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Research Article

Characterizing objective and self-report habitual physical activity and sedentary time in outpatients with an acquired brain injury

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ABSTRACT

Outpatients with an acquired brain injury (ABI) experience physical, mental, and social deficits. ABI can be classified into two subgroups based on mechanism of injury: mild traumatic brain injury (mTBI; e.g., concussion) and other ABI (e.g., stroke, brain aneurysm, encephalitis). Our understanding of habitual activity levels within ABI populations is limited because they are often collected using self-report measures. The purpose of this study was to, 1) describe the habitual activity levels of outpatients with ABI using objective and self-report monitoring, and 2) compare the activity levels of outpatients with mTBI vs. other ABI. Sixteen outpatients with other ABI (mean ± standard deviation: [58 ± 13] years, 9 females) and 12 outpatients with mTBI ([48 ± 11] years, 9 females) wore a thigh-worn activPAL 24 h/day (h/day) for 7-days. Outpatients with ABI averaged (6.0 ± 2.3) h/day of upright time, (10.6 ± 2.2) h/day of sedentary time, (5.6 ± 2.7) h/day in prolonged sedentary bouts > 1 h, (5 960 ± 3 037) steps/day, and (11 ± 13) minutes/day (min/day) of moderate-vigorous physical activity (MVPA). There were no differences between activPAL-derived upright, sedentary, prolonged sedentary time, and physical activity between the mTBI and other ABI groups (all, $p > 0.31$). Outpatients with ABI overestimated their MVPA levels (+138 min/week) and underestimated sedentary time (−4.3 h/day) compared to self-report (all, $p < 0.001$). Despite self-reporting high activity levels, outpatients with ABI objectively exhibit highly inactive and sedentary lifestyles. The habitual movement behaviours of our sample did not differ by mechanism of injury (i.e., mTBI versus other ABI). Targeting reductions in objectively measured sedentary time are needed to progressively improve the habitual movement behaviours of outpatients with ABI.

1. Introduction

People with an acquired brain injury (ABI) experience a wide range of physical (e.g., headaches, chronic fatigue, paralysis), mental (e.g., depression, anxiety), and social (e.g., lack of motivation) deficits for years after their injury.[1] ABI is an umbrella term used in high-income countries like Canada, the United Kingdom, and Australia to describe a group of medical conditions that are caused by an injury to the brain that happens after birth and does not typically get worse over time.[2] ABI includes mild traumatic brain injuries (mTBIs) such as concussion and non-traumatic brain injuries (other ABI) such as stroke, brain aneurysm, and encephalitis.[2] ABI is one of the leading causes of long-term disability and death, with mTBI and stroke accounting for ~3% and ~10% of deaths in high-income countries, respectively.[3] Despite mTBI more commonly occurring in people < 45 years and other ABI typically impacting people ≥ 45 years, outpatients with ABI deal with a variety of cognitive, mental, and neurological deficiencies.[4] Due to these additional challenges, outpatients with ABI experience difficulties limiting their sedentary time and replacing it with upright time (i.e., standing, stepping).[5]

Existing literature demonstrates that an ABI can greatly affect one's ability to live a physically active lifestyle.[6–8] A sample of hospital inpatients with stroke and mTBI capable of walking independently averaged ~ 4 000 steps/day, which is below their daily step count recommendations of 5 000 steps/day.[6] The impacts of an ABI often linger for years post-injury, leading to many people with ABI receiving outpatient care (i.e., continued care after being released from the hospital) and

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List of abbreviations:

ABI	acquired brain injury
LPA	light-intensity physical activity
METs	metabolic equivalents of task
MPA	moderate-intensity physical activity
mTBI	mild traumatic brain injury
MVPA	moderate-vigorous-intensity physical activity
VPA	vigorous-intensity physical activity

adopting inactive, sedentary lifestyles.[7–9] Compared to healthy age-matched controls, outpatients with stroke typically engage in 50% fewer steps[5] and spend more than 10 h/day sedentary.[7] Meanwhile, outpatients with mTBI have self-reported similar sedentary activity levels (10.3 h/day of sedentary time), as it has been identified physical activity levels decrease by 75% post-injury.[8] While these results indicate outpatients with mTBI and other ABI may be similarly inactive, existing research demonstrates that people often self-report being more physically active than they are.[10] Furthermore, roughly 60% of outpatients with stroke[11] and 55% of outpatients with mTBI[12] demonstrate some form of cognitive impairment. Self-report in ABI populations often requires additional memory compensation strategies due to the increased prevalence of cognitive impairment and memory loss.[13] No existing study has characterized habitual movement behaviours in outpatients with mTBI and other ABI using device-based measures. In regions (e.g., Canada) with shared mTBI and other ABI health care services, understanding the similarities and differences between the subgroups is vital to providing physical activity counselling and elevating the standard of outpatient care for this diverse population.

