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Cognition and motor impairment correlates with exercise test performance after stroke

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Abstract

Introduction—Exercise not only benefits physical and cardiovascular function in older adults with multiple chronic conditions, but may also improve cognitive function. Peak heart rate (HR), a physiological indicator for maximal effort, is the most common and practical means of establishing and monitoring exercise intensity. In particular, in the absence of graded maximal exercise tests (GXT) results, age-predicted maximal HR values are typically used. Using individuals with stroke as a model for examining older adults with co-existing cardiovascular and neuromotor conditions, the purpose of this paper was to examine the determinants associated with achieving age-predicted maximal HR on a GXT, with respect to neurological, cognitive and lower limb function.

Methods—Forty-seven participants with stroke (mean±SD age 67±7 years, 4±3 years post-stroke) performed GXTs. Peak values for gas exchange, HR and ratings of perceived exertion were noted. Logistic regression analysis was performed to examine determinants (neurological impairment, leg motor impairment, Montreal Cognitive Assessment (MoCA) score, walking ability) associated with the ability to achieve age-predicted maximal HR on the GXT.

Results—VO_2peak was 16.5±6 ml•kg^{-1}•min^{-1}. Fourteen (30%) participants achieved ≥ 100% of age-predicted maximal HR. Logistic regression modeling revealed that the ability to achieve this threshold was associated with less leg motor impairment (P=0.02, OR 2.3) and higher cognitive scores (P=0.048, OR 1.3).

Conclusions—These results suggest that non-cardiopulmonary factors such as leg motor impairment and cognitive function are important contributors to achieving maximal effort during exercise tests. This study has important implications for post-stroke exercise prescription whereby

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training intensities that are based on peak HR from GXTs may be underestimated among individuals with cognitive and physical impairments.

Keywords

Exercise testing; rehabilitation; stroke; cognition

Introduction

Seniors are the fastest growing age group and commonly present with multiple co-morbidities and chronic health conditions. Eighty-five percent of people over 65 have at least one chronic health condition and 62% have 2 or more (4) that frequently impair physical and cognitive ability. Cognitive impairment occurs in approximately 20% of older adults (23) and lower limb muscle strength declines about 15% per decade (21). Regular physical activity and exercise are important for older adults, as they are particularly vulnerable to the negative health consequences of sedentary behavior.

Stroke may be a useful model for examining older adults with multiple chronic health conditions, functional limitations and elevated cardiovascular risk. Stroke incidence increases steadily with each decade of life particularly after the age of 65 (16) and, in the United States, 1 in 6 older adults has cardiovascular disease (38). Cognitive impairment is prevalent after stroke, occurring in 35% of cases (34), and motor function is compromised in ambulatory individuals with stroke, where leg muscle strength was as low as 60% of age-matched values (22). Engaging in regular exercise is critical for older adults with stroke, particularly as a strategy for secondary prevention (18).

For health professionals wishing to initiate exercise training for their clients with stroke, heart rate (HR) prescription is the most commonly used and clinically feasible means for establishing and monitoring exercise intensity in the clinical setting. It is easy to measure and monitor with minimal equipment. HR is associated with oxygen consumption (VO_2), rising linearly with increasing VO_2 during exercise (2), and peak HR achieved during a graded exercise test (GXT) may be used as a surrogate physiological indicator for effort put forth by the subject. Normative age-predicted maximal HR values have been established (19), and achievement of these predicted values reflects maximal or near-maximal effort (2). Age-related decline in maximal HR is a well-established phenomenon, is a key contributor to reductions in exercise capacity (11), and is relatively independent of physical activity (10, 28). Importantly, stroke clinicians turn to these predictive equations to provide an estimate of maximal HR and determine appropriate intensities for aerobic training since the equipment and resources needed to perform GXTs are not often available or easily accessible.

