

Evaluation of corticospinal drive during ground walking with visual guidance

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Abstract

Background: Current methods for evaluating body movements—controlled by brain and nervous system functions—do not effectively assess internal processes such as brain and nervous system activity related to movement output. Therefore, there is a need to develop an evaluation method for human physical function that specifically targets brain and nervous system. **Aim:** To investigate the differences in brain and nervous system function during various walking tasks. **Methods:** The participants were 10 healthy adults (10 women, aged 19–35 years). The exercise tasks were (i) a 20-m round-trip walk as a normal walk and (ii) a target-task walk, which involved walking with the task of stepping on a line every 3 m on a course similar to that for normal walking. Electromyography (EMG) was applied to the proximal tibialis anterior (pTA), distal tibialis anterior (dTA), medial gastrocnemius (MG), and lateral gastrocnemius (LG) muscles to record muscle activity. **Results:** No difference was noted between normal walking and target-task walking for the pTA and dTA ($t(9) = 0.479$, $p = 0.643$, $d = 0.090$). However, between the MG and LG, coherence in target-task walking showed a trend toward higher values ($t(8) = -2.185$, $p = 0.060$, $d = 0.404$), although this was not statistically significant. **Conclusions:** The results of this study indicate that the neural drive might be stronger during target walking movements with visual tasks than during simple walking movements, and that neural activity tends to be more active when accompanied by visual feedback. This study implemented it during ground walking. Beyond the laboratory setting, it holds promise for future application as a practical method in educational settings. Therefore, further data accumulation is necessary going forward.

Key Words: Multitask, Motor control function, Electromyography (EMG), EMG-EMG coherence, Walking

Introduction

Locomotor syndromes (or locomotive syndromes) are increasingly becoming a concerning issue owing to the decrease in exercise opportunities caused by a predominantly sedentary lifestyle. In locomotive syndrome, basic physical abilities such as standing and walking are impaired due to locomotor disorders. It is estimated that 45.9 million people in Japan have conditions in which the decline of mobility function has begun (The Japanese Orthopaedic Association and Japanese Society for Musculoskeletal Medicine, 2021), increasing the risk of falling or becoming bedridden in the future. Therefore, it is imperative to increase physical activity on a daily basis while the risk is still low, thereby improving motor function and preventing locomotive syndrome (Ministry of Health, Labour and Welfare, 2023).

The Guide to Physical Activity and Exercise for Health Promotion 2023 indicates that the amount of physical activity should be at least 6,000 steps per day for the elderly (those aged >65 years) and 8,000 steps per day for younger adults (20–64 years) (Ministry of Health, Labour and Welfare, 2023). Given that brain atrophy and neuronal cell loss occur with aging, and low physical activity increases the risk of brain atrophy (Yuki et al., 2012), exercise should be proposed not only to increase physical activity but also to prevent functional decline, with an emphasis on evaluating the functional perspective of the brain and nervous system.

The human body is driven by the functions of the brain and nervous system (Kitajo et al., 1998), making it important to maintain and improve their function. There are various methods for evaluating body movements, such as observing a movement and scoring the degree of achievement or performing movement analysis based on joint angles and trajectories (Chen et al., 2010; Nakamura et al., 2011). However, although these methods are versatile, they evaluate the events output as physical movements, making it difficult to evaluate internal events such as brain/nervous system activity related to the output process. Consequently, it is not possible to grasp the factors of movement tasks from multiple angles. Therefore, it is necessary to develop an evaluation method for human physical function that focuses on the function of the brain and nervous system.

As a neurophysiological method for evaluating motor control function, the electroencephalography-electromyography (EEG-EMG) coherence method, which shows the synchronization of electrical signals of brain and muscle activity, has already been demonstrated (Halliday et al., 1995). This method detects the firing of neural activity of the brain and muscles in the beta band (13–35 Hz) during muscle contraction using signals

from EEG and EMG and indicates the degree of neural drive, or the state of command transmission of information from the brain, from the tuning (coherence) between the two electrical signals (Halliday et al., 1995). In the tuning between two electrical signals, the closer the coherence is to 1, the higher the coherence and the more pronounced the neural coupling. Based on this principle, EEG is expected to be used as a method to evaluate neural functions. However, EEG measurement equipment is expensive, and noise tends to be introduced when measuring physical movements. Furthermore, the method lacks versatility due to limitations in measurement conditions, such as physical activity restrictions and psychological burden on the participant. In contrast, the coherence method, which evaluates EMG intervals based on the same principle, can evaluate EMG alone and is expected to be particularly useful for measurements during physical activity (Baker et al., 1997; Hansen et al., 2001; Halliday et al., 2003; Norton & Gorassini, 2006).