Therefore, the purpose of this exploratory study was to, 1) describe the habitual activity levels of outpatients with ABI using a self-report measure and a thigh-worn inclinometer and 2) compare the activity levels of outpatients with mTBI versus other ABI.

2. Methods

2.1. Participants

The sample included 28 adult outpatients (i.e., dealing with symptoms for >6 months) who had been previously diagnosed with an ABI by a primary care physician. ABI can be subclassified by the mechanism of injury, which includes traumatic (e.g., external blow to the brain) and non-traumatic injuries (e.g., hemorrhage of a blood vessel within the brain). This study divided outpatients into two groups based on mechanism of injury; mTBI (i.e., concussion) and other ABI (stroke: $n=12$, brain aneurysm: $n=2$, encephalitis: $n=1$, brain anoxia: $n=1$). It was unclear how many participants were required for the study, given that prior work in outpatients with mTBI was based on self-report questionnaire outcomes without ABI condition comparisons.[8] Accordingly, effect sizes are included throughout to inform future studies. Participants were recruited from Nova Scotia Health's ongoing ABI Day Program waitlist, a specialized outpatient centre providing care to outpatients with ABI. This outpatient resource is designed to help outpatients with ABI who are dealing with prolonged impairments after their injury. Prospective participants were contacted via phone by an ABI Day Program coordinator on a first-come, first-serve basis. Participants were included in the study if they were ≥ 18 years of age, were previously professionally diagnosed with an acquired brain injury >6 months prior, were functionally independent (e.g., able to walk independently), and could provide written or verbal informed consent (i.e., completed the necessary forms and/or questionnaires).

2.2. Ethical approval

Informed consent was obtained from each participant before enrolling in the study. The study was reviewed and approved by Nova Scotia Health's Research Ethics Board prior to any data collection (REB #1027312).

2.3. Study design

Height and weight (to the nearest 0.5 cm and 0.1 kg, respectively) were measured using a calibrated stadiometer (Health-*O*-Meter, McCook, IL, USA) and body mass index (BMI) was calculated as weight ÷ height squared ($kg\cdot m^{-2}$). The number of comorbidities and medications were also collected to provide additional information regarding health status of the sample. Participants' self-reported habitual physical activity and sedentary levels using the Physical Activity Sedentary Behaviour Questionnaire.[14] This questionnaire is used in the outpatient clinic to determine patients' physical activity and sedentary time. Weekly physical activity levels were calculated by multiplying the answers of the following two questions.

1) "In a typical week, how many days do/did you do moderate-intensity (like brisk walking) to vigorous-intensity (like running) aerobic physical activity?"
2) "On average for days that you do/did at least moderate-intensity aerobic physical activity (as specified just above), how many minutes do/did you do?"

Sedentary activity levels were estimated by calculating a weighted average [(5 × weekday response + 2 × weekend response) ÷ 7] using the following questions.

1) "How many hours per day do you typically spend sitting, reclining, or lying down on a weekday? (Include time at work, school, at home or while commuting. Exclude time spent sleeping or napping)."
2) "How many hours per day do you typically spend sitting, reclining, or lying down on a weekend day? (Include time at work, school, at home or while commuting. Exclude time spent sleeping or napping)."

