right of the L3 spinous process (L3). A reference electrode was placed over the clavicle. These muscles were chosen because they contribute significantly to the anterior–posterior trunk stabil-