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Sympathetic nervous system activity measured by skin conductance quantifies the challenge of walking adaptability tasks after stroke

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ABSTRACT

Background: Walking adaptability tasks are challenging for people with motor impairments. The construct of perceived challenge is typically measured by self-report assessments, which are susceptible to subjective measurement error. The development of an objective physiologically-based measure of challenge may help to improve the ability to assess this important aspect of mobility function. The objective of this study to investigate the use of sympathetic nervous system (SNS) activity measured by skin conductance to gauge the physiological stress response to challenging walking adaptability tasks in people post-stroke.
Methods: Thirty adults with chronic post-stroke hemiparesis performed a battery of seventeen walking adaptability tasks. SNS activity was measured by skin conductance from the palmar surface of each hand. The primary outcome variable was the percent change in skin conductance level (ΔSCL) between the baseline resting and walking phases of each task. Task difficulty was measured by performance speed and by physical therapist scoring of performance. Walking function and balance confidence were measured by preferred walking speed and the Activities-specific Balance Confidence Scale, respectively.
Results: There was a statistically significant negative association between ΔSCL and task performance speed and between ΔSCL and clinical score, indicating that tasks with greater SNS activity had slower performance speed and poorer clinical scores. ΔSCL was significantly greater for low functioning participants versus high functioning participants, particularly during the most challenging walking adaptability tasks.
Conclusion: This study supports the use of SNS activity measured by skin conductance as a valuable approach for objectively quantifying the perceived challenge of walking adaptability tasks in people post-stroke.

1. Introduction

Walking adaptability is defined as the ability to modify walking behavior to meet the demands of the environment and the objectives of the task [1]. Successful ambulation in the home and community requires walking adaptability, such as when walking on different surfaces, over various terrains, and with differing ambient conditions. Individuals who have had a stroke often report that walking adaptability tasks are challenging [2]. The construct of perceived challenge is generally measured by self-report assessments including mobility self-efficacy, balance confidence, and fear of falling. A number of studies have shown that these measures of perceived challenge are linked to fall risk, engagement in community mobility, and performance of life role activities [2–7]. Even after accounting for physical capabilities, balance/falls self-efficacy has been shown to be independently linked to activity and participation [3,4,8–11]. Accordingly, assessing the perceived challenge of walking may serve an important role when evaluating mobility deficits and recovery after neurological injury.

A drawback of self-report assessments of perceived challenge is that they are susceptible to subjective measurement error and bias [12–15]. The development of an objective physiologically-based measure of challenge may help to improve the ability to assess this important aspect of mobility function. One promising objective approach is to measure task-related increases in sympathetic nervous system (SNS)

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activity. Increased SNS activity is a physiological stress response (i.e., the 'fight or flight' response) that occurs under conditions of heightened attention, state anxiety, cognitive loading, and/or physical exertion [16,17]. SNS activity can be robustly measured by recording changes in skin conductance on the palmar surface of the hands [18,19]. Several prior studies have demonstrated that skin conductance is increased during walking tasks with greater task demands and/or perceived challenges. For instance, studies requiring participants to step over obstacles or to dual-task while walking have reported marked increases in skin conductance during performance of those tasks [17,20]. Task demands are not the only factors contributing to perceived challenge. Other factors that may contribute to perceived challenge are the individual's skill level, past experience with a particular task (positive or negative), the consequences of success/failure, and trait anxiety. Prior studies have shown an increase in perceived challenge in the absence of a change in physical demands of a task. Most notably, self-reported anxiety and skin conductance have been reported to increase when the perceived challenge is increased by asking participants to perform walking or postural tasks on an elevated platform [20,21]. Although the physical demands of walking/balancing on an elevated platform are identical to when performed at ground level, the consequences of falling are potentially much more serious and likely account for the perceived challenge.

Based on the evidence discussed above, it is known that SNS activity is elevated by heightened task demand and under walking conditions that are perceived as challenging. However, it is not known whether the specific amplitude of this response closely corresponds to task difficulty, or if instead it is a generic response that is similar across many tasks. Furthermore, the potential influence of walking function and balance confidence on SNS activity during walking are not known. The objective of the present study is therefore to (1) quantify SNS activity level measured by skin conductance during a battery of walking adaptability tasks after stroke, (2) investigate the association between task difficulty and skin conductance, (3) assess the effect of functional status on the task-related increase of skin conductance, and (4) asses the effect of self-reported balance confidence on the task-related increase of skin conductance. The primary hypotheses are that greater task difficulty will be associated with higher skin conductance during walking, and that participants with better walking function and balance confidence will exhibit lower skin conductance during walking.

