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Postural challenge affects motor cortical activity in young and old adults

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ABSTRACT

When humans voluntarily activate a muscle, intracortical inhibition decreases. Such a decrease also occurs in the presence of a postural challenge and more so with increasing age. Here, we examined age-related changes in motor cortical activity during postural and non-postural contractions with varying levels of postural challenge. Fourteen young (age 22) and twelve old adults (age 70) performed three conditions: (1) voluntary contraction of the soleus muscle in sitting and (2) leaning forward while standing with and (3) without being supported. Subthreshold transcranial magnetic stimulation was applied to the soleus motor area suppressing ongoing EMG, as an index of motor cortical activity. The area of EMG suppression was ~60% smaller ($p < 0.05$) in unsupported vs. supported leaning and sitting, with no difference between these latter two conditions ($p > 0.05$). Even though in absolute terms young compared with old adults leaned farther ($p = 0.018$), there was no age effect or an age by condition interaction in EMG suppression. Leaning closer to the maximum without support correlated with less EMG suppression ($rho = -0.44$, $p = 0.034$). We conclude that the critical factor in modulating motor cortical activity was postural challenge and not contraction aim or posture. Age did not affect the motor control strategy as quantified by the modulation of motor cortical activity, but the modulation appeared at a lower task difficulty with increasing age.

1. Introduction

Although historical studies in intact and decerebrate animals identified subcortical neural circuits, especially spinal reflexes, as centers to control upright standing (Sherrington, 1910; Magnus, 1926), recent studies have provided evidence for the involvement of the motor cortex (Tokuno et al., 2009; Taube et al., 2006; Horak et al., 1989; Malouin et al., 2003). However, it remains elusive if the motor cortical control differs between voluntary and postural contractions and if age affects this control (Papegaaij et al., 2014a).

When humans voluntarily activate a muscle, the magnitude of short-interval intracortical inhibition (SICI) decreases (Ridding et al., 1995; Rantalainen et al., 2013; Sharples and Kalmar, 2012; Ortu et al., 2008). It is thought that inhibitory intracortical circuits modulate the excitability of the cortical neurons that project to the spinal motor neurons of the muscles involved in the task (Reis et al., 2008). The degree of reduction in intracortical inhibition is related to contraction intensity (Rantalainen et al., 2013; Ortu et al., 2008), contraction type (Howatson et al., 2011), and whether the movement starts or ends (Sidhu et al., 2013). SICI is also modulated during postural contractions, defined as contractions with the aim to maintain a certain posture, as shown by a reduction in SICI in the soleus muscle during standing as compared with sitting (Soto et al., 2006).

In addition to the aim of the contraction (postural vs. non-postural), postural challenge may also affect inhibition. We define postural challenge as the degree of difficulty one encounters in holding a specific body position. SICI in the tibialis anterior is lower during standing as compared with sitting, even though this muscle is only weakly activated during these tasks (Obata et al., 2014). Such a context-related reduction in SICI suggests that increased postural challenge is coupled with higher motor cortical excitability. A limitation of comparing sitting with standing is that not only postural challenge but also posture itself is different between conditions, which may affect motor cortical excitability (Ginanneschi et al., 2005; Dominici et al., 2005). However, also when normal standing was compared with supported standing, motor cortical excitability in the soleus muscle was higher (Tokuno et al., 2009) and SICI was lower (Papegaaij et al., submitted for publication) during normal standing. The emerging picture is that the motor cortex is involved in postural contractions to control upright standing and that its excitability increases with increasing postural challenge.

There is some evidence that the postural challenge-related increase in motor cortical excitability increases with age. When healthy adults stood on a rigid surface and then on foam, this increase in postural

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challenge resulted in a decrease in SICI in old but not in young adults' tibialis anterior muscle (Papegaaij et al., 2014b). However, this age by condition interaction was not present in normal standing, a relatively easy postural task (Papegaaij et al., submitted for publication; Baudry et al., 2015). Therefore, it is unclear if the modulation between a stable and unstable condition in old adults reflects a different motor control strategy or different relative task difficulty (i.e., the same task being more difficult for old than young adults). Moreover, it is unclear if age affects the motor cortical control of postural and non-postural contractions.

Therefore, the aim of the current study was to examine age-related changes in motor cortical activity during non-postural and postural contractions in a postural challenging and non-challenging context. Subjects were asked to (1) voluntarily contract the soleus muscle during sitting (SIT), (2) lean forward during standing, with support at the chest (SL), and (3) lean forward during standing, without support (UL). These conditions allowed us to disentangle the effects of contraction aim, postural challenge, and posture, and to investigate the interaction with age. To examine motor cortical activity, we applied transcranial magnetic stimulation pulses at subthreshold intensities (subTMS). Such pulses suppress ongoing electromyographic (EMG) activity through the activation of inhibitory intracortical circuits (Davey et al., 1994).

