

## COGNITIVE LOAD IN INDIVIDUALS WITH A TRANSFEMORAL AMPUTATION DURING SINGLE- AND DUAL-TASK WALKING: A PILOT STUDY OF BRAIN ACTIVITY IN PEOPLE USING A SOCKET PROSTHESIS OR A BONE-ANCHORED PROSTHESIS

Saffran MÖLLER<sup>1</sup>, Kerstin HAGBERG<sup>2,3</sup> and Nerrolyn RAMSTRAND<sup>1</sup>

From the <sup>1</sup>Department of Rehabilitation, School of Health and Welfare, Jönköping University, Jönköping, Sweden, <sup>2</sup>Department of Orthopaedics, Sahlgrenska University Hospital, Gothenburg, Sweden, and <sup>3</sup>Department of Orthopaedics, Institute of Clinical Sciences, Sahlgrenska Academy, University of Gothenburg, Gothenburg, Sweden

**Objective:** To explore cognitive load in people with transfemoral amputations fitted with socket or bone-anchored prostheses by describing activity in the left and right dorsolateral prefrontal cortices during single- and dual-task walking.

**Design:** Cross-sectional pilot study.

**Patients:** 8 socket prosthesis users and 8 bone-anchored prosthesis users. All were fitted with microprocessor-controlled prosthetic knees.

**Methods:** Participants answered self-report questionnaires and performed gait tests during 1 single-task walking condition and 2 dual-task walking conditions. While walking, activity in the dorsolateral prefrontal cortex was measured using functional near-infrared spectroscopy. Cognitive load was investigated for each participant by exploring the relative concentration of oxygenated haemoglobin in the left and right dorsolateral prefrontal cortex. Symmetry of brain activity was investigated by calculating a laterality index.

**Results:** Self-report measures and basic gait variables did not show differences between the groups. No obvious between-group differences were observed in the relative concentration of oxygenated haemoglobin for any walking condition. There was a tendency towards more right-side brain activity for participants using a socket prosthesis during dual-task conditions.

**Conclusions:** This pilot study did not identify substantial differences in cognitive load or lateralization between socket prosthesis users and bone-anchored prosthesis users.

**Key words:** attention; limb prosthesis; neuroimaging; osseointegration.

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Correspondence address: Saffran, Möller, Department of Rehabilitation, Jönköping University, Gjutergatan 5, SE-551 11 Jönköping SE, Sweden. E-mail: saffran.moller@ju.se

Under favourable conditions, maintenance of balance and walking are largely controlled by postural responses at sub-cortical levels and require minimal attentional resources (1). If balance and pos-

### LAY ABSTRACT

For able-bodied individuals, the act of walking requires little cognitive effort; for people who need a prosthesis to walk, more cognitive effort is required. Prosthesis users are also less proficient at performing secondary tasks while they walk. This study assessed the cognitive effort required to walk in 2 groups of people with amputations above the knee. One group were fitted with prostheses incorporating a rigid socket (8 participants) while the other group were fitted with prostheses that were directly attached to the residual skeleton (8 participants). Cognitive effort was measured using a neuroimaging system recording activity in the frontal cortex of the brain. Increased activity in this area of the brain is associated with increased cognitive effort. Results showed no substantial differences in brain activity between the 2 groups of prosthesis users. This information is of importance when advising patients who are considering undergoing treatment for a bone-anchored prosthesis.

ture are compromised, as is the case for lower-limb prosthesis users, it becomes necessary to allocate more attention at the perceptual level, requiring activation of cortical areas in the brain. The dorsolateral pre-frontal cortex (dlPFC), responsible for working memory and executive functions, is one such area (2). The explicit postdictive engagement of working memory and executive functions generates *cognitive load* and is perceived as *effort* (3). Excessive cognitive load can have negative effects on task performance and is associated with cognitive fatigue (4).

Traditionally, lower-limb prostheses are designed with a rigid socket encompassing the residual limb (socket prosthesis). In these prostheses, forces are transferred to and from the prosthesis via the soft tissues surrounding the residual skeleton. Any movement occurring between the socket and the residuum (e.g., distal translation or pistoning) creates inefficiency in the system and is considered undesirable (5).

Bone-anchored prostheses (BAPs) are an alternative to socket prostheses and are attached directly to an intramedullary implant osseointegrated in the residual skeleton. Direct skeletal attachment is advantageous for people experiencing problems maintaining sus-

pension of their device or having issues with skin breakdown or discomfort due to a socket (6).

Studies comparing BAP's to socket prosthesis users have reported similar results for walking speed and cadence (7, 8) but conflicting results when it comes to measurement of balance. Gailey et al. (7) reported no difference in self-reported balance confidence, measured using the Activities-specific Balance Confidence Scale (ABC) while Gaffney et al. (9), using the same outcome measure, reported more positive results for BAP users, suggesting the difference was likely due to improved proprioception with a BAP. An improved ability to detect vibrations among BAP users has also been recorded (10).