All participants were outfitted with one activPAL device secured on the front right thigh via transparent medical dressing and worn 24 h/day for seven days. Participants were asked to maintain their normal physical activity levels and sedentary behaviours throughout the study. Participants self-reported their sleep time via daily diaries to filter sleep time from waking sedentary time. Further, we inspect the data to ensure that the monitor did not fall off or taken off for long periods of time (e.g., long-periods 0 acceleration in XYZ axis). The activPAL data were analyzed in 15-second (s) epochs using custom MATLAB program (MathWorks, Portola Valley, CA, USA) that summarized daily averages of time awake (i.e., 24 h – self-reported sleep time), time spent standing, time spent sedentary (i.e., sitting/lying/reclined postures), and time spent stepping (i.e., walking, running). Prolonged bouts of sedentary time (i.e., bouts of >1 h in sitting/lying posture) were also filtered to better describe sedentary patterns of participants. Anthropometrics were used to calculate stepping cadence thresholds which sorted time spent in physical activity into light-intensity physical activity (LPA), moderate-intensity physical activity (MPA), vigorous-intensity physical activity (VPA), and moderate-to-vigorous-intensity physical activity (MVPA) for each participant (e.g., <100 steps/min = LPA, 100–120 steps/min = MPA, $\geq$ 120 steps/min = VPA). Previously validated equations based on height (Eq. (1), for adults ≤ 55 years)[15] and BMI (Eq. (2), for adults >55 years)[16] were used to calculate MPA and VPA thresholds by entering the participant's height (cm) or BMI ($kg\cdot m^{-2}$) and the metabolic equivalents of task (METs) corresponding to MPA (i.e., 3 METs) and VPA (i.e., 6 METs).

(for adults ≤ 55 years) [15] $= 73.490 - (0.513 \times \text{height}) + (59.867 \times \text{METs}) - (8.500 \times \text{METs}^2) + (0.436 \times \text{METs}^3)$ Eq. 1

(for adults > 55 years) [16] $= -84.321 + (91.209 \times \text{METs}) - (12.968 \times \text{METs}^2) + (0.772 \times \text{METs}^3) + (2.211 \times \text{BMI}) - (0.549 \times \text{BMI} \times \text{METs})$ Eq. 2

Time spent stepping above and below these step-rate thresholds were summed to provide an index of physical activity intensity. For more information on the anthropometric-derived cadence threshold equations presented, refer to the previously published studies.[15,16] The time spent within these thresholds were summed and averaged to characterize the weekly habitual activity levels of outpatients with ABI.

2.4. Statistical analysis

All continuous variables were checked for normal distribution via the Shapiro-Wilk test. Pairwise comparisons between mTBI and other ABI were conducted using independent-sample *t*-tests for parametric continuous variables and Mann-Whitney *U*-tests for non-parametric continuous variables (i.e., age, weight, body mass index, step counts, stepping time, MVPA, and self-reported MVPA) and χ^2 testing for categorical variables (i.e., sex). Self-reported versus activPAL-derived sedentary time was evaluated by paired-sample *t*-tests while self-reported versus activPAL-derived MVPA was evaluated by a Wilcoxon Signed-Rank test (non-parametric test for paired samples). Effect sizes were reported as Cohen's *d*. Potential covariates (i.e., age, sex, comorbidities) were also included. To test the impact of age, sex, and number of comorbidities, each potential covariate was individually inputted into linear regression modelling as an independent variable for outcome variables with between-group differences. Statistical analyses were completed using IBM SPSS Statistics (IBM, Armonk, NY, USA, Version 28.0) and results presented as means ± *SD*.

3. Results

Table 1 provides sample characteristics for the pooled sample ($n = 28$), mTBI group ($n = 12$), and the other ABI group ($n = 16$). The mTBI group was younger ($p = 0.023$, $d = 0.83$) and had fewer co-morbidities ($p = 0.017$, $d = 0.92$) than the other ABI group. All 28 participants completed the self-report questionnaires and wore the activPAL 24 h/day for seven days.

As shown in Fig. 1A, the pooled sample was in an upright posture for (6.0 ± 2.6) h/day, which included standing for (4.7 ± 2.1) h/day, stepping for (1.3 ± 0.6) h/day, and spent (5.3 ± 2.1) h/day in prolonged sedentary postures ≥ 1 h. The pooled sample under-reported their sedentary time ([6.3 ± 2.6] h/day) compared to activPAL-derived sedentary time ([10.6 ± 2.4] h/day, $p < 0.001$, $d = 1.72$). There were no differences between activPAL-derived total upright, standing, stepping, sedentary, and prolonged sedentary time between mTBI and the other ABI group (all, $p > 0.31$).

The pooled sample accumulated (5 960 ± 3 037) steps/day based on activPAL. As shown in Fig. 1B, the pooled sample completed (491 ± 224) min/week of LPA. There were no differences in activPAL-derived physical activity between mTBI and other ABI (all, $p > 0.40$). Outpatients with ABI overpredicted their self-reported MVPA levels ([213 ± 263] min/week) compared to the activPAL-derived MVPA ([75 ± 91] min/week, $p < 0.001$, $d = 0.70$).