The intermuscular or intramuscular coherence shown by the synchrony between EMGs is similar to that of the EEG-EMG coherence method (Baker et al., 1997; Grosse et al., 2002), enabling a simple evaluation of nervous system function. Studies examining the validity of this evaluation method have reported that this synchrony is rarely demonstrated in patients with neurological diseases, and that the neural drive is weak or absent (Norton & Gorassini, 2006; Hansen et al., 2005). In addition, a positive correlation has been shown EMG-EMG coherence method and transcranial magnetic stimulation (Norton & Gorassini, 2006), and it is therefore considered a valid method for evaluating the neural drive through the corticospinal tract. Intermuscular coherence values tend to be less synchronous in the elderly than in younger adults, indicating a weak neural drive in the former (Bayram et al., 2015; Yoshida et al., 2017). Furthermore, EMG-EMG coherence values and actual performance recordings, lower coherence values are reported to be associated with lower actual performance recordings, indicating that the neural drive is related to motor function (Spedden et al., 2018).

In everyday life, movements are rarely performed with only locomotion in mind. Walking, in particular, is a dual-task activity wherein the participant performs physical actions while also making decisions to walk straight and avoid obstacles.

This involves using visual information to understand the surrounding environment while walking. Compared to simple walking, in treadmill walking, coherence has been shown to be higher, i.e., synchronization and neural drive are stronger when walking while stepping on marks indicated on the belt as a dual-task activity (Jensen et al., 2018; Spedden et al., 2019a; Zipser-Mohammadzade et al., 2023). Therefore, the ability to objectively evaluate the characteristics of brain and nervous system activity between walking in the dual-task state and simple walking could prompt more effective planning of exercise programs for fall prevention.

Walking on a treadmill is form of walking exercise performed on a machine. However, the purpose of this study was to examine the differences in neural drive during walking exercise on the ground, which is more similar to everyday movement, by evaluating EMG-EMG coherence while performing a visual task during walking.

Methods

Participants

Ten healthy adults (ten women, aged 19–35 years) without orthopedic or neurological conditions were included in the study. The participants were informed about the study orally and in writing, and consent was obtained before the study was conducted. This study was approved by the ethics committee of author affiliation.

Experimental procedure

For normal walking, the participants walked back and forth between 20-m intervals set up with colored cones at both ends. In the target-task walking with a visual task, a line was set every 3 m along the 20 m walking course, and the participant walked while stepping on the line. Participants performed two trials of 3 min each of normal walking and target-task walking, with a 2-min rest between each exercise task. In the target-task walking, the participant was instructed to use the dominant foot when stepping on the line, and each task was set randomly for each participant. Participants were instructed to perform each task at their daily walking speed.

Data collection

EMG measurement (S&ME DL-5500, Tokyo, Japan) was performed on the dominant leg muscle group, and the dominant leg was defined as the one used to kick a ball (Fumoto, 1982). The four application sites were the proximal tibialis anterior(pTA) muscle, distal tibialis anterior(dTA) muscle, medial gastrocnemius (MG) muscle, and lateral gastrocnemius (LG) muscle of the dominant foot. The electrodes were placed at least 10 cm apart from one another to minimize the effect of crosstalk due to muscle activity. The electrodes were attached with double-sided tape to fix them on the surface and prevent them from peeling off.

Extraction of electromyograms

The combination between two electrical signals was assumed to be between the joint muscles, between the pTA and dTA, and between the MG and LG (Jensen et al., 2018; Nojima et al., 2020). To exclude the impact of ground contact, muscle activity during walking was extracted for 600 ms between 50 ms and 650 ms before heel contact in the late swing phase between the pTA and dTA, and for 700 ms between 100 ms and 800 ms after heel contact in the stance phase for the MG and LG. The coherence values were calculated by combining each segment (Jensen et al., 2018). This extraction time was confirmed to be during the period of muscle activity. The time of heel–ground contact was identified from the acceleration in the Z-axis direction, which is the direction of walking, based on the triaxial acceleration of the electrode attached to the dTA during each gait cycle. For

analysis, 2 min and 30 s data around the stable period of 3 min of walking were extracted. The EMG data were sampled at 1,000 Hz, band-pass filtered at 10–450 Hz, AD converted, and stored as digital data on a computer for offline analysis. The above periods were confirmed and identified by several skilled researchers.