When balance is challenged in able-bodied individuals, by altering surface stability or adding a secondary task (dual-task), neural activity in the pre-frontal cortex (PFC) increases. A systematic review of studies measuring brain activity during walking (11) in older adults concluded that activity in the PFC is higher during dual-task walking (12). Research comparing socket prosthesis users with a group of able-bodied individuals provides evidence to suggest that walking with a prosthesis is also a cognitively challenging task, with prosthesis users activating the PFC to a greater extent than their able-bodied peers (11). Interestingly, the type of prosthetic knee unit used by prosthesis users has been found to affect PFC activity, with users of microprocessor-controlled prosthetic knees recording lower levels of activity during walking when compared with users of mechanical knee joints (11).

Challenging walking conditions have also been linked to lateralization in the PFC. St George et al. (13) demonstrated that left side dominant activity in the PFC becomes increasingly bilateral when walking becomes more challenging. This is believed to result from a need for additional cognitive processing and suggests that the PFC has a compensatory role in maintaining postural stability.

The aim of this study was to explore cognitive load in people with a transfemoral amputation fitted with a socket or a bone-anchored prosthesis by describing activity and lateralization in the dorsolateral prefrontal cortex during single- and dual-task walking.

## METHOD

This was an observational pilot study involving existing prosthesis users and using a cross-sectional design describing 2 groups. Participants were not prospectively assigned to specific interventions and as such the research was not registered as a clinical trial. To compare characteristics of the 2 groups, gait variables and self-report measures of mobility and balance confidence were collected. Activity in the dlPFC was measured using functional near-infrared spectroscopy (fNIRS) under 3 conditions: 1 single-task walking condition and 2 different

dual-task walking conditions. fNIRS estimates of cortical brain activity were derived by measuring the relative concentration of oxygenated haemoglobin (HbO<sub>2</sub>) in the brain (14). Activity in both the left and right dlPFC of the brain were recorded.

### Participants

Participants with a unilateral TFA using a BAP were recruited via the university hospital where their surgical treatment for a BAP had been performed. All had had an OPRA implant (Integrum AB, Mölndal, Sweden) for a minimum of 2 years and lived in Sweden. Data for participants with a unilateral TFA using a socket prosthesis were taken from a previous study (11). For inclusion, participants were required to be able to walk 500 m with the support of no more than a single cane or crutch, to currently use a microprocessor-controlled prosthetic knee joint, and to not have any other impairment or disease that could affect their gait. Individuals with cognitive impairment (Mini-Mental State Examination <27 (15) were excluded. Prosthetic knees were standardized to include only microprocessor-controlled joints as these are commonly prescribed to users of BAPs. The study was approved by the Regional Ethics Committee in Linköping, Sweden (Dnr 2015/1526, Dnr 2018/289-32). Written informed consent was received from all participants.

### Procedure

Participants were asked to take part in 1 single testing occasion lasting for approximately 2 h. Testing took place at a rehabilitation centre or in a gait laboratory depending on the most convenient location for each participant. Testing locations were quiet and free from activities that might otherwise distract the participant. Testing sessions were initiated by collecting participants' demographic data and requesting them to complete questionnaires on self-reported prosthetic mobility and balance confidence as well as performing tests measuring ambulation and functionality (described below).

### Self-report questionnaires

Three validated self-report questionnaires were used to describe the prosthetic mobility: (i) the Q-TFA Prosthetic Use Score (16), (ii) the Activities-Specific Balance Confidence Scale (ABC) (17), and (iii) the Prosthetic Limb Users Survey of Mobility (PLUS-M™) 12-item Short Form (18). The Prosthetic Use score (scored 0–100) measured the amount of time the prosthesis users wore their device during a normal week. The ABC (scored 0–100) was used to evaluate perceived balance confidence in performing daily activities and the PLUS-M (expressed as a T-score between 21.8 and 71.4) was used to assess the prosthesis users' perceived ability to ambulate using a prosthesis in daily activities.

### Gait tasks

fNIRS data were collected while participants walked back and forth along a 14-m level walkway that was free from distractions. Participants were instructed to walk at a self-selected speed and were permitted to use one mobility aid if they wished, i.e., a crutch or stick. The single-task walking condition involved walking on a hinder-free level track, while the dual-task walking conditions included walking while finding numbered and coloured keys (key-test) (19) and a modified trail-walking test (TWT) (20). These specific dual-task activities were selected as they have been used previously in studies with lower-limb prosthesis users. All 3 conditions have been described in detail in a previous publication (21). Each condition was repeated 4 times.

