Please cite this article in press as: Watanabe T et al. Preparatory state and postural adjustment strategies for choice reaction step initiation. Neuroscience (2016), http://dx.doi.org/10.1016/j.neuroscience.2016.06.055

Neuroscience xxx (2016) xxx–xxx

PREPARATORY STATE AND POSTURAL ADJUSTMENT STRATEGIES FOR CHOICE REACTION STEP INITIATION

TATSUNORI WATANABE,[a] KAZUTO ISHIDA,[a] SHIGEO TANABE[b] AND IPPEI NOJIMA[a]*

[a] *Department of Physical Therapy, Nagoya University Graduate School of Medicine, Aichi 461-8673, Japan*

[b] *Faculty of Rehabilitation, Fujita Health University School of Health Sciences, Aichi 470-1192, Japan*

Abstract—A loud auditory stimulus (LAS) presented simultaneously with a visual imperative stimulus can reduce reaction time (RT) by automatically triggering a movement prepared in the brain and has been used to investigate a movement preparation. It is still under debate whether or not a response is prepared in advance in RT tasks involving choice responses. The purpose of the present study was to investigate the preparatory state of anticipatory postural adjustments (APAs) during a choice reaction step initiation. Thirteen young adults were asked to step forward in response to a visual imperative stimulus in two choice stepping conditions: (i) the responding side is not known and must be selected and (ii) the responding side is known but whether to initiate or inhibit a step response must be selected. LAS was presented randomly and simultaneously with the visual imperative stimulus. LAS significantly increased the occurrence rates of inappropriately initiated APAs while reducing the RTs of correct and incorrect trials in both task conditions, demonstrating that LAS triggered the prepared APA automatically. This observation suggests that APAs are prepared in advance and withheld from release until the appropriate timing during a choice reaction step initiation. The preparatory activity of APAs might be modulated by the inhibitory activity required by the choice tasks. The preparation strategy may be chosen for fast responses and is judged most suitable to comply with the tasks because inappropriately initiated APAs can be corrected without making complete stepping errors.

Key words: anticipatory postural adjustments, choice stepping, gait initiation, preparation, loud auditory stimulus.

*Corresponding author. Address: Department of Physical Therapy, Nagoya University Graduate School of Medicine, 1-1-20 Daiko-Minami, Higashi-ku, Nagoya-shi, Aichi 461-8673, Japan. Fax: +81-0-52-719-1365.
E-mail address: nojima@met.nagoya-u.ac.jp (I. Nojima).
Abbreviations: ANOVA, analysis of variance; APAs, anticipatory postural adjustments; COP, center of pressure; CRT, choice reaction time; EMG, electromyogram; GNG, go/no-go; LAS, loud auditory stimulus; RT, reaction time; SCM, sternocleidomastoid; SD, standard deviation; SEM, standard error of the mean; TA, tibialis anterior.

http://dx.doi.org/10.1016/j.neuroscience.2016.06.055
0306-4522/

INTRODUCTION

Initiation of gait, the transition period from standing to walking, is a seemingly simple but challenging task. This process leads an individual to an unstable posture as she/he stands on a single leg while concurrently swinging the other leg forward to generate the momentum to take a step. The ability to initiate a step quickly and efficiently is a fundamental human skill required for maintaining an upright position and to avoid losing balance and falling. Indeed, recent evidence suggests that a slow stepping reaction time (RT) is related to future falls in the elderly (Lord and Fitzpatrick, 2001; Pijnappels et al., 2010).

Anticipatory postural adjustments (APAs) that occur before the step initiation are the strategies to minimize the postural disturbances and maintain balance (Massion, 1992; Malouin and Richards, 2000; Kaminski and Simpkins, 2001; Timmann and Horak, 2001). APAs include consecutive muscle activations that generate a backward displacement of the center of pressure (COP) toward the swing leg, followed by a forward COP displacement toward the stance leg. This consecution of postural movements unloads the swing leg and creates the forces that propel the body mass into forward motion (Burleigh et al., 1994; Elble et al., 1994). Although the precise neural origin of APA generation is unknown, they are known to be controlled by subcortical mechanisms (Massion, 1992; Schepens and Drew, 2003, 2004) and can be modulated by several cortical mechanisms (e.g., Tard et al., 2013, 2016).

Recently, several studies have indicated that errors in the initial direction of weight transfer, known as APA errors, could occur when there is uncertainty regarding the direction of step initiation and that these may slow the stepping RT, conceivably increasing the risk of falls (e.g., Cohen et al., 2011). As the number of errors increases when performing a stimulus–response incompatibility task, inhibitory control is related to APA errors (Sparto et al., 2013; Uemura et al., 2013; Watanabe et al., 2015). Likewise, in choice RT (CRT) tasks involving hand responses (e.g., button-push tasks), subthreshold electromyogram (EMG) activity of an incorrectly responding hand muscle, known as partial errors, can be detected in trials where the incorrect EMG response precedes the execution of the correct response (e.g., Vidal et al., 2000; Burle et al., 2002, 2008; Masaki et al., 2012). Although these two types of errors seem similar in that neither of them is complete or overt, the error rates are quite different and generally more than two times higher in APA errors than in partial errors (e.g., Schreiber et al., 2011;

Masaki et al., 2012; Uemura et al., 2013; Watanabe et al., 2015). This observation led us to suspect that the difference in error rates is caused by pre-programing or preparation of APA. In other words, even though a required stepping leg is not known in advance (i.e., a CRT task), individuals are likely to prepare APA beforehand, with the prepared APA required to be withheld or inhibited until it needs to be released. Thus, disinhibition of the incorrect APA preparation during the CRT task would make the individuals more liable to APA errors.