Table 1
Comparing the self-reported participant characteristics, physical functioning, and habitual physical activity levels across types of ABI.

Characteristics	Pooled (n = 28)	mTBI (n = 12)	Other ABI (n = 16)	*p*-value	Effect Size
Age (years)	53 ± 13	48 ± 11	58 ± 13	**0.023***	0.83
Sex (# male, # female)	10, 18	3, 9	7, 9	0.434	–
Height (cm)	165 ± 9	167 ± 7	163 ± 10	0.240	0.46
Weight (kg)	83 ± 25	92 ± 31	76 ± 18	0.205	0.63
Body Mass Index ($kg \cdot m^{-2}$)	30.3 ± 7.8	32.8 ± 10.5	28.5 ± 4.4	0.241	0.53
Number of comorbidities	4.0 ± 3.7	2.3 ± 2.3	5.3 ± 4.0	**0.017***	0.92
Number of medications	2.3 ± 1.5	1.8 ± 1.0	2.6 ± 1.7	0.147	0.57

Note: Pairwise comparisons between mild traumatic brain injury (mTBI) and other ABI groups were conducted using Mann-Whitney U-testing (non-parametric) for continuous variables and Chi-square testing for categorical variables (i.e., sex). Effect sizes reported as Cohen's *d*.; *, indicates statistical significance of $p \leq 0.05$ between groups. Data presented as means ± standard deviation or proportions.

4. Discussion

The purpose of this study was to describe the habitual activity levels of outpatients with ABI using a common questionnaire and the activPAL thigh-worn activity monitor, as well as compare the activity levels of outpatients with mTBI versus other ABI. Outpatients with ABI were highly sedentary, spent ~50% of their sedentary time in prolonged bouts ≥ 1 h, and accumulated ~6 000 steps/day. These objective measures contrasted with self-report measures that calculated ~2.8 times and ~1.7 times more MVPA and less sedentary time than activPAL-derived approximations, respectively. The inactive, sedentary lifestyles of our sample did not differ by mechanism of injury (i.e., mTBI versus other ABI). These observations may provide useful information for measuring habitual activity and identifying target postures for movement interventions.

Outpatients with ABI frequently experience diminished motivation,[7] impaired physical function,[17] and mental deficiencies[4] for years post-injury. The additional challenges faced by outpatients with ABI likely contributed to the surplus of sedentary time ([10.6 ± 2.4] h/day), lack of upright time ([6.0 ± 2.6] min/day), and lack of MVPA ([77 ± 98] min/week) observed, which was consistent with existing studies in stroke survivors.[9] Perhaps the most alarming finding from the present study was that outpatients with ABI were accumulating (5.3 ± 2.1) h/day of sedentary time in prolonged bouts > 1 h. The World Health Organization recommends limiting sedentary time as much as possible, especially prolonged sedentary bouts due its link to an increased risk of all-cause mortality.[18] Existing literatures has demonstrated that excess time in sedentary postures is associated with detriments to physiological function, including impaired cardiometabolic, musculoskeletal, and cognitive function.[19] For inactive populations like outpatients with ABI who may have limited capacity to increase their habitual physical activity levels, targeting reductions in sedentary time may be more manageable.

Based on our objective monitoring outcomes, outpatients with ABI exhibit challenges leading physically active lives. However, a meta-analysis comparing daily step counts and all-cause mortality rates indicated that older adults (> 60 years old) achieving 6 000–8 000 steps/day were at a reduced risk of cardiovascular disease and all-cause mortality.[20] Our sample averaged (5 960 ± 3 037) steps/day, which was close to this step count recommendation for healthy older populations. When considering physical activity intensity, most of our sample ([75 ± 91] min/week of MVPA) was far from the 150 min/week of MVPA in absolute intensity (i.e., 3 times resting energy expenditure) recommended by the World Health Organization.[18] For clinical populations like outpatients with ABI, achieving what would be considered LPA by our "absolute" intensity thresholds may have felt like MVPA when considering the decreased physical fitness, suggesting the need to consider participants' relative intensity in the future (e.g. MPA: ~40% of maximal aerobic fitness). This was apparent in the self-reported activity levels, which indicated that our sample engaged in (226 ± 265) min/week of MVPA. Though the Physical Activity Sedentary Behaviour Questionnaire has had questionable validity in healthy populations,[14,21] it is integrated into the Canadian Society for Exercise Physiology training manual and