Coherence analysis

Intramuscular coherence analysis was performed from two locations on the same muscle, and intermuscular coherence analysis was performed by Fourier transforming the EMG signals recorded from the two muscles and performing frequency analysis. Coherence analysis was then performed to assess the tuning of the two muscles (Halliday et al., 1995), and coherence values in the β -band frequency were calculated. Dazy Lab (coherence analysis program AO-V1, Applied Office, Tokyo, Japan.) was used for this series of analyses. The range of frequencies analyzed was the average coherence value in the band of 24–40 Hz, as in dynamic cases such as walking, common drive is observed at higher frequencies than in static contraction (Halliday et al., 2003). The level of significance of the coherence values that indicate the presence of synchrony was calculated using the equation of Halliday et al. (Halliday et al., 1995). The coherence value is expressed between 0 and 1, where 0 indicates that the two signals are not synchronized at all and 1 indicates that the two signals are perfectly synchronized.

Table 1. 24–40 Hz coherence values and comparison between normal and target-task walking

N	muscle	Coherence $\pm$ SD		t-value	p	d
		normal	target			
10	pTA-dTA	0.228 $\pm$ 0.137	0.216 $\pm$ 0.134	0.479	0.643	0.090
9	MG-LG	0.169 $\pm$ 0.106	0.214 $\pm$ 0.116	-2.185	0.060	0.404

pTA: proximal tibialis anterior; dTA: distal tibialis anterior; SD: standard deviation; d: effect size

Statistical analysis

Statistical analysis was performed using Excel statistical software. The *F*-test was used to examine the population variance. Given that the population variance could be assumed to be equal, a paired two-tailed *t*-test was used to compare normal walking and target-task walking. The significance level was set to less than 5%. The effect size (*d*) was calculated by dividing the difference between the two means by the standard deviation (Cohen, 1988).

Results

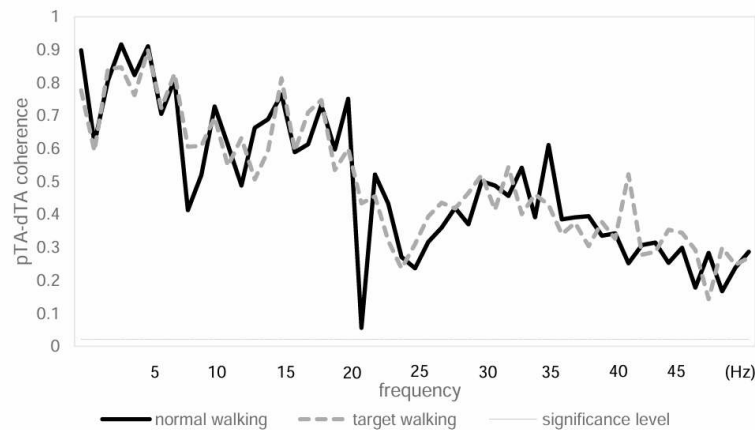


Fig. 1. Proximal tibialis anterior (pTA)–distal tibialis anterior (dTA) coherence at the respective frequencies in one participant. Grey wavy lines indicate coherence during target walking and black practice indicates coherence during normal walking. Light grey practices indicate significance levels of coherence

Of the 10 participants in this study, 1 had disconnected the MG and LG EMG; thus, MG-LG coherence was analyzed in the other 9 participants.

Table 1 shows the results of the inter-task comparison of normal and target-task walking. pTA-dTA showed that the coherence value $\pm$ SD for normal walking was 0.228 ± 0.137 and that for target-task walking was 0.216 ± 0.134 , showing no difference between the two tasks ($t(9) = 0.479$, $p = 0.643$, $d = 0.090$). Meanwhile, the coherence value $\pm$ SD between MG-LG was 0.169 ± 0.106 during normal walking and 0.214 ± 0.016 during target-task walking, indicating that coherence tended to increase during target-task walking ($t(8) = -2.185$, $p = 0.060$, $d = -0.404$).