2. Methods

2.1. Participants

Inclusion criteria were prior occurrence of a single stroke primarily affecting motor function on one side of the body, no other major neurological diagnoses, no major visual impairment, able to walk at least 10 meters independently (the use of a cane or an orthotic device was acceptable), age 18 years or older, able to follow verbal commands, and willing to provide informed consent. All participants provided written informed consent as approved by the local university Institutional Review Board.

2.2. Walking adaptability tasks

Each participant performed the study procedures during a single visit to a research laboratory. All testing was led by a licensed physical therapist with research experience, with assistance from trained research staff. Participants performed a battery of walking adaptability tasks (Table 1) in random order. Two consecutive trials of each task were performed. The tasks were selected to represent a broad range of walking adaptability domains [1,22].

2.3. Measurement of sympathetic nervous system activity with skin conductance

SNS activity was measured with skin conductance during each walking adaptability task using a commercially available portable data acquisition unit (Flexcomp Infiniti, Thought Technologies Ltd., QC, Canada). Data acquisition procedures were consistent with the recommendations of the 2012 committee report from the Society For Psychophysiological Research Ad Hoc Committee On Electrodermal Measures [23]. Adhesive electrodes (10 mm Ag/AgCl recording surface) with conductive paste (0.5% saline in a neutral base) were placed on the palmar surface of the proximal phalanges of the index and ring fingers. Skin conductance signals were acquired separately from both hands for each participant, sampled at 32 Hz, and saved directly to an onboard flash memory card.

Analysis of skin conductance data was performed with Matlab version R2015a (The Mathworks, Natick MA) using Ledalab v3.4.7 [24] and custom analysis programs. The raw skin conductance data were downsampled to 8 Hz and visually examined for the presence of motion artifact, as indicated by high frequency fluctuations in the signal amplitude. The relatively few artifacts that were identified were replaced using linear interpolation. Continuous decomposition analysis [24] was performed to separate the tonic component (skin conductance level, or SCL) and the phasic component (skin conductance response, or SCR) of the signal using an amplitude criterion of 0.04 microsiemens (μS) for defining SCRs. The SCL signal was used for data analysis. For each walking task, three values were extracted from the SCL data. The first value was the minimum SCL that occurred during the baseline period of quiet standing that preceded each walking task. The other values were the maximum SCL occurring during each of the two consecutive trials of walking adaptability tasks. Exemplar data are shown in Fig. 1. The primary outcome variable for SCL is the percent change in SCL (denoted by ΔSCL) between the resting and walking phases of each task:

$$\Delta SCL = [(\text{Walking Maximum} - \text{Resting Minimum})/\text{Resting Minimum}] * 100.$$

Calculating the percent change from rest reduces the confounding influence of inter-individual differences in the absolute amplitude of skin conductance.

2.4. Estimating difficulty of walking adaptability tasks

The difficulty level of walking adaptability was estimated by calculating task performance speed and by assigning a clinical performance score. Task performance speed was calculated by dividing the performance time by the length of the walking course. Task performance speed was calculated only for those tasks that were performed at a continuous preferred walking speed. The tasks that were omitted from the analysis were *Opening Door*, *Change Speed*, *Fast*, *Stairs*, and *Fast Obstacles*. The clinical score used an ordinal scale, similar to other established instruments of mobility function. Scoring was based on a set of qualifying statements, as shown below, that could be used across the diverse set of walking tasks tested here. If qualifiers were spread across scores, the lowest applicable score was assigned. Clinical grading was performed by a licensed physical therapist with advanced expertise and training in neurologic physical therapy.

Score 0–Severe Impairment: Loss of balance and severe difficulty adapting to the task.

Score 1–Moderate Impairment: Loss of balance and some/no difficulty adapting to the task OR no loss of balance but severe difficulty adapting to the task.

Score 2–Mild Impairment: no loss of balance and some/no difficulty adapting to the task OR no loss of balance but appears unsafe.

Score 3–No Impairment: no loss of balance, no difficulty adapting to the task, and appears safe.