Time and number of steps over the first 10 m of single-task walking were recorded to determine cadence. Upon completion of all walking conditions the fNIRS system was removed and the participant performed a 6-Minute Walk Test (6MWT). This test has been identified as a valid measure of ambulation and functional level in lower-limb prosthesis users (22). The 6MWT was performed once on a 25-m stretch of walkway and the total distance travelled was measured to the closest metre.

#### fNIRS data acquisition

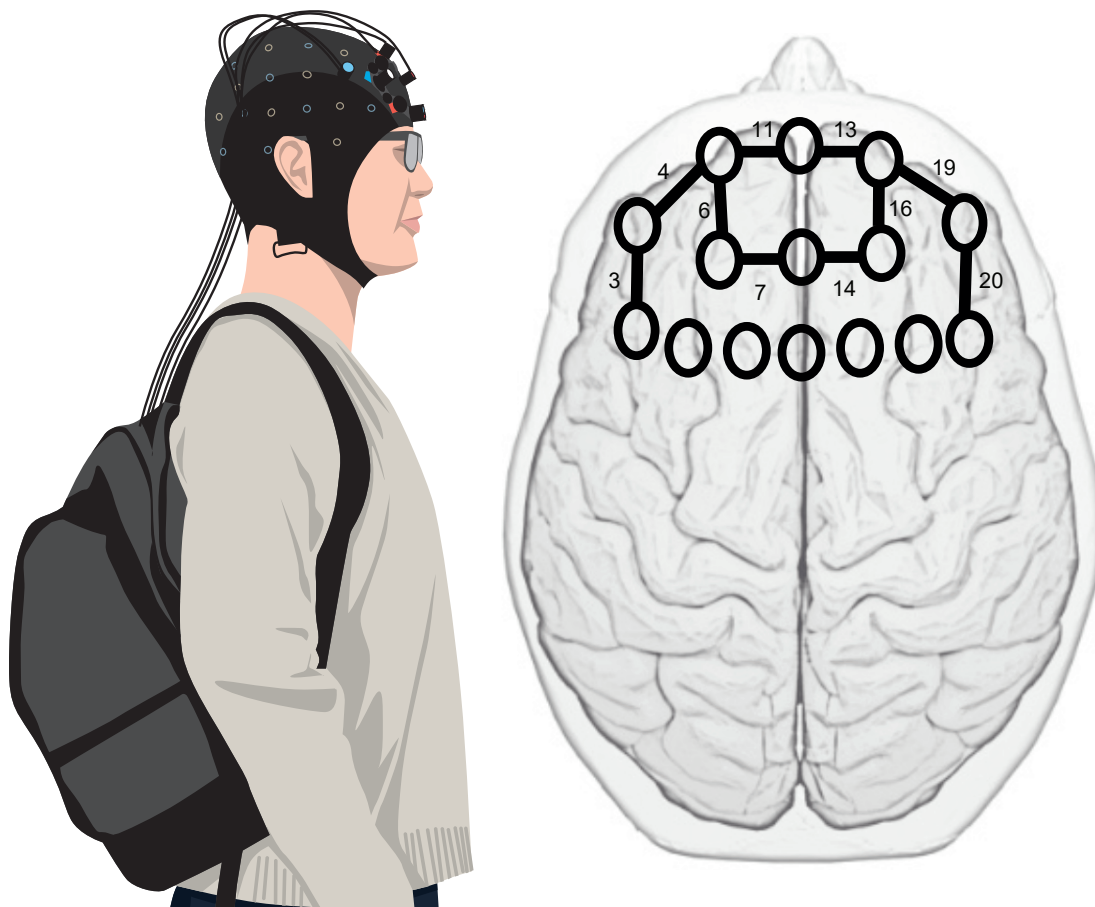
To capture cortical brain activity during walking a portable, continuous wave, NIRSSport tandem fNIRS system was used, (NIRx Medical Technologies LLC, NY, USA). This required participants to be fitted with an elastic cap in which 16 optodes were positioned to cover both hemispheres of the PFC (Fig. 1, right). Optodes were positioned according to the International 10–20 System (23). To maximise reliability of Optode placement, measurements and positioning were always performed by the same investigator (SM). The coordinate system used to measure for cap size and to position optodes followed recommendations from Oostenveld and Praamstra (24). Optodes were tethered to a laptop computer placed in a backpack worn by the participant (Fig. 1, left). Data were captured using NIRStar acquisition software (NIRx Medical; NIRx Medical Technologies LLC, Glen Head, NY, USA).

The fNIRS testing procedure began with a 30 s baseline measurement, performed in accordance with the recommendations of Herold et al. (25) and during which the participants sat in silence with their eyes closed. After the baseline measurement participants were asked to stand for a further 30 s to allow the signals to return to pre-test levels and avoid non-linear effects of the haemodynamic refractory period.