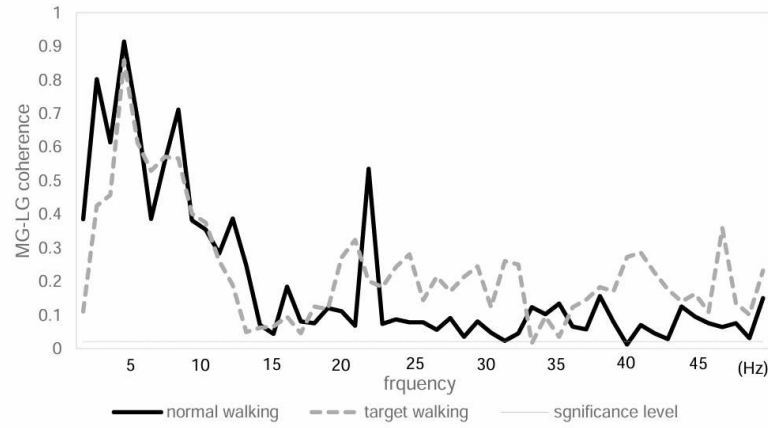


Fig. 2. Medial gastrocnemius (MG)-lateral gastrocnemius (LG) coherence at the respective frequencies in one participants. Grey wavy lines indicate coherence during target walking and black practice indicates coherence during normal walking. Light grey practices indicate significance levels of coherence.

Figure 1 shows the coherence values for one representative participant between the pTA and dTA, and Figure 2 shows those between the MG and LG. pTA-dTA showed no difference in coherence for normal walking and target-task walking. However, MG-LG showed higher coherence values at frequencies higher than 20 Hz for target-task walking than for normal walking. As shown in Figure 1, the coherence between the pTA and dTA exceeded the level of synchrony in the 24–40 Hz frequency range, indicating that there was neural drive to the lower leg during walking.

Table 2 shows the coherence values for each participants. The individual coherence values indicate that the MG-LG in the participants, except one participant, showed an increase in coherence values during target-task walking than during normal walking. In contrast, six participants showed a decrease and four participants showed an increase in pTA-dTA coherence in target-task walking than during normal walking.

Table 2. pTA-dTA and MG-LG coherence value and percentage increase or decrease from normal walking (100%) in the 24–40 Hz band.

No	pTA-dTA				MG-LG			
	normal	target	change(%)		normal	target	change(%)	
1	0.116	0.149	△	128.4	0.190	0.225	△	118.4
2	0.131	0.264	△	201.5	0.088	0.141	△	160.2
3	0.098	0.071	▼	72.4	0.432	0.441	△	102.1
4	0.402	0.416	△	103.5	0.193	0.380	△	196.9
5	0.122	0.102	▼	83.6	0.147	0.159	△	108.2
6	0.313	0.119	▼	38.0	0.121	0.154	△	127.3
7	0.182	0.162	▼	89.0	0.145	0.149	△	102.8
8	0.103	0.105	△	101.9	0.131	0.113	▼	86.3
9	0.404	0.364	▼	90.1	-	-		
10	0.407	0.404	▼	99.3	0.076	0.166	△	218.4

△: Indicates an increase over single-task walking

▼: Indicates a decrease from single-task walking

pTA: proximal tibialis anterior; dTA: distal tibialis anterior; MG: medial gastrocnemius; LG: lateral gastrocnemius

Discussion

This study aimed to evaluate the strength of the neural drive in different motor tasks by using the EMG-intercalated coherence method, focusing on the brain and nervous system functions that govern physical movement. The coherence values between the MG and LG were higher in target-task walking while stepping on a line than that with normal walking, indicating that “walking + α ” exercise enhanced neural drive more than did the simple walking exercise. This result was similar to that of a study by Jensen et al. (2018) that reported increased coherence with visually guided walking in the beta (β) band (15–35 Hz) and gamma (γ) band (35–60 Hz) between joint muscles. That is, the coherence of motor units increases with visual guidance even in ground

walking (Laine et al., 2014; Hwang et al., 2017) and enhances the neural drive. The coherence of the motor units in the β -band (15–30 Hz) and γ -band (30–60 Hz) is considered to indicate the motor cortical drive (Farmer et al., 1993; Feige et al., 2000; Marsden et al., 2000), supporting that the neural drive is stronger in the target-task gait. Coherence in the case of isometric contraction, which is a holding movement, is involved in spinal neuron-cortical coupling (Takei & Seki, 2008), and high coherence between EMGs is observed in the range of 15–30 Hz, indicating high coherence in the β -band (Kilner et al., 1999).

