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ORIGINAL ARTICLE

Change in H-reflex amplitude associated with cognitive load

Manami FUJIWARA-OHYA,[1*] Takahiro HORAGUCHI,[2*] Seigo MINAMI[3]

1Department of Rehabilitation, KitakantoJunkanki Hospital, 2Department of Physical Therapy, Faculty of Rehabilitation, Gunma Paz University, 3Department of Occupational Therapy, Faculty of Rehabilitation, Gunma Paz University

* These two authors contributed equally to this work

Correspondence: Takahiro Horaguchi, PhD, Department of Physical Therapy, Faculty of Rehabilitation, Gunma Paz University, 1-7-1, Tonyamachi, Takasaki-shi, Gunma, 370-0006, Japan. E-mail: horaguchi@paz.ac.jp

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Abstract

During voluntary movements like walking, the spinal cord regulates functions such as motor and posture control and through inputs from higher cortical areas such as the motor cortex, and from peripheral sources such as the skin and muscle spindles. When cognitive processes are involved during voluntary movements, further input from higher cortical areas may also modulate the spinal cord function. To investigate how changes in the functioning of the higher central nervous system responsible for cognitive functions affect spinal cord function, the amplitude of H-reflexes was induced in the gastrocnemius muscle during a choice reaction time task and a numerical comparison task. Response times to visual stimuli increased in the order of the choice reaction time task and the numerical comparison task. Furthermore, the amplitude of the H-reflex increased as the response times increased. Our findings suggest that changes in activity of the higher central nervous system such as the parietal association cortex and the prefrontal cortex (which are thought to be active in this task) may modulate the degree of spinal cord disinhibition and, in turn, regulate motor function.

INTRODUCTION

People go about their lives constantly having some form of thought, irrespective of whether walking or standing still. Voluntary movements like walking and maintaining posture involve the regulation of excitability in alpha motor neurons in the ventral horn of the spinal cord through ascending impulses from proprioceptors such as the skin and muscle spindles (Forssberg, 1979; Nakajima, 2006; Zehr, 1997, 1998) and descending impulses from higher cortical areas like the motor cortex and cerebellum (Kuypers, 1964). Furthermore, when thinking alongside performing activities such as walking, there is potentially the influence of impulses from other higher cortical areas, which might affect spinal cord function.

The H-reflex is one such crucial indicator used to assess spinal cord function (Aagaard, 2002; Clark, 2006). It is an electromyogram evoked by stimulation of the Ia group sensory nerves in the stretch reflex pathway (Wang, 2012). The changes in H-reflex amplitude due to peripheral and cortical activation associated with loading have been widely investigated, but most previous studies have been related to motor and posture control research. One study investigated the amplitude change in H-reflex due to motor imagery task (Oishi, 1994) and did not use an actual motor task. There have been no studies that are purely related to cognitive loads and without association with motor tasks.

The present study therefore aims to investigate whether the amplitude of H-reflexes recorded in the triceps surae changes with an increase in cognitive load unrelated to motor tasks. As a cognitive task, we used a typical choice reaction time task. A black circle appears on the left or right of a computer screen, and participants select it by pressing the corresponding left or right button. We also employed a derivative of this task, a numerical comparison task. In this task, participants choose the larger number between a pair of single-digit numbers presented on the left or right side, again by pressing the corresponding left or right button. This numerical comparison task is generally more difficult compared with the typical choice reaction time task, and reaction times are longer. Furthermore, when the difference between the number pairs is small, there is increased activity in the posterior parietal cortex and there are longer reaction times compared with when there are larger differences in the numbers (Horaguchi, 2008; Ogata, 2011; Pinel, 2001, 2004).

METHODS

Participants

Nineteen healthy student subjects from Gunma Paz University (21.2 ± 0.8 years old, 11 men and 8 women) were recruited. All had normal or corrected-to-normal vision and were right-handed according to the Edinburgh Handedness Inventory. This study was approved by the Gunma Paz University Ethics Committee and was conducted in accordance with the Declaration of Helsinki. Informed consent was obtained after the subjects were provided with information about the purpose and procedures of the study, as well as the potential benefits and risks. Participants completed a consent form before participating in the experiment.

