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Improvement of anticipatory postural adjustments for balance control: Effect of a single training session

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ABSTRACT

Humans use anticipatory and compensatory postural strategies to maintain and restore balance when perturbed. Inefficient generation and utilization of anticipatory postural adjustments (APAs) is one of the reasons for postural instability. The aim of the study was to investigate the role of training in improvement of APAs and its effect on subsequent control of posture. Thirteen healthy young adults were exposed to predictable external perturbations before and after a single training session consisting of catches of a medicine ball thrown at the shoulder level. 3-D body kinematics, EMG activity of thirteen trunk and lower limb muscles, and ground reaction forces were recorded before and immediately after a single training session. Muscle onsets, EMG integrals, center of pressure (COP), and center of mass (COM) displacements were analyzed during the anticipatory and compensatory phases of postural control. The effect of a single training session was seen as significantly early muscle onsets and larger anticipatory COP displacements. As a result, significantly smaller peak COM displacements were observed after the perturbation indicating greater postural stability. The outcome of this study provides a background for examining the role of training in improvement of APAs and its effect on postural stability in individuals in need.

1. Introduction

Anticipatory postural control strategies are mostly acquired through learning and based on previous experience of the postural disturbance (Massion, 1992; Schmitz et al., 2002; Witherington et al., 2002). Historically, it was considered that APAs are acquired only in preparation for a self-generated perturbation, for example, resulting from a focal movement. Anticipatory postural adjustments were considered to differ from compensatory postural adjustments (CPAs) because their organization was thought to be based on experience in performing intentional actions (Massion, 1992). However, it has long been shown that while APAs are certainly generated prior to an intentional motor action, they are also produced in preparation for an external predictable perturbation. Thus, several studies involving bimanual loading and unloading tasks, have demonstrated the presence of anticipatory adjustments in the postural forearm and the trunk and leg muscles, even in the absence of an explicit voluntary movement (Aruin et al., 2001; Massion, 1992; Shiratori and Latash, 2001). Moreover, the outcome of the experiments where the kinetic energy of the impact could be estimated through visual or proprioceptive cues, confirmed that anticipatory adjustments can be produced based on available visual information about the forthcoming body perturbation (Aruin et al., 2001; Massion, 1992; Shiratori and Latash, 2001). Likewise, it was also shown that APAs are generated in trunk and leg muscles based on an accurate prediction of the timing of the whole body perturbation (induced with pendulum-impact paradigm) using visual inputs (Santos and Aruin, 2008, 2009). Thus, APAs are generated prior to a "predictable" perturbation, irrespective of its internal or external origin.

While APAs are acquired based on previous experiences and learning, they are also capable of short-term adaptation in response to immediate environmental changes. Thus, APAs are scaled according to the actual or perceived level of body stability. For example, in experiments where a standard action initiated a standard perturbation, APA amplitude was reduced in conditions of low initial stability (such as standing on a narrow beam or see-saw) and the magnitude of APAs was scaled according to the magnitude of postural instability (Aruin et al., 1998; Gantchev and Dimitrova, 1996). In some muscles the onset of activation was also delayed as the instability levels increased. Also, the effect of instability was stronger when the direction of perturbation

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coincided with the direction of instability (Aruin et al., 1998). In other experiments, where leg flexions were performed from initial bipedal and unipedal stance conditions, APA amplitudes were reduced when the initial conditions were unstable (unipedal stance) (Nouillot et al., 1992). This suppression of APAs was thought to be protective in nature, since APAs by definition are based on an approximation of the perturbation and they may act as a source of instability if inappropriately executed. Besides the presence of instability, it has been found that the nature of the instability is also important to the generation of APAs. If the instability is due to reduced base of support, APA amplitudes are reduced, however if the instability is due to diminished friction between the feet or shoes and the surface (such as standing on roller skates) or due to other causes that are not mechanical in nature (such as under conditions of muscle vibration that induce postural illusion), APAs are increased in magnitude (Shiratori and Latash, 2000; Slijper and Latash, 2004). At the other extreme are highly stable conditions, wherein APA amplitudes are also reduced, for example in sitting condition (Aruin and Shiratori, 2003), or with an additional finger touch support during arm flexion in standing (Slijper and Latash, 2000) or hand support during rocking on heels movement (Noe et al., 2003). In highly stable conditions, APAs would not be required to maintain equilibrium and they are therefore scaled down. These changes in APAs that occur immediately following modifications in the environmental factors are considered to be short-term adaptations based on sensory cues about the new environmental conditions (Massion, 1992).