#### fNIRS data processing

NirsLAB 2017.06 software (NIRx Medical Technologies LLC, NY, USA) was used for post processing of fNIRS data. The first walking trial of each condition was considered a practice trial and removed from the data set while 10 s of data were extracted from each of the remaining 3 trials. The 10 s period did not include the first 5 s of walking as this period would have included a period of acceleration, which may have placed a greater demand on the PFC. In this pilot study we chose to extract data only for oxygenated haemoglobin (HbO<sub>2</sub>) as this is where the largest variations in signal amplitude are likely to be seen (26).

Processing of fNIRS data began by calculating the coefficient of variation (CV) for the unfiltered channels and estimating the signal-to-noise performance. Possible sources of an increased CV are relative motion between the optodes and the tissue of the scalp, as well as physiological artifacts such



**Fig. 1.** Illustration of the fNIRS equipment and placement of optodes. Left: equipment worn by the participants. A backpack including a laptop and an elasticized cap to secure the optodes. Right: circles define placement of the 16 optodes (8 sources and 8 detectors) covering both hemispheres of the pre-frontal cortex. Black lines define the channels selected (left 3, 4, 6, 7, 11 and right 13, 14, 16, 19, 20) to represent the region of the dorsolateral prefrontal cortex.



as blood-pressure induced haemodynamics (27). Potential artefacts were addressed by removing channels with a CV greater than 7.5%.

A bandpass filter (0.01 to 0.2Hz) was then used to eliminate fluctuations related to external factors such as respiration, heart-beat, and low-frequency signal drift. Signals were converted from light intensity levels to concentrations of haemoglobin using the modified Beer–Lambert Law (28) and then normalized to baseline values.

Channels representing the left dIPFC (channels 3, 4, 6, 7, 11) and the right dIPFC (channels 13, 14, 16, 19, 20) were averaged to create 2 regions of interest (ROI) (Fig. 1, right). These regions were then averaged across the 3 x 10 s sets of data that had been extracted for each of the 3 test conditions. To assess the degree of lateralization we calculated a laterality index to reflect symmetry of cortical brain activity in the ROI of the left and right sides. Several different formulae to calculate the laterality index have been proposed in the literature. As use of 1 formula over another does not appear to alter outcomes (29), we chose to use the index published by St George et al. (13), calculated using the formula below. Positive values indicate greater activity in the left cortical region relative to the right, whereas negative values indicate greater activity in the right cortical region relative to the left.

$$\text{Laterality index} = \frac{\text{left D [HbO}_2\text{]} - \text{right D [HbO}_2\text{]}}{\text{left D [HbO}_2\text{]} + \text{right D [HbO}_2\text{]}}$$

#### Statistical analysis

IBM SPSS Statistics 21 (IBM Corp, Armonk, NY, USA) was used for all analyses. Demographic and descriptive data are presented as means and standard deviations as well as median and minimum/maximum values. To assess potential differences between the 2 groups (socket prosthesis and BAP users) in regard to demographic and descriptive data a Man–Whitney U test was used. The critical alpha level was set at  $p < 0.05$ .

In this pilot study fNIRS-average data are presented as graphs illustrating left and right dIPFC activity (HbO<sub>2</sub>) for each

participant (socket prosthesis users and BAP users) and each condition (single-task walking, key-test and TWT).

## RESULTS

Participant demographics including age, sex, time since amputation, cause of amputation, height, and current prosthetic knee component are summarized in Table I. Eight participants used a socket prosthesis (1 woman, 7 men, mean age 46 years) and 8 used a BAP (1 woman, 7 men, mean age 52 years). The main cause of amputation among participants was trauma or tumour and the mean time since amputation was 23 years in the group using a socket prosthesis and 16 years in the BAP group. The participants using a BAP had received osseointegration treatment between 4 and 16 years prior to testing. No statistically significant differences were found between the 2 groups in relation to demographic data (Table I), self-reported data (prosthetic use score, ABC, and PLUS-M) or gait data (cadence and 6MWT) (Table II).

Fig. 2 illustrates an example of fNIRS data for 1 participant from each group and presents mean activity in the left and right dIPFC (HbO<sub>2</sub>) for each walking condition. Graphs for all participants are seen in Figs S1–S3; due to technical difficulties data for 2 participants were missing. During the single-task walking condition, no obvious differences could be seen between socket prosthesis users and BAP users, with the amplitude of haemodynamic signals (HbO<sub>2</sub>) being similar for each group. Haemodynamic signals during the 2 dual-task conditions, the key-test and the TWT, were also relatively similar between the 2 groups. In these dual-task conditions both groups showed higher