Experimental Procedure

Participants were well-rested before the experiment. They were instructed to lie supine in a comfortable position before the experiment and maintain this position throughout. The monitor of a laptop computer (D430, IBM) was placed 70 cm in front of the participants. During the experiment, to eliminate external noise and to create a concentrated environment, participants wore noise-canceling headphones (Quietcomfort 15, BOSE Corporation, Framingham, MA, USA) and listened to pre-recorded white noise on a portable music player (iPod shuffle, Apple Inc., Cupertino, CA, USA). The tasks below were created using task presentation software (E-prime 2.0, Psychology Tools) and displayed on the computer monitor. The tasks were performed in a random order.

Numerical Comparison Task

Visual stimuli

A red circle fixation point (diameter 0.5°, Figure 1a) was presented in the center of the computer screen. To the left and right of this point at 1.1°, a pair of single-digit numbers (vertical 2.0° × horizontal 0.75°) were presented as visual stimuli. Pairs presented included large differences (6-8) and small differences (1-3), each with 12 variations.

This task required the participant to choose the larger number in the pair of numbers that appeared to the left and right of the fixation point (Figure 1b). Participants were asked to press the left or right cross button (USB mobile controller, JY-PMUW, Sanwa Supply Inc., Okayama City, Japan) held in their dominant hand (right hand) as quickly as possible.

The task began with the presentation of a fixation point in the center of the computer monitor. This fixation point was displayed continuously during the experiment, and participants were instructed to maintain their gaze on it at all times. After 3 or 6 seconds, a pair of numbers appeared to the left and right of the fixation point as visual stimuli. Participants were asked to choose the larger number by pressing the left or right cross button with their dominant thumb as quickly as possible. After making a selection, the pair of numbers disappeared,

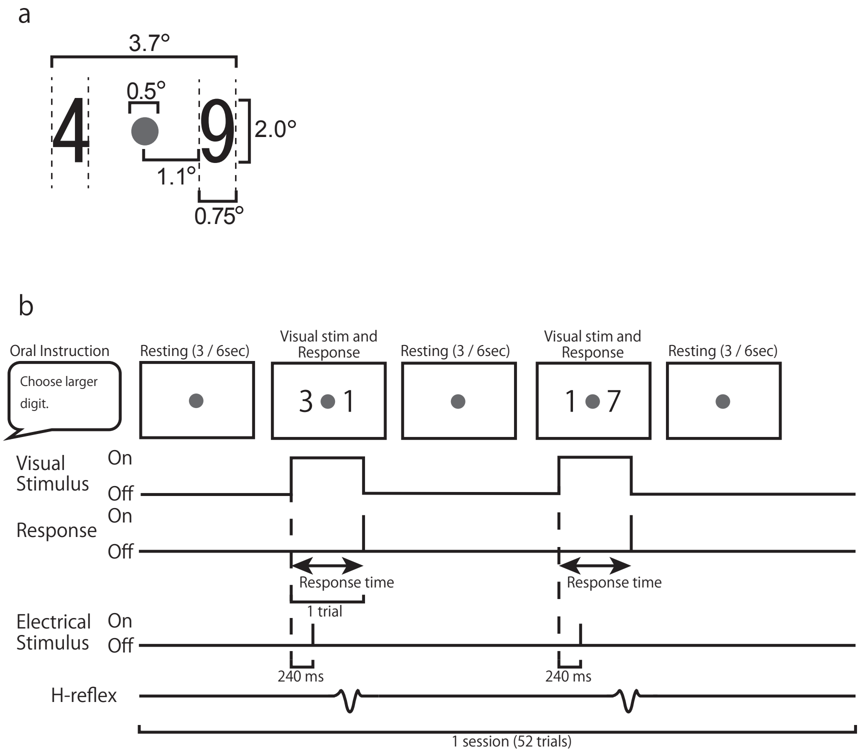

Figure 1. a. The size and spatial arrangement of central fixation point and visual stimuli. b. The overview of the procedure of the numerical comparison task.

and only the fixation point remained. The presentation of visual stimuli and the completion of the selection is defined as one trial. A total of 48 trials were conducted, with intervals of 3 or 6 seconds between trials. The positions of the correct numbers were arranged in a random order.