Based on fMRI and TMS studies, suggesting that motor control relies more on cortical structures in old compared with young adults (Papegaaij et al., 2014b; Mattay et al., 2002; Heuninckx et al., 2008; Baudry et al., 2014), we hypothesized an age by condition interaction in motor cortical activity as indexed by TMS-induced EMG suppression. We also expected that the pattern of changes in EMG suppression between the conditions would provide insights into which of the three factors (contraction aim, postural challenge, posture) is critical in modulating motor cortical activity (see Fig. 1). If contraction aim is a critical factor, we would expect a gradual change in TMS-induced EMG suppression from sitting to supported leaning to unsupported leaning. We note that during supported leaning the contraction was a combined postural and non-postural contraction. As support was provided only at the chest, a postural contraction was still needed to prevent the body from buckling at the hip. To reach the target EMG level subjects were instructed to add a small amount of voluntary activation to the ongoing activation produced by the postural contraction, resulting in a mix of voluntary and postural soleus activation. If postural challenge is a critical factor in modulating motor cortical activity, we would expect similar TMS-induced EMG suppression in sitting and supported leaning, with different suppression in unsupported leaning. If posture is critical, we would expect supported and unsupported leaning to be similar, with different TMS-induced EMG suppression in sitting.

2. Materials and methods

2.1. Subjects

Sixteen young (20–31 years) and seventeen old adults (64–83 years) participated in the study (Table 1). Participants were free of neurological or orthopedic conditions, non-dental associated metal within the cranium, did not take neuroactive drugs or drugs known to affect balance, and reported to be not pregnant. General cognitive function was assessed by the Mini-Mental State Examination (MMSE) and physical activity level by the Short Questionnaire to Assess Health-enhancing physical activity (SQUASH). Lower extremity function was evaluated by the Short Physical Performance Battery (SPPB), including standing balance, walking speed and chair stand tests (Guralnik et al., 1994). Before the experiment, all subjects signed an informed consent document approved by the Medical Ethics Committee of the University Medical Center Groningen.

2.2. Experimental protocol

The experiments were conducted in one, 3-hour-long session. Subjects were standing on two force platforms with the feet in a self-selected position that was marked on the force platforms to ensure consistent positioning throughout the experiment (intermalleolar distance, young: 17.3 ± 1.1 cm, old: 14.0 ± 1.1 cm). SubTMS was applied while subjects subsequently performed the following three tasks in a randomized order: unsupported leaning (UL), supported leaning (SL), and sitting (SIT). During UL, subjects were instructed to lean forward by dorsal flexing their ankles while keeping the rest of the body straight. Subjects received online feedback by watching a red ball moving over a black background, representing the movements of the CoP in the anterior–posterior direction. Upward movement of the ball corresponded to a forward shift of the CoP. A dark green horizontal line was set as a CoP target at 75% of the maximum voluntary and unaided forward lean. Thus, task difficulty was adjusted to individual skill level. Two light green horizontal lines at 70% and 80% of the maximum cued the subjects to keep the CoP on the dark green target line and within the

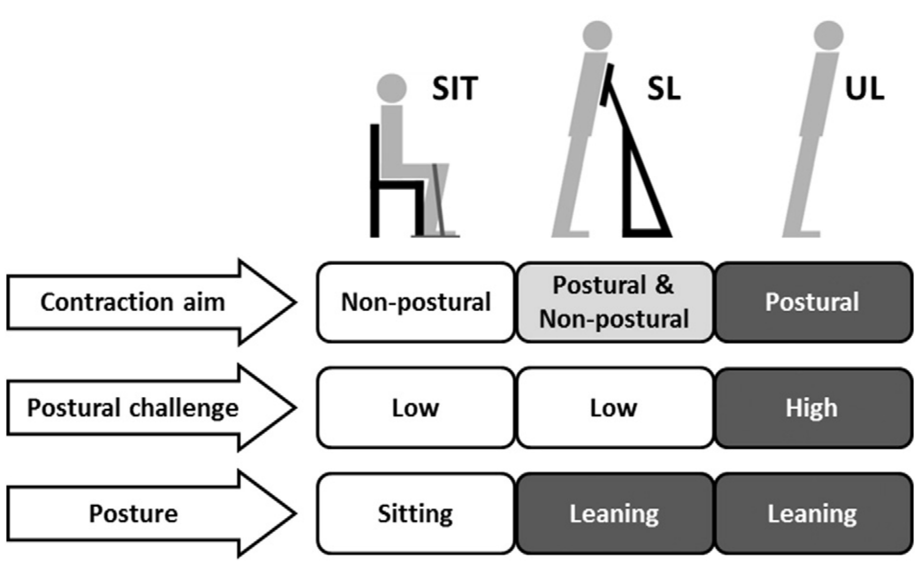

Fig. 1. A summary of experimental conditions and conceptual interactions between three different conditions (sitting — SIT, supported leaning — SL, unsupported leaning — UL) that could influence intracortical inhibition (contraction aim, postural challenge, posture).