**Table I.** Participant details

Groups	Age (years)	Sex	Time since amputation (years)	Cause of amputation	Height (cm)	Prosthetic knee component
Socket prosthesis	56	Male	39	Tumour	180	Genium <sup>a</sup>
	51	Male	33	Tumour	180	Rheo Knee <sup>®b</sup>
	54	Male	46	Tumour	178	Rheo Knee <sup>®b</sup>
	54	Male	43	Tumour	183	C-leg <sup>a</sup>
	32	Male	6	Trauma	180	Genium <sup>a</sup>
	38	Female	3	Tumour	178	Rheo Knee <sup>®b</sup>
	46	Male	9	Tumour	181	C-leg <sup>a</sup>
	35	Male	8	Trauma	180	Rheo Knee <sup>®b</sup>
<i>Mean (SD)</i>	<i>46 (9.5)</i>		<i>23 (18.5)</i>		<i>180 (1.4)</i>	
BAP	63	Male	10	Trauma	188	C-leg <sup>a</sup>
	62	Male	6	Trauma	190	Genium <sup>a</sup>
	52	Male	13	Trauma	187	Genium <sup>a</sup>
	27	Male	10	Trauma	187	C-leg <sup>a</sup>
	47	Male	16	Trauma	188	Genium <sup>a</sup>
	77	Male	42	Tumour	178	C-leg <sup>a</sup>
	41	Male	19	Tumour	187	C-leg <sup>a</sup>
	48	Female	13	Trauma	167	Genium <sup>a</sup>
<i>Mean (SD)</i>	<i>52 (15.3)</i>		<i>16 (11.2)</i>		<i>184 (7.7)</i>	
<i>p-value</i>	0.442		0.009		0.083	

<sup>a</sup>Ottobock, <sup>b</sup>Ossur.

BAP: bone-anchored prosthesis; SD: standard deviation.

**Table II.** Description of self-reported prosthetic mobility, balance confidence, and basic gait tasks and comparisons between the groups

Outcome measures	Socket prosthesis	BAP	p-value
	Mean (SD) Median (min-max)	Mean (SD) Median (min-max)	
Prosthetic use score	94 (11.0) 100 (71-100)	93 (13.4) 100 (71-100)	0.890
ABC	88 (9.2) 93 (74-98)	79 (8.78) 81 (63-89)	0.130
PLUS-M	56.8 (6.5) 56.3 (48.4-67.1)	51.8 (5.2) 51.6 (44.5-61.0)	0.161
Cadence	102 (8.3) 100 (92-112)	99 (9.67) 99 (80-111)	0.505
6MWT	548 (166) 470 (412-806)	412 (59.7) 420 (310-497)	0.094

SD: standard deviation. BAP: bone-anchored prosthesis. 6MWT: 6-Minutes' Walk Test. PLUS-M: Prosthetic Limb Users Survey of Mobility. ABC: Activity Balance Confidence Scale.

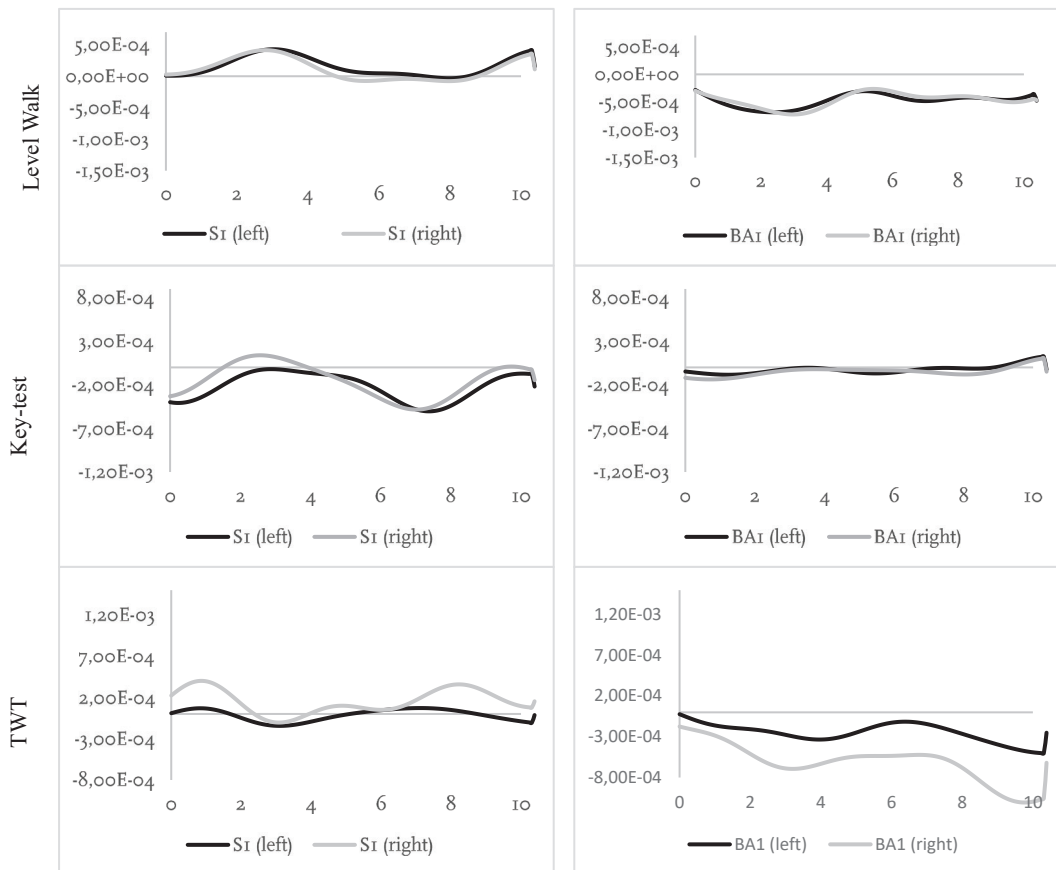
level fluctuations in amplitude of the haemodynamic signal as compared with single-task walking.