Choice Reaction Time Task

Visual stimuli

A red circle fixation point (diameter 0.5°) was presented in the center of the screen. A black circle (diameter 0.5°) was presented as a visual stimulus at 1.1° left or right of the fixation point.

Task procedure

Participants had to choose the side of the fixation point the presented black circle appeared as quickly as possible by pressing the corresponding left or right cross button (USB mobile controller, JY-PMUW, Sanwa Supply Inc.) which was held in the dominant hand (right hand).

Similar to the numerical comparison task, the experiment began with the presentation of the fixation point in the center of the computer monitor, which was continuously displayed throughout the experiment, and participants were instructed to maintain their gaze on it.

A trial was defined as the presentation of a visual stimulus and the selection by pressing the cross button; the experiment consisted of 24 trials. The intervals between trials were set at 3 or 6 seconds, and the positions of the visual stimuli were arranged in a random order.

H-reflex Recording

In the supine position, stimulating electrodes were applied to the right popliteal fossa of the subject, and electrical stimulation of 3 msec duration was administered to the tibial nerve to induce H-reflex using an Electronic Stimulator (Nihon Koden Corporation, Shinjuku, Japan) from the right triceps surae. The H-reflexes data were recorded using a basic medical research system (LEG-1000, Nihon Koden). We induced H-reflex from the right triceps surae based on previous research which suggested that the left parietal cortex is critical for numerical processing. If the left hemisphere showed greater activation, then the H-reflexes induced from the contralateral limb would be more influenced. The electrical stimulation was set to be delivered 240 ms after the presentation of visual stimuli (Figure 2). This timing was chosen based on the appearance of electroencephalogram (EEG) responses in the parietal region during numerical comparison tasks (Dehaene, 1996; Hyde, 2009; Pinel, 2001; Szucs, 2007) and responses in the parietal EEG to specific visual stimuli during tasks that required button presses, which typically occurred around 250 ms after the presentation of visual stimuli (Kumagai, 2018).

Statistical Analysis

SPSS 25.0 (IBM) was used for statistical analysis. In this study, statistical analysis was performed on the reaction times for correctly selected trials and the amplitude of H-reflexes. To account for differences in subcutaneous fat thickness among participants, the amplitude of H-reflexes was transformed into z-scores for each participant using the formula below:

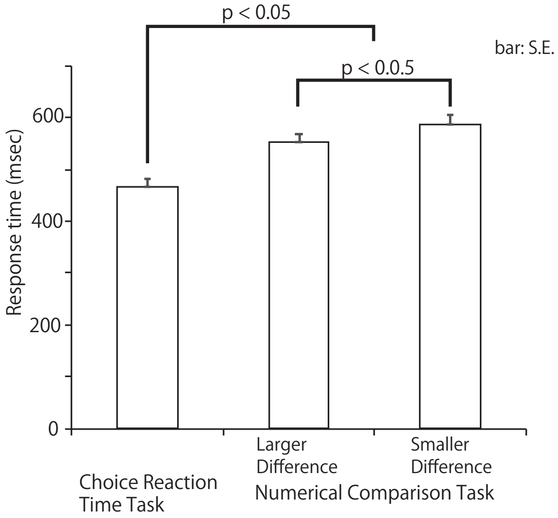

Figure 2. The mean response times for the choice response time task and the numerical comparison task.

$$\text{H-reflex amplitude (z-score)} = \frac{\text{(H-reflex amplitude induced in each trial} - \text{averaged H-reflex amplitude induced in choice reaction time task)}}{\text{standard deviation of H-reflex amplitude induced in choice reaction time task}}$$

For statistical analysis between choice reaction time task and numerical comparison task, paired t-tests and one-sample t-test were performed for reaction times and H-reflex amplitude, respectively. For the numerical comparison task, a two-factor repeated-measures analysis of variance (ANOVA) was performed on reaction times and H-reflex amplitudes, with the factors being the difference in magnitude of numbers (levels: large/small number differences) and left/right selection (levels: selection of numbers on the left/right side of the field of view).