One challenge in performing GXTs with individuals with physical and cognitive impairments is whether the peak HR reflects established predicted values for maximal effort. Normal age-related changes to the cardiopulmonary system may contribute to chronotropic incompetence and thus, reduced exercise capacity (10), but for individuals with stroke, non-cardiopulmonary factors may also limit the ability to achieve sufficiently high workloads during a GXT to attain age-predicted maximal HR. It has been suggested that neuromotor sequelae from stroke may limit performance more so than cardiovascular function (25, 32), but the contribution of neurological (motor and/or cognitive) factors has not been previously examined. The purpose of this study was to examine determinants associated with achieving maximal exercise effort on a GXT, defined as reaching 100% age-predicted maximal HR, among individuals with stroke. We hypothesized that variables related to neurological, cognitive and lower limb motor impairment would be associated with participants' ability to achieve this threshold. Given the potential for exercise to improve cardiovascular function in individuals with multiple chronic conditions, in addition to the growing evidence that exercise can improve cognitive function in older adults with cognitive impairment (36), it is important to understand the influence of physical and cognitive impairments on parameters of exercise prescription.

Methods

This study was a cross-sectional analysis of baseline data from a larger trial examining the effects of post-stroke aerobic exercise (33). Study procedures were approved by the ethics boards of the University of British Columbia and the Vancouver Coastal Health Research Institute. Informed written consent was obtained from all participants.

All participants were at least 1 year post-stroke, living in the community, able to walk 5 meters independently (with or without gait aids), free of other neurological conditions, and able to follow instructions and procedures for exercise testing. Individuals presenting with non-cardiogenic stroke (e.g. aneurysm, tumor, infection), uncontrolled arrhythmias, pacemaker, or musculoskeletal or other issues that would preclude participation were excluded. The sample size was determined as 50 participants for the main trial (33), and exercise test data was available for a subset of 47 participants. Participant demographics were recorded, including age, sex, and relevant medical and stroke history.

Assessments

Given the sample size of 47 participants, a logistic regression model can accommodate 4 to 5 variables (29). To capture the influence of common issues pertinent to the stroke population, the following assessments were prioritized as indices of global neurological impairment, cognitive impairment and lower limb function, and were considered as potential correlates with the ability to achieve age-predicted maximal HR on the GXT.

Neurological impairment and cognitive function

Global neurological impairment was assessed using the National Institutes of Health Stroke Scale (NIHSS) (9). This scale evaluates a broad range of neurologic outcomes including visual fields, speech and language, and motor and sensory function.

The Montréal Cognitive Assessment (MoCA) is a screening tool for cognitive impairment among older adults with greater sensitivity and specificity than the Mini-Mental Status Examination. A threshold score of 26 and below (out of 30) identifies individuals with mild cognitive impairment (12, 27).

Lower limb impairment and function

Motor recovery of the lower limb was assessed using the Leg and Foot Impairment Inventories of the Chedoke-McMaster Stroke Assessment (CMSA) (20), and combined for a maximum score of 14. Higher scores indicate greater motor recovery.

Two measures of walking ability were included as indices of lower limb function. Gait aids were permitted for both walk tests. Firstly, self-selected gait speed was measured over a 9-meter distance, where the middle 5 meters were timed. The average across 2 trials was calculated. Secondly, the 6-Minute Walk Test (6MWT) was performed using standardized instructions (3) to walk as far as possible in 6 minutes over a 30-meter square course. This test has high test-retest reliability (17) among people with stroke, and concurrent validity with VO_2peak (14).