Laterality indices for each participant are presented in Figs 3–5. During single-task walking most participants had left lateralized dlPFC activity with no obvious differences between participants using socket prosthesis and BAPs. For both dual-task walking conditions (key-test and TWT) there appeared to be more right side dlPFC activity when compared with the single-task condition. For the key-test condition

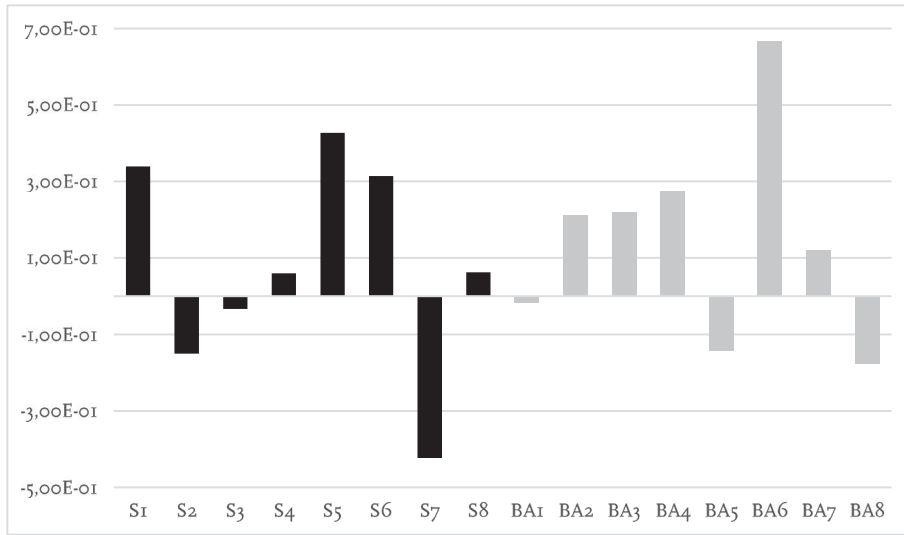
there were more socket prosthesis users with right lateralized dlPFC as compared with BAP users. This was not the case in the TWT condition.

**DISCUSSION**

To the authors' knowledge, this is the first study to describe cognitive load by measuring HbO<sub>2</sub> during walking in people with a unilateral transfemoral amputation using a BAP.



**Fig. 2.** Illustrating cortical brain activity (millimoles of oxygenated haemoglobin, HbO<sub>2</sub>) in the left and right regions of interest in 1 individual from each group and for each walking condition. The Y axis represents the relative concentration of HbO<sub>2</sub> (mM). The X axis represents time (s). S: socket prosthesis user. BA: bone-anchored prosthesis user. TWT: trail-walking test.