RESULTS

The success rate in the choice reaction task and numerical comparison task was 99.3 (mean) ± 1.6 (S.E.)% and 98.1 ± 3.1%, respectively.

Reaction Time

Results of reaction times in the choice reaction time task and numerical comparison task are shown in Figure 2. In the choice reaction time task, the mean reaction time was 467.3 ± 14.5 (S.E.) msec, while in the numerical comparison task overall, it was 574.9 ± 16.5 msec, and the latter had a significantly longer reaction time ($p < 0.05$). Furthermore, in the repeated measures ANOVA for the two factors in the numerical comparison task, there was a main effect for the factor of 'difference in magnitude of numbers', where the reaction time was 552.6 ± 15.8 msec when the difference between numbers was large, and 587.3 ± 17.2 msec when the difference was small, and the reaction time was significantly longer when the difference was small ($p < 0.05$).

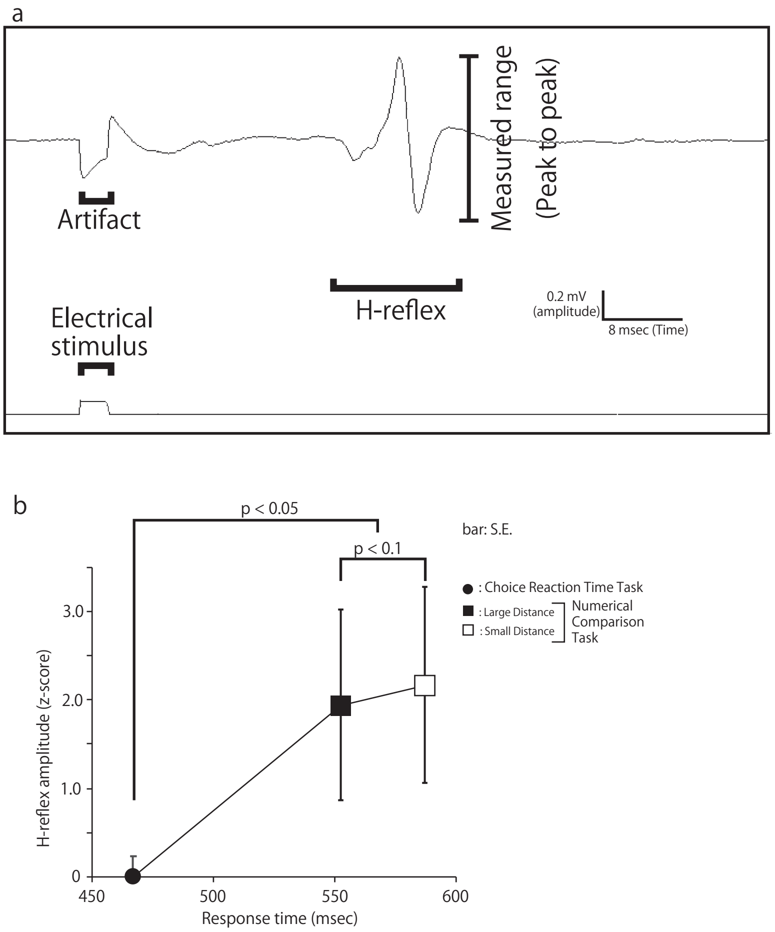

Figure 3. a. An example of the H-reflex. b. The correlation between response times in each task and H-reflex amplitude.

H-reflex Amplitude

Data from one participant were excluded because H-reflex amplitude data could not be recorded in the choice reaction time task. An example of H-reflex and the range of measurement is shown in Figure 3a, while Figure 3b shows the results of reaction time and H-reflex amplitude (z-value) in the choice reaction time task and numerical comparison task. The z-values were calculated with the amplitude for the choice reaction time task as the reference, which was 0.0 (mean) ± 0.2 (S.E.), whereas that for the numerical comparison task overall was 2.05 ± 1.10 (not shown). The recorded amplitude in the numerical comparison task was significantly larger ($p < 0.05$). Additionally, in the repeated measures ANOVA for the two factors in the numerical comparison task, there was no significant effect of the difference in magnitude of numbers, but there was a tendency for H-reflexes to be larger when the difference between the numbers was small ($p = 0.056$; large difference: 1.94 ± 1.08; small difference: 2.17 ± 1.11).

