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Relationship between improvements in motor performance and changes in anticipatory postural adjustments during whole-body reaching training

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ABSTRACT

Anticipatory postural adjustments (APAs) provide postural stability and play an important role in ensuring appropriate motor performance. APAs also change in various situations. However, it is unknown whether changes in APAs during repetitive movement training contribute to improvement in motor performance. This study aimed to investigate the relationship between improvement in motor performance and changes in APAs during repeated reaching training, as well as the learning effects on APA changes. Sixteen healthy subjects (23 ± 2 years of age) stood barefoot on a force platform and reached as quickly and accurately as possible to a target placed at their maximum reach distance immediately following a beep signal in a reaction time condition. Whole-body reaching training with the right arm was repeated 100 times for three consecutive days. Motor performance and APAs were evaluated on the first day, after discontinuation of training for one day, and again at three months. In addition, reaching with the left arm (untrained limb) was tested on the first and the fifth training day. Body position segments were measured using three-dimensional motion analysis. Surface electromyography of eight postural muscles in both lower limbs was recorded. Kinetics data were recorded using the force platform. Whole-body reaching training induced not only improvements in motor performance (e.g., increased peak hand velocity), but also changes in APAs (e.g., earlier APA onset and increased amplitude). These changes were strongly correlated with and occurred earlier than improvements in motor performance. The learning effects on APAs were retained after the discontinua-

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tion of training and were generalized to the untrained limb. These results suggest that change in APAs contributes to improvement in motor performance; that is, the central nervous system may be able to adapt APAs for improvement in motor performance.

1. Introduction

Motor learning is a set of processes associated with practice or experience leading to relatively permanent changes in performance parameters and electromyographic activity for movement (Schmidt, 1988). Repetitive training in a motor task leads to improvements in motor performance, which is defined in terms of accuracy, force, reaction time, movement time, and peak velocity (Singer, 1980; Winstein & Schmidt, 1990). In particular, a reaching movement to touch or grasp an object is a motor task commonly used to investigate motor learning mechanisms, and is an important action in daily life. Postural stability is well known to influence the performance of reaching movements. For example, when sitting subjects pushed a bar in front of them with maximal force as rapidly as possible, the push force was enhanced by limiting the area of contact between the thigh and seat (Le Bozec & Bouisset, 2004). The peak hand velocity during an arm pointing task in an erect posture increased when the base of support size was enlarged (Yiou, Hamaoui, & Le Bozec, 2007). Thus, postural control including postural stability may be a major factor for improvements in motor performance.

Changes in postural control are also induced through practice or repeated experience. For example, postural sway and postural responses to repeated rotational or horizontal support surface perturbation clearly decrease after a few cycles when the amplitude of the perturbation is constant (Horak, Diener, & Nashner, 1989; Nashner, 1976). Repeated perturbation training to induce a loss of balance during gait using a low-friction moveable platform (Bhatt, Wening, & Pai, 2006; Pai, Wang, Espy, & Bhatt, 2010), during treadmill stepping over an obstacle with minimal foot clearance and without visual information about the obstacle, which appears with predictable timing (Lam & Dietz, 2004), or during gait on an unexpected soft support surface embedded in hard walkway (Bierbaum, Peper, Karamanidis, & Arampatzis, 2010) leads to rapid adaptation of lower limb reactive responses. In addition, postural stability while standing is improved during the learning of arm movement tasks (Galgon, Shewokis, & Tucker, 2010; Patton, Lee, & Pai, 2000). However, the relationship between improvements in motor performance and changes in postural control are unclear. That is, it remains unknown whether positive changes in postural control by repetitive motor training (e.g., the increased amplitude and prolonged duration of postural muscle activity) lead to improvements in motor performance, and whether the learning processes of postural control are similar to those of motor control.

To perform functional and accurate arm movement while standing, postural compensations for predictable perturbations created by self-initiated movements, such as raising an arm (Bouisset & Zattara, 1987) or releasing a load (Aruin & Latash, 1995), are required (Cordo & Nashner, 1982; Oddsson & Thorstensson, 1987). In this regard, APAs are observed as changes in postural muscle activity (Kaminski & Simpkins, 2001; Santos, Kanekar, & Aruin, 2010) and center of pressure (COP) displacements (Yiou et al., 2007) prior to the onset of a focal movement. The roles of APAs are to reduce postural disturbance due to a forthcoming perturbation (Bouisset & Zattara, 1981) and create a driving force to initiate forward whole-body movement when the reaching movement is directed to a target placed at a distance greater than arm length while standing (Oddsson & Thorstensson, 1987; Stapley, Pozzo, & Grishin, 1998; Tyler & Karst, 2004). Several studies reported that the central nervous system (CNS) adequately modulates anticipatory postural responses to compensate for focal movement performance depending on the amount of bodily support provided for stability (Friedli, Hallett, & Simon, 1984; van der Fits, Klip, van Eykern, & Hadders-Algra, 1998), the difference in target size and distance (Bonnetblanc, Martin, & Teasdale, 2004; Kaminski & Simpkins, 2001), and growth (Assaiante, Mallau, Viel, Jover, & Schmitz, 2005; Schmitz, Martin, & Assaiante, 2002). Furthermore, some studies have reported a relationship between APAs and motor performance. During pointing