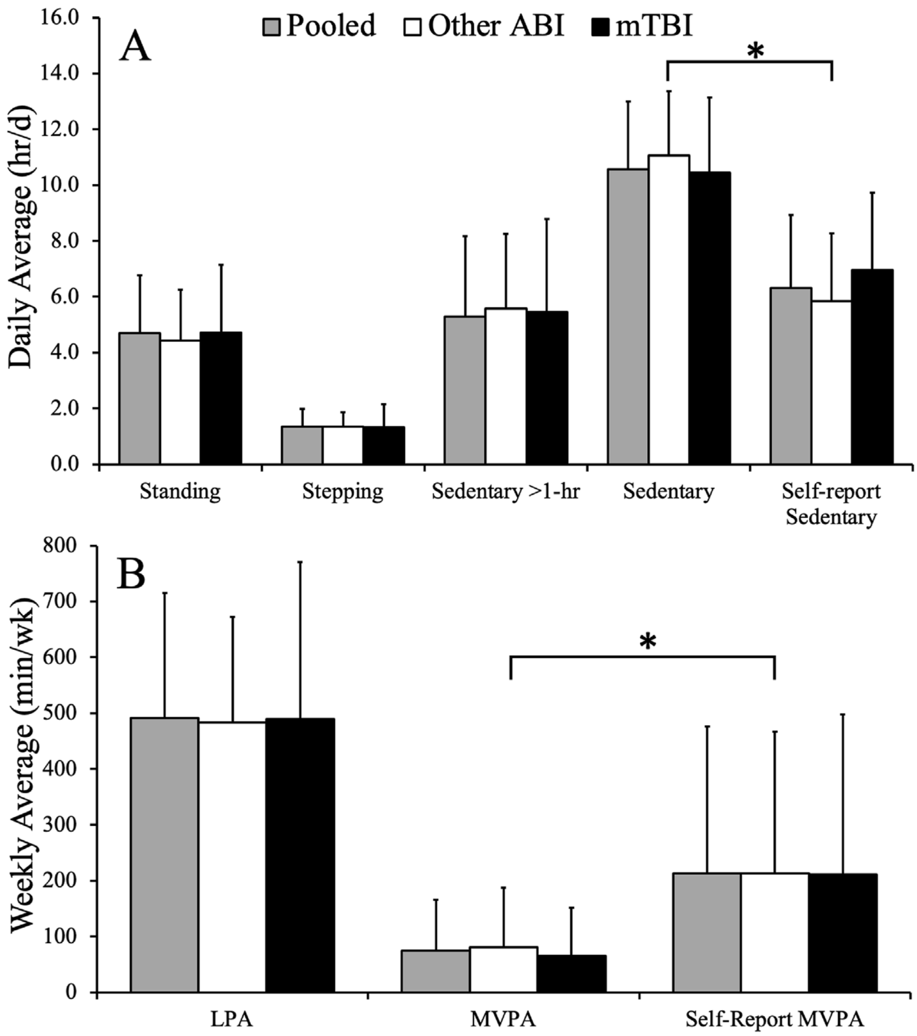

Fig. 1. Displays the, [A] daily movement behaviours, and [B] weekly physical activity levels of the pooled sample (grey), outpatients with other acquired brain injury (ABI; white), and outpatients with mild traumatic brain injury (mTBI; black). LPA, light-intensity physical activity; MVPA, moderate-to-vigorous-intensity physical activity, hr/d, hours per day, min/wk, minutes per week. *, indicates statistical significance of $p \leq 0.05$ between activPAL-derived and self-reported outcomes. Data presented as means ± standard deviation.

used in this specific outpatient clinic. It is also possible that in a population that often deals with mental fatigue, memory loss, and cognitive impairment,[22] the accuracy of self-report questionnaires may be further reduced. With self-report measures being used in many clinical settings to quickly gauge activity levels, our findings also demonstrate the challenges of selecting an appropriate method to measure habitual movement behaviours. Despite the additional resources required, it is encouraged that future work in this field consider objective measures of habitual activity whenever possible.