Graded Exercise Test (GXT)

Symptom-limited GXTs were performed on an upright cycle ergometer (Excalibur, Lode Medical Technology, Groningen NL). A metabolic cart with breath-by-breath analysis (ParvoMedics, Sandy UT) was used, and a 12-lead electrocardiographic system (CardioCard, Nasiff Associates, New York NY) monitored cardiac activity throughout the test and into recovery. Cycle ergometry was selected as the testing modality as it can accommodate individuals with a broader range of balance and lower limb control after stroke. Additional strapping was provided as needed to secure participants' feet to the pedals. The ramp protocol was individualized to progress work rate by 10- or 15-watts per minute to maintain a total test time of 8–10 minutes. The American College of Sports Medicine test termination guidelines were followed (1), or when the participant was unable to maintain target pedaling cadence of 50 revolutions per minute. Peak VO_2, work rate, HR and respiratory exchange ratio were recorded. Ratings of perceived exertion (RPE, 6–20 scale (8)) were provided at the end of the test.

Analysis

Descriptive statistics were performed. Age-predicted maximal HR was calculated as [206.9 – (0.69 × Age)] (19), and adjusted accordingly for participants (n=20) taking beta-blocker medications (age-predicted maximal HR × 70% (35)). Peak HR was expressed as a percentage of age-predicted maximal HR, and the number of participants who achieved ≥ 100% age-predicted maximal HR was determined.

To examine potential factors related to the ability to achieve age-predicted maximal HR, the sample was dichotomized into 2 groups using this cut-point (±100% age-predicted maximal HR). Factors hypothesized to influence participants' ability to reach this threshold were entered into a logistic regression model (age, NIHSS, MoCA and CMSA scores, gait speed and 6MWT distance). Variables were then removed (least significant first) in an iterative process until significant ones remained (final model). For the stepwise procedure of the regression analysis, a threshold of $P<0.10$ was used to determine which variables remained in each iteration of the model, as conventional variable selection criteria (e.g. $P< 0.05$) can fail to identify variables that are potentially important (26).

Data were analyzed using Statistical Package for the Social Sciences (Version 17.0, Chicago IL) using significance level of $P<0.05$ for all other analyses.

Results

Forty-seven participants performed the GXT. They were a representative sample of individuals with stroke living in the community, and presented with multiple co-morbidities (mean±SD 4±2.5 chronic conditions), and risk factors such as diabetes and hypertension. While NIHSS scores (1.2±1.9) indicated that this was a sample of mild stroke severity, functional limitations were present. Mean gait speed (0.94±0.37 meters/second) represented 72% (7) of values for age-matched healthy individuals, 6MWT distance of 320.3±134.8 meters was 64% of predicted (15) and VO_2peak of 16.5±6.0 ml•kg^{-1}•min^{-1} was 53% of normative values (1). MoCA scores (25.0±4.0) were below the normal threshold and indicated mild cognitive impairment (12, 27).

Two subgroups were created based achieving ±100% age-predicted maximal HR on the GXT, where 14 (30%) participants reached this threshold. Subgroup comparisons of participant characteristics are presented in Table 1.

GXT results

Subgroup comparisons of the exercise test results are presented in Table 2. Gas exchange data was not obtained for 1 participant due to equipment problems, but work rate and HR data were collected. Data from one participant was not included in the analysis as the GXT was terminated early due to a major adverse event (ventricular tachycardia). For the remaining participants, reasons for test termination included: general fatigue or breathing effort (n=8, 17%), leg fatigue (n=9, 19%), inability to maintain pedaling cadence (n=9, 19%), participant's request (n=2, 4%), pain (n=3, 6%), and not specified (n=18, 35%).

Factors associated with ability to achieve age-predicted maximal HR

Potential correlates were first entered into a logistic regression model (Model 1), and after 3 iterations, the final model ($\chi^2(4)=13.5$, $P=0.009$) revealed that CMSA lower limb impairment ($P=0.02$, OR 2.3) and MoCA scores ($P=0.048$, OR 1.3) were significant contributors to the participants' ability to achieve age-predicted maximal HR (Table 3). Age and NIHSS score remained in the model but were not significant independent contributors. All models had acceptable goodness-of-fit levels (all Hosmer-Lemeshow tests $P>0.39$).