On the contrary, at 24–40 Hz, there were no differences between the pTA and dTA during the two tasks. It is often reported that coherence between the pTA and dTA is synchronized within the same muscle during walking (Petersen et al., 2010; Willerslev-Olsen et al., 2015; Ritterband-Rosenbaum, 2017; Sato & Choi, 2019; Spedden et al., 2019b). While pTA-dTA coherence increases during targeted walking compared to normal walking (Jensen et al., 2018; Spedden et al., 2019a; Zipser-Mohammadzadeh, 2023), the present results showed a different outcome. The reason for this difference may be due to the difference in the exercise task. Treadmill gait is less variable than ground walking (Dingwell et al., 2001; Chiu et al., 2015), and gait style differs between ground walking and treadmill walking (Alton et al., 1998; Ochoa et al., 2017; Roeder et al., 2018; Roeder et al., 2020). Furthermore, the coherence between EEG and EMG is physiologically higher in ground walking than in treadmill walking (Roeder et al., 2018), suggesting that the muscle coordination function to stabilize the body during ground walking is more activated than that during treadmill walking. The CMC has been reported to be higher when visual stimuli unrelated to muscle coordination are applied during muscle contraction (Mat Safri et al., 2007). Therefore, the fact that the coordination function to grasp spatial cues using visual information worked during normal walking on the ground, unlike walking on a treadmill, may have had an influence. Furthermore, in the walking motion, the effect of the dorsiflexion activity of the tibialis anterior muscle in moving the foot forward was significant during the pTA-dTA period.

These factors resulted in higher coherence in normal walking, and no significant change in coherence was observed between tasks, which differs from the results of previous studies. However, the coherence between the pTA and dTA exceeded the significance level in the 24–40 Hz band, indicating that the neural drive was stronger in both normal and target walking tasks.

The brain and nervous system develop through adolescence (Takei & Saki, 2008), and many participants in this study were aged approximately 20 years; therefore, the development of the brain and nervous system was close to maturity, making the motor task simple for them. When setting exercise tasks, it is necessary to set tasks that are appropriate for the participant's age and consider the prevalence of neurological diseases. In addition, this evaluation method using EEG-EMG coherence and EMG-EMG coherence is subject to large individual differences (Ushiyama et al., 2011). In this study as well, the coherence values tended to have large individual variations. The range of coherence values in normal gait between the pTA and dTA was 0.116 - 0.407, and it is difficult to exclude the possibility of the influence of individual differences. Therefore, although this study examined intra-individual changes, age-related changes and differences in physical characteristics in a larger number of participants should be examined in future studies. Nevertheless, the evaluation methods examined in this study will not only lead to a better understanding of the design of exercise programs for the prevention of falls in the elderly, but will also be effective in the development of growth and development and exercise programs for children, for whom it is difficult to evaluate brain and nerve functions.

Conclusions

Assessments of physical motor function in older adults often focus on muscle mass and strength. However, because nervous system function is essential for human movement, motor function must be assessed from the perspective of nervous system function in addition to muscle mass and strength. We applied electromyographic coherence analysis (a method for evaluating brain and nervous system functions) to examine differences in neural drive between simple walking and walking in conjunction with a visual target task. Coherence between the co-contracting muscles MG and LG increased during target-task walking compared with simple walking, indicating a tendency for neural activity patterns to differ between tasks. Neural function differences with different tasks suggest that when considering motor programs, incorporating movements guided by visual cues, may enhance improvements in motor control function and better prevent decline. The findings of this study may provide important guidance in designing exercise programs aimed at preventing falls and reducing prevalence of bedridden status among the elderly.

Evaluating brain and neural system activity typically requires expensive, large-scale measurements, such as EEG or MRI, which are limited to laboratory settings, making field investigations difficult. However, this coherence method, which relies solely on electromyography (EMG), is simpler and more versatile than other brain and nervous system assessment methods, enabling field measurements that were previously difficult to obtain, allowing accrual of more data. Movement task difficulty can also be adjusted according to age, physical condition, and fitness level, permitting continuous evaluation under various conditions in the future, making it a promising, broadly applicable indicator for assessing motor control function.

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