On the other hand, changes in feedforward postural strategies that are observed after several trials or after several days of exposure to new environmental conditions signify short-term learning related changes. For example, it was reported that patients with low back pain frequently show delayed anticipatory activation of the deep trunk muscle, transversus abdominis (TrA); such a delay is considered as a consistent marker of dysfunction in trunk motor control (Hodges and Richardson, 1996). Thus, in experiments involving patients with low back pain, a single training session involving isolated voluntary contraction of the TrA muscle in supine resulted in early APA onset in this muscle prior to arm flexion movements (Tsao and Hodges, 2007). Moreover, with 4 weeks of such training early onsets were seen along with consistent activation of this muscle during walking as opposed to phasic activity prior to training (Tsao and Hodges, 2008). These effects were retained at 6 month follow up. Additionally, with training, the patterns of anticipatory activation of the deep trunk muscle seen in individuals with low back pain became closer to the patterns of activity observed in healthy individuals and may have led to possible improvements in symptoms (Tsao and Hodges, 2008).

While motor adaptive changes in APAs have been seen with training, it is not known how training-related modifications in anticipatory postural activity can affect the functional role of APAs, mainly control of equilibrium. Particularly, previous studies on training based changes in APAs have focused on the role of APAs with respect to perturbations that were self-initiated, either directly or indirectly (Massion et al., 1999; Tsao and Hodges, 2007). It is not known how a short training session that involves a functional activity such as catching a ball may affect the generation of APAs prior to a predictable external perturbation and the effect of these motor learning induced changes in APAs on subsequent balance control. Thus, the objective of the study was to investigate the immediate effects of a single training session in enhancing the utilization of anticipatory postural adjustments in balance control of healthy young adults. We hypothesized that early onset of anticipatory muscle activity will be observed following training. This enhanced postural preparation will result in reduced COM and COP peak displacements (indicating greater postural stability) following a predictable external perturbation.

2. Methods

2.1. Subjects

Thirteen healthy young adults (7 males and 6 females) without any neurological or musculoskeletal disorders participated in the study. The mean age of the group was 26.69 ± 3.72 years; mean body mass 68.10 ± 13.61 kg, and mean height 1.74 ± 0.09 m. All the subjects signed a written informed consent approved by the university's Institutional Review Board.

2.2. Experimental set-up and procedure

The subjects participated in a single training session and they were tested twice, before and immediately after the end of training. During the tests the subjects stood on the force platform and were exposed to external perturbations induced by a pendulum (Santos and Aruin, 2008, 2009). A load (mass, m = 3% of the subjects' body weight) was attached to the pendulum next to its distal end (Fig. 1). The subjects were required to receive each pendulum impact with their hands, while their arms, wrists, and fingers were extended at the shoulder level, and to maintain their balance after the perturbation. The impact was induced in a sagittal plane and posterior direction; the amplitude of the pendulum impact when it hit the subject's hands was about 90 Nm. Two to three practice trials were given prior to initial testing. The subjects received a series of predictable perturbations (eyes were open) before (pre-training) and immediately after (post-training) a short training session. Ten trials, each 5 s in duration, were performed in each experimental condition involving assessment with pendulum perturbations.

The training session consisted of 130 catches of a medicine ball thrown at the shoulder level from a distance of 3 m and lasted for about 20–25 min. The catches included the ball being thrown either directly toward the subjects' midline or slightly to the right or left of midline. The subjects caught the ball while standing with feet shoulder width apart. Thus, the training session involved perturbations that were predictable and as such would generate both, APAs and CPAs. A 0.9 or 1.8 kg medicine ball was used for subjects weighing below or above 55 kg, respectively. The weight of the ball and the number of catches were decided based on pilot experiments in which subjects were surveyed about their tolerance to catching balls of different weights. For safety purposes in all the experiments, the subjects wore a harness (NeuroCom, USA) with two straps loosely attached to the ceiling. All participants were allowed to have rest periods as needed.

2.3. Instrumentation

Electromyographic (EMG) activity of thirteen right trunk and lower limb muscles was recorded with disposable surface electrodes (Red Dot 3M). After the skin area was cleaned with alcohol preps, electrodes were attached to the muscle belly of erector spinae longus (ESL, 3 cm lateral to the first lumbar vertebra), rectus abdominis (RA, 3 cm lateral to the umbilicus), external oblique (EO, midpoint on the axial line between the 10th rib and the anterior superior iliac spine (ASIS)), gluteus medius (GMED, midpoint on the line from the iliac crest to the greater trochanter), semitendinosus (ST, midpoint on the line from the ischial tuberosity to the medial epicondyle of the tibia), biceps femoris (BF, midpoint on the line from the ischial tuberosity to the lateral epicondyle of the tibia), vastus lateralis (VL, at 2/3rd on the line between ASIS and the lateral side of the patella), vastus medialis (VM, at lower 25% on the line between ASIS and medial knee joint space), rectus femoris (RF, midpoint on the line from the ASIS to the superior part of the patella), medial gastrocnemius (GASM, on the most