Discussion

Stroke is a useful model for examining older adults with multiple health issues, including impaired cognitive and neuromotor function and cardiovascular co-morbidities. Our participants were a representative sample of individuals living in the community with stroke, as they presented with multiple risk factors, compromised fitness and mild cognitive impairment. Age-associated changes to cardiopulmonary function, such as decreased maximal HR or chronotropic incompetence, may contribute to lowered exercise capacity (10). This is the first study to identify the contribution of non-cardiopulmonary factors, specifically motor and cognitive status, to the ability to achieve maximal effort. Participants in the group that achieved age-predicted maximal HR had a higher cognition (MoCA) and lower leg impairment (CMSA) scores.

That cognitive status was associated with the ability to achieve age-predicted maximal HR is a novel finding. Of note, MoCA scores among participants who achieved the target HR were above the 26-point threshold for identifying individuals with cognitive impairment, whereas those who did not were 2 points below. Owing to the safety risks associated with performing GXTs, such tests are performed only if the subject is able to understand and follow testing instructions and procedures. Although MoCA scores did indicate that our sample presented with mild cognitive impairment, all participants were living independently in their own homes and were judged to possess sufficient cognitive capacity to safely perform the GXTs.

We explored several potential explanations for this finding. To rule out the possibility that cognitive impairment was simply associated with low absolute levels of aerobic fitness (as VO_2peak is a surrogate measure of daily physical activity (6)), we performed post-hoc correlation analysis but found no significant relationship between VO_2peak and MoCA scores (r=0.19, P=0.20). We also considered that individuals with cognitive impairment might have opted to terminate the test prematurely, perhaps due to discomfort or anxiety as they approached near-maximal levels of effort. Secondary analyses did not reveal any association between MoCA scores and peak respiratory exchange ratio, nor were we able to discern any patterns related to reasons for test termination across MoCA scores.

We did note, however, a small (non-significant) difference between the 2 groups in RPE provided at the end of the GXT, with higher values among participants who did not achieve age-predicted maximal HR. This mismatch between reported and actual exertion may reflect impairments in perception regarding the effort of exercise performed. Greater variability in interpreting RPE among individuals with brain injury (including stroke) has been attributed to cognitive impairment (13). Individuals in the current study with MoCA scores <26 may have altered perceptions of effort during the GXT. This disparity has implications for exercise programming, whereby training intensities may be underestimated for a given level of effort among individuals with cognitive impairment. Interpreting GXT results in these cases should be done with caution, but should not preclude them from participating in exercise. Exercise-related improvements in cognitive function have been reported among older adults (36), and similar evidence is emerging for individuals with stroke (30, 31).

We also found that lower limb impairment was an important contributor to GXT performance on a cycle ergometer. Arguably, the challenge of reaching true maximal aerobic capacity among individuals with physical impairment may be a product of the testing modality used. Alternative modalities, such as treadmill testing, might circumvent the issue of localized muscle fatigue as walking is a more familiar activity (2), but would still have limited application for individuals with compromised walking ability. Furthermore, achieving near-maximal exercise effort may remain problematic as previous studies have reported that only 50% of participants with Parkinson’s (37) and stroke (24) achieved 85% age-predicted maximal HR on treadmill GXTs. Thus, cycle ergometry remains a suitable testing modality, applicable for individuals with a broader range of physical abilities (e.g., balance and walking impairments) and is also a safer alternative for those with cognitive impairment. Of note, the use of total-body recumbent steppers for post-stroke GXTs was examined, where higher VO_2peak values were achieved compared to a cycle ergometer tests, and a greater proportion of participants achieved at least 80% of predicted maximal HR (5). It is possible that modalities that engage both upper and lower limb muscle groups may provide a greater opportunity to achieve maximal exercise capacity, and warrant further study.