DISCUSSION

We examined whether changes in cognitive load affect spinal cord function by inducing H-reflexes from the right triceps surae while subjects performed the choice reaction time task and the numerical comparison task in the supine position, and investigated their amplitude. We observed a significant increase in H-reflex amplitude when the cognitive load was greater, shown by an increase in reaction time of about 100 msec in choice reaction time and numerical comparison tasks. However, when the reaction time increase was about 35 msec in cases with large and small differences in the numerical comparison task, there was a tendency of increase in H-reflex amplitude, but without statistical significance. Based on EEG results from previous studies (Dehaene, 1996; Hyde, 2009; Kumagai, 2018; Pinel, 2001; Szucs, 2007), we fixed the H-reflex induction to 240 msec after the presentation of visual stimuli. However, some previous studies reported significant activity occurring at a later timing (around 450 msec) in the parietal cortex (Liu, 2011). Stimulation at a later timing might have led to different results. Additionally, H-reflexes were induced only from the right leg in this study because we anticipated activity in the left parietal cortex due to the numerical comparison task. However, if we had also induced H-reflexes from the left leg and compared them, we might have obtained different results.

Cognitive load is defined as the load on an individual's information processing capacity when performing cognitive activities (Singh, 2022). Generally, as the cognitive load imposed by a task increases, reaction times become longer, and brain activity increases. In the numerical comparison task, reaction times are generally longer when the numerical difference is small compared to when it is large (distance effect). This leads to increased activity in the parietal cortex (Cohen Kadosh, 2005; Dehaene, 1997; Horaguchi, 2008; Ogata, 2011; Pinel, 2001, 2004) and the prefrontal cortex (Chochon, 1999). In this study, reaction times significantly increased in the order of the choice reaction time task, the numerical comparison task with a large difference, and with a small difference. This suggests that this study was able to manipulate cognitive load across three levels and record the associated changes in H-reflex amplitude.

In this study, H-reflexes increased with cognitive load. However, research on H-reflex amplitude has shown varied results, including an increase with load (Chochon, 1999), no change (Aoyama, 2011; Bonnet, 1997; Hashimoto, 1999; Meester, 2014; Oishi, 1994), and a decrease (Capaday, 1986, 1987; Llewellyn, 1990; Oishi, 1994; Sibley, 2007; Weaver, 2012). There is therefore no unified consensus. In the case of walking, the spinal cord receives both descending projections from the cerebral cortex and ascending projections from the skin of the soles and muscle spindles (Forssberg, 1979; Nakajima, 2006; Zehr, 1997, 1998). These projections can modulate spinal excitability (Burke, 1999; McCrea, 2001; Rossignol, 2006). However, in this study, subjects maintained a supine position during the experiment, allowing us to ignore the influence of such ascending projections. Our results are therefore believed to be primarily due to changes in the activity of the cerebral cortex and other areas projecting down to the spinal cord that occurred with increasing cognitive load. While the primary motor cortex is well known for its descending projections to the spinal cord, other areas, like the prefrontal cortex and parietal lobe, also have known projections to the spinal cord (Cheney, 1985; Schieber, 2007). The numerical comparison task used in this study activates not only the parietal cortex but also the prefrontal cortex (Chochon, 1999), so changes in activity in these cortices may have influenced the spinal cord, causing an increase in H-reflex amplitude. Our results suggest the possibility that motor function in the spinal cord may vary with the strength of thought processes.

AUTHOR CONTRIBUTIONS

MF-O performed all experiments and analyses and drafted this paper. TH designed this study, procured the research funding and equipment, and completed this paper by adding to and revising the draft prepared by MF-O. SM and other authors substantially contributed to the revision of the manuscript drafts. All authors have approved the submitted version of the manuscript and agreed to be accountable for any part of the work.

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