This was the first study to directly compare the habitual activity levels of outpatients with mTBI and other ABI using objective activity monitoring. Despite our mTBI sample being younger with fewer comorbidities, there were no differences observed across the groups. The increased age of the other ABI group is consistent with existing evidence demonstrating that non-traumatic brain injuries (e.g., stroke, brain aneurysm, brain anoxia, encephalitis) typically occur in adults ≥ 45 years old.[4] Outpatients with non-traumatic brain injuries also experience a higher rate of cardiovascular and metabolic conditions,[23] suggesting that concerns of an adverse health event (e.g., another stroke) may be a limiting factor when trying to increase post-injury activity levels. Both increased age and risk of chronic disease could have theoretically translated to increased sedentary time, reduced upright time, and/or lower physical activity levels in the other ABI group compared to the mTBI group. However, our findings demonstrated that mTBI and other ABI groups were living similarly inactive, sedentary lifestyles. This suggests that the severity of impairments from ABI (e.g., cognitive function, mental health, and physical fitness) is likely more important to the habitual movement behaviours (e.g., physical activity, sedentary time) than the mechanism of injury (i.e., traumatic versus non-traumatic). Our findings also encourage the development of more community programming like Nova Scotia Health's ABI Day Program where outpatients with all types of ABI are welcomed with individualized care to target their symptoms and impairments.

To improve the overall habitual activity levels of outpatients with ABI, providers may need to implement a stepwise approach to educate outpatients with ABI on the benefits of reducing sedentary time before trying to integrate more physical activity.[24] For instance, our pooled sample was in upright postures for (6.0 ± 2.6) h/day but only (1.3 ± 0.6) h/day was spent stepping. For outpatients with ABI, simply replacing some of their 10.5 h/day of sedentary time with upright time could be a feasible first step. For example, standing breaks every 15–30 min of sitting (e.g., watching television) may be a more realistic movement strategy than formal exercise training. Over time, adaptations can be made to slowly implement light-intensity physical activity (e.g., walking) and progress to MVPA (e.g., climbing stairs, jogging) when appropriate. Creating community programming alongside counselling by health care providers, who implement this stepwise approach, may be the key to increasing the activity levels of outpatients with ABI.

Due to the cross-sectional study design, we are unable to establish causality, demonstrating a need for longitudinal and interventional studies. Our study findings are specific to independently-functioning outpatients with ABI (e.g., able to walk with assistance, transfer from a chair, carry out a conversation) and may not apply to people currently or recently hospitalized for ABI reasons. Our findings are likely not representative of all people living with severe ABI and/or hospitalized for an ABI, who are probably even more inactive and sedentary. The present study was limited to using absolute physical activity intensity thresholds based on anthropometrics. Implementing relative physical activity intensity thresholds would require a measurement of maximal aerobic fitness, which discourages their utility in this population and is not something we conducted in this study. Despite our sample including 28 outpatients with ABI, we included effect sizes throughout the study to help guide future research comparing types of ABI. Notably, this was one of the first studies to objectively monitor the habitual postures and physical activity levels of outpatients with ABI, and documents the large variability between self-report and objective monitoring in this population.

5. Conclusions

Outpatients with ABI appear to live inactive, sedentary lifestyles for months after their injury. Our sample spent most of their day in prolonged sedentary postures with limited time in upright postures. Self-reported measures reported drastically more MVPA and less sedentary time than activPAL-derived approximations. The habitual movement behaviours of our sample did not differ by mechanism of injury (i.e., mTBI versus other ABI). For health care professionals working with outpatients with ABI, implementing a stepwise approach which considers one's social, mental, and physical abilities and targets initial reductions in sedentary time may be a more feasible strategy to improving habitual movement patterns.

Submission statement

The work described has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis), is not under consideration for publication elsewhere, is approved by all authors and Nova Scotia Health, and will not be published elsewhere including electronically in the same form, in English or any other language, without the written consent of the copyright-holder.

Ethical approval statement

Informed consent to was obtained from each participant before enrolling in the study. Participants consented to their data being published. The study was reviewed and approved by Nova Scotia Health's Research Ethics Board prior to any data collection (REB #1027312).

Data availability

The data that support the findings of this study are available from the corresponding author upon request.

CRediT authorship contribution statement

Liam P. Pellerine: Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Katerina Miller:** Writing – review & editing, Resources, Methodology, Data curation, Conceptualization. **Ryan J. Frayne:** Writing – review & editing, Supervision, Project administration, Methodology. **Myles W. O'Brien:** Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Methodology, Formal analysis, Conceptualization.

Conflict of interest

KM is a licensed physiotherapist employed by Nova Scotia Health as part of the ABI Rehabilitation Day Program.

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