Study limitations

As this is a correlative study, we cannot infer causation but can only conclude that associations exist between GXT performance and cognitive and motor impairment. We also acknowledge that the cut-point of 100% age-predicted maximal HR used to create the subgroups may seem arbitrary, but this threshold was chosen because exercise intensity is most commonly prescribed based on a percentage of 100% age-predicted maximal HR when GXT results are not available. Post-hoc logistic regression analyses using similarly high thresholds (85%, 90% and 95% of age-predicted maximal HR) yielded similar trends, where MoCA score, NIH score and self-paced walk speed remained in the final model. Additionally, while our sample of community-dwelling individuals with stroke was representative of older adults with multiple co-morbidities, they were relatively high functioning and results from this study may not be generalizable to a lower functioning cohort. In the interest of selecting a representative sample of individuals with stroke presenting with multiple co-morbidities and pharmacological therapies, we did not exclude participants taking beta-blocker medications but did account for their use when calculating age-predicated maximal HR. Finally, we acknowledge that the MoCA was designed as a global screening tool, and future studies could explore the importance of specific aspects of cognition (e.g. memory, executive function) on GXT performance.

Conclusions

Previous research has suggested that neuromotor sequelae and disability levels after stroke may limit exercise test performance more so than cardiopulmonary function (25, 32). No previous study has examined the contribution of neurological factors commonly observed after stroke, including motor and cognitive function, on the ability to achieve maximal exercise effort on a GXT. Results from this study suggest that training intensities, based on peak HR from GXTs, may be underestimated among individuals with stroke-related cognitive and physical impairments. Given that HR prescription is the most commonly used and clinically feasible means for establishing and monitoring exercise intensity in clinical settings, these findings have important implications for exercise prescription for this population.

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Table 1

Comparison of participant characteristics between subgroups of achieving <100% or ≥100% age-predicted maximal heart rate on the graded exercise test

	<100% Age-predicted maximal HR n=32	≥ 100% Age-predicted maximal HR n=14	*P* value
Sex, Men / Women	18 (56) / 14 (44)	9 (64) / 5 (36)	0.43
Age, years	66.1 ± 7.2 (53–80)	67.8 ± 6.5 (58–79)	0.46
Stroke details			
Time post-stroke, years	4.4 ± 3.1 (1.1–11.2)	4.1 ± 2.8 (1.2–9.8)	0.79
Lacunar / Ischemic / Hemorrhagic / Unknown type	6 (19) / 12 (38) / 11 (34) / 1 (9)	0 (0) / 7 (50) / 4 (29) / 3 (21)	0.32
Cortical / Subcortical / Brainstem / Other location	8 (25) / 16 (50) / 5 (16) / 3 (9)	2 (14) / 5 (36) / 1 (7) / 6 (43)	0.37
Right / Left / Bilateral limbs affected	12 (38) / 19 (59) / 1 (3)	4 (29) / 10 (71) / 0 (0)	0.64
Number of chronic conditions	4.0 ± 2.5 (1–14)	4.3 ± 2.4 (1–11)	0.69
Diabetes, None / Type 2	25 (78) / 7 (22)	9 (64) / 5 (36)	0.26
Gait aids, None / Cane / Walker	18 (56) / 10 (31) / 4 (13)	10 (71) / 3 (21) / 1 (7)	0.62
Body mass index, kg/m^2	27.8 ± 5.0 (15.9–37.1)	27.6 ± 3.9 (21.2–34.6)	0.91
NIHSS score	1.2 ± 2.0 (0–10)	0.9 ± 1.4 (0–4)	0.66
CMSA lower limb impairment score	11.4 ± 2.7 (3–14)	13.1 ± 1.6 (9–14)	0.06
MoCA score	24.2 ± 4.1 (15–30)	26.6 ± 3.3 (20–30)	0.04*
Gait speed, m/s	0.88 ± 0.38 (0.10–1.69)	1.08 ± 0.31 (0.54–1.45)	0.10
6-Minute Walk Test, m	302.6 ± 142.2 (27–600)	359.5 ± 111.3 (147–553)	0.19