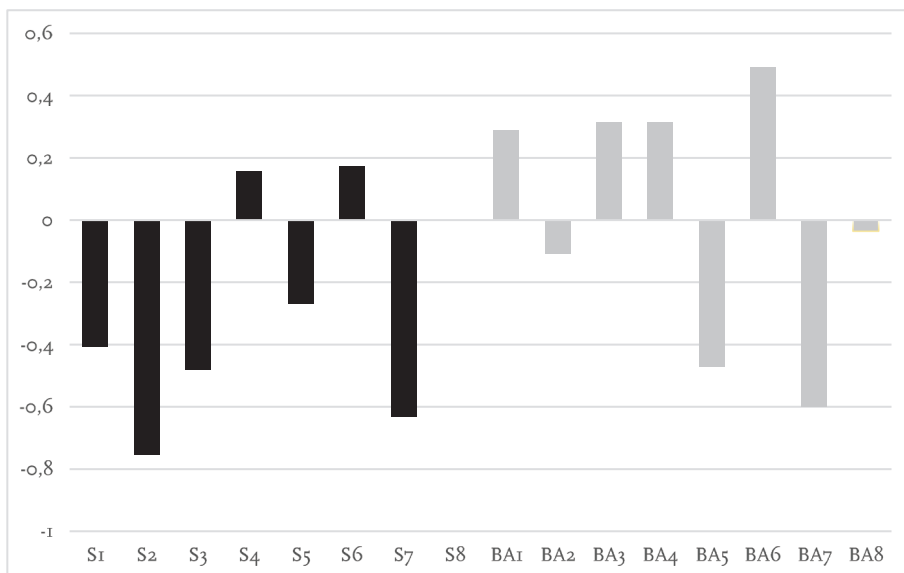


**Fig. 3.** Laterality index for level walking showing activation symmetry between left and right cortical regions (millimoles of oxygenated haemoglobin, HbO<sub>2</sub>). Positive values indicate greater activity in the left cortical region relative to the right, whereas negative values indicate greater activity in the right cortical region relative to the left. The Y axis represents the relative concentration of HbO<sub>2</sub> (mM). The X axis represents participants. S: socket prosthesis user. BA: bone-anchored prosthesis user.

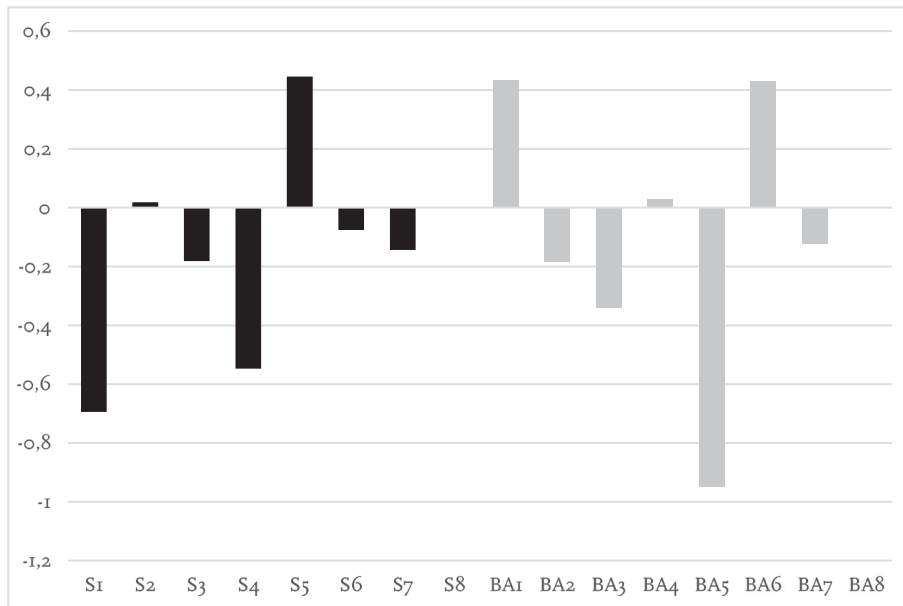
Except for the coupling between the prosthesis and the residuum the 2 groups included in this study were considered comparable. All were established prosthesis users, fitted with the same category of prosthetic knee mechanism, and used their prosthetic limb to a high degree. No significant group differences were observed in measures related to prosthetic mobility.

With group equivalence established, the primary aim of our pilot study was to explore cognitive load in socket prosthesis users versus BAP users by measuring cortical brain activity in the left and right dlPFC.

The association between increased PFC activity and an increase in cognitive demand is well established (30) and higher amplitude HbO<sub>2</sub> signals reported when comparing prosthesis users with able-bodied controls suggest that the cognitive resources required for walking are greater in this population (11). In the present study, haemodynamic activity in the dlPFC, during both single- and dual-task walking conditions, was similar between the two groups (i.e., no group displayed signals that were consistently higher or lower than the other). While these fNIRS data suggest



**Fig. 4.** Laterality index for key-test showing activation symmetry between left and right cortical regions (millimoles of oxygenated haemoglobin, HbO<sub>2</sub>). Positive values indicate greater activity in the left cortical region relative to the right, whereas negative values indicate greater activity in the right cortical region relative to the left. The Y axis represents the relative concentration of HbO<sub>2</sub> (mM). The X axis represents participants. S: socket prosthesis user. BA: bone-anchored prosthesis user. Note S8 missing data.



**Fig. 5.** Laterality index for trail-walking test (TWT) showing activation symmetry between left and right cortical regions (millimoles of oxygenated haemoglobin,  $\text{HbO}_2$ ). Positive values indicate greater activity in the left cortical region relative to the right, whereas negative values indicate greater activity in the right cortical region relative to the left. The Y axis represents the relative concentration of  $\text{HbO}_2$  (mM). The X axis represents participants. S: socket prosthesis user. BA: bone-anchored prosthesis user. Note S8 and BA8 missing data.

little difference in cognitive load between the groups it should be recognized that fNIRS technology measures cortical activity in the order of seconds and does not allow for discrimination of events that may occur within a gait cycle (31). Analysis of events within a gait cycle is better addressed using electroencephalography (EEG), which has lower spatial resolution when compared with fNIRS but can measure electrophysiological brain activation within milliseconds (31). Preliminary EEG data comparing BAP and socket prosthesis users have provided some evidence to suggest that there may be differences in brain activity that occur around the time of heel strike, but further research is required to confirm this preliminary finding (32).