The preparation of movements can be assessed using a loud auditory stimulus (LAS). A number of studies have reported, using a simple RT (SRT) paradigm in which the appropriate response is known in advance and thus can be fully prepared before the presentation of an imperative stimulus, that the prepared movements, stored in the subcortical region, are triggered unintentionally by LAS at short latency (e.g., Carlsen et al., 2004b). Based on an activation model, where a movement is initiated when activation of neural network responsible for the movement reaches a threshold (Carpenter and Williams, 1995; Hanes and Schall, 1996), the neural activity develops over time during preparation to a level below the movement threshold, and LAS drives the already elevated neural activity beyond the threshold, resulting in a dramatic reduction of RT (Tresilian and Plooy, 2006; Marinovic et al., 2013, 2014). Accordingly, RT would indicate the time required to reach the movement threshold from the preparatory level (Maslovat et al., 2015). That means, when the preparatory activity is higher, LAS triggers the prepared movement with a shorter latency.

In contrast to SRT tasks, there have been discrepancies in results regarding CRT tasks. Some studies found that the response may be prepared in advance (Kumru et al., 2006; Nijhuis et al., 2007; Maslovat et al., 2011) while others did not (Carlsen et al., 2004a, 2008). In the field of step initiation, it has been shown that APAs are prepared in advance when stepping leg is known beforehand (i.e., a SRT task) and possibly even when the stepping leg selection is required (i.e., a CRT task) (MacKinnon et al., 2007). However, as there was an unequal probability of left and right responses (i.e., there were more right responses) and EMG electrodes were attached only to the right leg, a possible response bias toward the right side was postulated by the authors (MacKinnon et al., 2007). Thus, their study may have unintentionally treated the CRT task as a SRT task, and would, thus, not have been able to properly examine the effects of response conflicts created by the choice task on the APA preparation. Furthermore, the authors failed to examine RTs for error trials, even though reduced RTs are crucial not only in the correct trials but also in the incorrect trials to conclude the preparation of a movement (Carlsen et al., 2008). Surprisingly, no other studies have evaluated the preparatory state during a choice reaction step initiation, although Delval et al. (2012) extended the research on simple step initiation and revealed possible modulation of the APA initiation by the cortex.

In the present study, we examined using LAS whether APAs are prepared during a choice reaction step initiation and how the inhibitory process contributes to APA initiation when the response requires a choice. We replicated the CRT study by MacKinnon et al. (2007) without the response bias and extended the data analysis to provide additional information. We further applied a different type of choice reaction step initiation task, namely, a go/no-go (GNG) task, in which the responding side is known but whether to initiate or inhibit a step response must be selected. Due to the advance information about the responding side, this task may be treated as a SRT task. At the same time, it involves the inhibition of a response, providing more pertinent information about the involvement of an inhibitory process in APA initiation. To compare our results with two previous studies (MacKinnon et al., 2007; Delval et al., 2012), we used the same intensity (115 dB) for LAS. We also focused specifically on the state of APA preparation and not on the effects of APA errors and LAS on the stepping performance, because these were clearly characterized in those and other previous studies (e.g., Cohen et al., 2011). We hypothesized that if an APA is prepared in advance and required to be inhibited from release until the response conflict is resolved during a choice reaction step initiation, then a LAS would trigger the prepared APA unintentionally and possibly inaccurately, increasing the rate of APA errors in the CRT task and inappropriate APA initiations in the no-go trials of the GNG task, shortening the latency of APA in both correct and incorrect trials.

EXPERIMENTAL PROCEDURES

Participants

Thirteen subjects (six males, seven females, mean age ± SD = 22 ± 1.94) from Nagoya University School of Health Sciences and Graduate School of Medicine participated in this study. They had no reported history of hearing, neurological, or orthopedic disorders that could influence the balance function. All had normal or corrected-to-normal vision and were right-leg dominant. The study was approved by the Ethics Committee of Nagoya University, and written informed consent was obtained from each participant before participation.

Protocol

Participants with their feet bare maintained a stationary standing posture on a force plate. The initial standing position was the same for all participants; each foot was placed 5 cm apart from a centerline, vertical to the frontal plane, drawn on the force plate. The participants were instructed to step forward as quickly as possible in response to a visual imperative stimulus that appeared on a computer screen set just below eye level at a distance of 1.0 m from the participant. They stepped forward with the leg specified by the stimulus onto a wood plate placed right front of the force plate and brought the other leg alongside. LAS (1000 Hz, 115 dB) was also delivered randomly and simultaneously with the visual stimuli from two speakers set just behind the head of the participants; we told participants to ignore this. They were instructed to balance the weight of their

Please cite this article in press as: Watanabe T et al. Preparatory state and postural adjustment strategies for choice reaction step initiation. Neuroscience (2016), http://dx.doi.org/10.1016/j.neuroscience.2016.06.055