Values are n (%) or Mean ± SD (min-max)

*$P<0.05$

Abbreviations: NIHSS – National Institutes of Health Stroke Scale; CMSA – Chedoke-McMaster Stroke Assessment; MoCA – Montréal Cognitive Assessment

Table 2

Comparison of exercise test results between participant subgroups of achieving <100% or ≥100% age-predicted maximal heart rate on the graded exercise test

	<100% Age-predicted maximal HR n=32	≥ 100% Age-predicted maximal HR n=14	*P* value
VO_2peak, L•min^{-1}	1.4 ± 0.7 (0.5–3.0)	1.4 (0.6 (0.4–2.4)	0.95
VO_2peak, ml•kg^{-1}•min^{-1}	16.3 ± 5.9 (7.3–28.8)	16.8 ± 6.3 (6.2–28.7)	0.80
Peak work rate, watts	79.7 ± 41.5 (20–210)	92.5 ± 46.1 (30–165)	0.36
Peak heart rate, beats•min^{-1}	123.0 ± 20.8 (73–159)	144.6 ± 22.2 (113–178)	0.003*
Peak heart rate, % of age-predicted maximal heart rate	81.5 ± 11.7 (58–99)	118.4 ± 17.9 (100–145)	<0.001*
Peak respiratory exchange ratio	1.17 ± 0.13 (0.93–1.49)	1.18 ± 0.24 (0.65–1.70)	0.80
Peak rating of perceived exertion	15.6 ± 2.0 (13–19)	14.6 ± 2.2 (11–18)	0.15

Values are Mean ± SD (min-max)

* $P<0.05$

Table 3

Logistic regression to determine correlates with ability to achieve age-predicted maximal heart rate on the graded exercise test

Correlates	B (SE)	Wald	*P* value	OR (95% CI)
Model 1: $\chi^2(6)=13.5$, $P=0.04^*$				
Age	0.12 (0.08)	2.35	0.13	1.13 (0.97, 1.32)
CMSA lower limb impairment	0.85 (0.46)	3.45	0.06	2.34 (0.95, 5.76)
MoCA	0.26 (0.14)	3.73	0.05	1.30 (1.00, 1.69)
NIHSS	0.74 (0.39)	3.55	0.06	2.10 (0.97, 4.55)
Gait speed	0.002 (0.03)	0.003	0.96	1.00 (0.94, 1.06)
6MWT distance	0.00 (0.006)	0.01	0.92	1.00 (0.99, 1.01)
Model 2: $\chi^2(5)=13.5$, $P=0.02^*$				
Age	0.12 (0.08)	2.37	0.12	1.13 (0.97, 1.32)
CMSA lower limb impairment	0.86 (0.40)	4.72	0.03*	2.37 (1.09, 5.17)
MoCA	0.26 (0.13)	3.90	0.048*	1.30 (1.00, 1.68)
NIHSS	0.75 (0.39)	3.66	0.06	2.11 (0.98, 4.53)
6MWT distance	0.00 (0.004)	0.01	0.92	1.00 (0.99, 1.01)
Model 3: $\chi^2(4)=13.5$, $P=0.009^*$				
Age	0.12 (0.08)	2.42	0.12	1.13 (0.97, 1.32)
CMSA lower limb impairment	0.85 (0.36)	5.48	0.02*	2.33 (1.15, 4.74)
MoCA	0.26 (0.13)	3.93	0.048*	1.30 (1.00, 1.68)
NIHSS	0.74 (0.39)	3.66	0.06	2.10 (0.98, 4.50)

* $P<0.05$

Abbreviations: CMSA – Chedoke-McMaster Stroke Assessment; MoCA – Montreal Cognitive Assessment; NIHSS – National Institutes of Health Stroke Scale; 6MWT – 6-Minute Walk Test