The left dlPFC has been linked to planning of motor sequences and allocation of attention (33). The goal of calculating a laterality index in the present study was subsequently to determine whether there was left or right-side hemispheric dominance that may distinguish between socket prosthesis and BAP users. In previous work, St George et al. (13) indicated that haemodynamic activity is more lateralized during easy balance tasks but, due to the need to engage more cognitive resources during challenging tasks, activity becomes more bilateral during more difficult tasks. During single-task walking, both the socket prosthesis and BAP groups in this study displayed largely left lateralized dlPFC activity. This suggests that neither group found it necessary to engage additional cognitive resources to complete the single-task walking condi-

tion. In addition, no obvious group differences were observed during the dual-task conditions; however, it is worth noting that both groups included more participants with right side dlPFC laterality. This finding is consistent with dual-task studies conducted on other populations (34). Right side laterality has been suggested to result from increased activity in the ventral attentional network, which aligns with the right PFC (34). The ventral attentional network is responsible for swapping attention between tasks (35) and would likely have been active during both the key-test and the TWT in the present study.

While this pilot study did not identify any major differences in cortical brain activity between socket prosthesis users and BAP users it is important to recognize that differences have previously been identified in other types of outcome measures. Qualitative results suggest that users of BAPs experience an increased feeling of their prosthesis being “an incorporated part of their body” (36). Quantitative studies have shown improvement in osseoperception, measured through the user’s ability to detect vibrations applied to the prosthesis (10), as well as more normal neuromuscular function in BAP users (37). Previous research has also shown that people who had experienced bothersome problems with a socket prosthesis and have transitioned to a BAP use their prosthesis more, and have improved mobility and an enhanced quality of life (38, 39). Given the substantial changes reported in individuals transitioning from a socket prosthesis to a

BAP and challenges to ensure homogeneity between groups of socket prostheses users and BAP users, we recommend that future studies investigate cognitive load prospectively within subjects.

### Limitations

Pilot studies, such as the present study, represent a fundamental phase of the research process by allowing researchers to examine the feasibility of recruitment procedures, assessment procedures, and methods for potential larger scale studies. As a pilot study, results of the present research are limited by a small sample size, which does not allow for testing of hypotheses or generalization of results (40). A further limitation of this study is our failure to control for the residual limb length of participants. Residual limb length is known to have a substantial influence on the gait outcomes of transfemoral prosthesis users (41) and a short residual limb is often an underlying reason why prosthesis users choose to undergo an osseointegration procedure (6). As a result, it is likely that participants in this study who were fitted with a socket prosthesis had longer residual limbs than those fitted with a BAP. The type of knee joint used in a prosthesis has previously been demonstrated to affect PFC activity (11). To control the potential effects of knee joint prescription we chose to standardize participants' knees to include only microprocessor-controlled joints. We did not, however, control for the specific type of microprocessor-controlled joint used by each individual and it is possible that this may account for some variance in PFC activity between participants.

The dual-task activities assessed in this pilot study were selected on the basis that they had been used in previous publications involving prosthesis users. The type of dual task performed during gait is, however, known to have an effect on brain activity (42, 43) and it is likely that selection of other tasks may have elicited different results.

While fNIRS offers a portable, non-invasive means of monitoring brain activity it does have some limitations, which may contribute to bias. These are largely related to artefacts caused by motion or physiological noise (44, 45). For example, blood flow changes in the extracerebral layers of the head are known to interfere with fNIRS signals. This can be addressed by using short-separation reference channels; however, we did not have access to short separation channels at the time these data were collected. As this is a pilot study, which will be used to determine whether future, large scale, studies are warranted, we limited our analysis to measures of oxygenated haemoglobin as this is where one would expect to see the largest variations in signal amplitude. To gain a complete picture of cortical brain

activity, we recommend that any future studies include data related to total haemoglobin concentrations and deoxygenated haemoglobin concentrations.

### Conclusion

The findings in this pilot study did not identify substantial differences in cognitive load and lateralization between socket prosthesis and BAP users, as measured using fNIRS during single- and dual-task walking conditions. Larger scale studies will be needed to confirm results, while controlling for residual limb length as an important variable that affects gait outcomes. We also recommend that future research, with larger sample sizes, continues to investigate activation symmetry between the left and right sides of the brain in this population as well as other groups with inherent balance and stability problems.

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*Availability of data and materials:* The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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*The authors have no conflicts of interest to declare.*

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