Brief Report

Characterizing Heart Rate Response During Upper Extremity Repetitive Task Practice in Chronic Stroke

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Importance: Although the cardiopulmonary benefits of aerobic exercise poststroke are well-established, typical stroke rehabilitation does not elicit an aerobic response.

Objective: To characterize heart rate response during upper extremity repetitive task practice (RTP) and determine factors that predict a higher aerobic intensity during RTP.

Design: Secondary analysis of a subset of data from a randomized clinical trial.

Setting: Research laboratory in a large academic medical center.

Participants: Patients with chronic stroke ($N = 19$).

Intervention: Participants received 90 min of RTP for 24 sessions across 8 wk.

Outcomes and Measures: Aerobic intensity as measured by heart rate reserve (HRR) during RTP.

Results: A total of 2,968 tasks were included in the analysis. Of the tasks performed, approximately 79.5% elicited a very light aerobic response (<30% HRR), 10.2% elicited a light aerobic response (30%–39% HRR), and 10.3% elicited a moderate to vigorous intensity aerobic response (≥40% HRR). Of the tasks that elicited a moderate to vigorous intensity aerobic response, 54.1% were performed in standing, 79.7% were gross motor in nature, and 27.9% had targets at or above shoulder height. Standing position, targets at or above shoulder height, and gross motor tasks predicted higher HRR (all $ps < .001$).

Conclusions and Relevance: To maximize aerobic intensity during poststroke RTP, therapists should include gross motor tasks trained in standing with targets at or above shoulder height.

Plain-Language Summary: The study characterizes heart rate response in stroke rehabilitation and identifies factors that predict a higher aerobic intensity during upper extremity repetitive task practice. Certain task characteristics were more likely to produce an aerobic response, including gross motor, targets at or above the shoulder, and a standing position. Occupational therapists should include gross motor tasks trained in standing with targets at or above shoulder height to maximize aerobic intensity during poststroke repetitive task practice. Monitoring heart rate may improve awareness of aerobic response to training.

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Approximately 800,000 people experience a stroke each year in the United States (Billinger et al., 2014). The motor consequences of stroke on the performance of activities of daily living (ADLs) are well recognized and documented (Dhamoon et al., 2009). An additional effect of stroke is diminished cardiopulmonary capacity because poststroke aerobic capacity (peak volume of oxygen consumption [VO_{2peak}]) ranges from 26% to 87% of normal values (Smith et al., 2012). Given that VO_{2peak} is associated with the ability to independently perform ADLs (Cress & Meyer, 2003), integrating aerobic activity during therapy may enhance recovery.

Engaging in aerobic exercise poststroke can improve cardiovascular function, depressive symptoms, cognition and memory, health-related quality of life, and fatigue (Billinger et al., 2014). Additionally, when coupled with medication (e.g., antihypertensives), aerobic exercise reduces risk of recurrent stroke by 80% (Billinger et al., 2014). Given its potential to facilitate recovery and protect against further cardiovascular complications, aerobic exercise may be a valuable intervention for survivors of stroke.

Sedentary behavior is common during acute stroke management, in which survivors are sedentary approximately 87% of a typical day (Barrett et al., 2018). Given that physical and occupational therapy are foundational in stroke rehabilitation, an opportunity exists for these professions to encourage safe and appropriate levels of physical activity in all phases of recovery. Traditional stroke rehabilitation interventions generally are low intensity with only a few minutes spent within in an aerobic zone in typical inpatient and outpatient sessions (Barrett et al., 2018; Kuys et al., 2006; MacKay-Lyons & Makrides, 2002a; Polese et al., 2014). However, researchers from these studies estimated aerobic intensity using age-predicted maximum heart rate. Survivors of stroke attain on average 77% to 85% of the age-predicted maximum heart rate during cardiopulmonary stress tests (Dobrovolny et al., 2003; MacKay-Lyons & Makrides, 2002b; Yates et al., 2004); thus, it is possible that researchers estimating poststroke aerobic intensity using age-predicted calculations are underestimating aerobic intensity.

It is also possible that even with accurate estimates of aerobic intensity, poststroke rehabilitation still is not eliciting a robust cardiovascular response. Several studies have shown that rehabilitation professionals typically do not monitor heart rate during poststroke rehabilitation (Doyle & MacKay-Lyons, 2013; MacKay-Lyons & Makrides, 2002a; Nathoo et al., 2018), which in part may be because they are prioritizing other aspects of recovery such as quality of movement and ADL independence (Connell et al., 2018; Latham et al., 2006; MacKay-Lyons & Makrides, 2002a). It may be feasible to address these deficits while eliciting an aerobic response. This method would allow clinicians to “kill two birds with one stone,” maximizing the benefits of poststroke rehabilitation.

No study to date has examined the aerobic response with repetitive task practice (RTP), which uses goal-oriented functional movements and emphasizes achieving a high volume of repetitions while still providing appropriate motor challenges (Lang & Birkenmeier, 2013). The primary aim of this analysis was to characterize heart rate response during upper extremity (UE) RTP administered to improve motor function. The secondary aim was to determine factors that predict a higher heart rate reserve (HRR) during UE RTP.

Method

A randomized clinical trial was conducted investigating the effects of aerobic exercise combined with UE RTP (Grant K01HD092556; ClinicalTrials.gov registration number NCT03819764). Data for this analysis were from a subset of participants randomized to the control group (UE RTP only). The study was approved by the Cleveland Clinic institutional review board, and participants completed the informed consent process in accordance with the Declaration of Helsinki.

Participants

A total of 19 participants with chronic stroke were included in the analysis. These participants were assessed at baseline for UE impairment with the Fugl-Meyer Assessment (UE–FMA; Singer & Garcia-Vega, 2017), and their scores ranged from 19 to 55. Our pilot studies have shown that people presenting within this range on the UE–FMA have sufficient volitional movement to participant in and make meaningful gains from RTP interventions. Additional inclusion criteria were (1) ≥6 mo since a single ischemic or hemorrhagic stroke confirmed by neuroimaging, (2) ambulatory ≥20 m with no more than contact guard assistance, and (3) ages 18 to 85 yr. Exclusion criteria were (1) hospitalization for myocardial infarction, heart failure, or heart surgery within 3 mo; (2) cardiac arrhythmia; (3) hypertrophic cardiomyopathy; (4) severe aortic stenosis; (5) pulmonary embolus; (6) significant contractures; (7) antispasticity injection to paretic UE within 3 mo of enrollment; and (8) other contraindications to exercise (Linder et al., 2023).

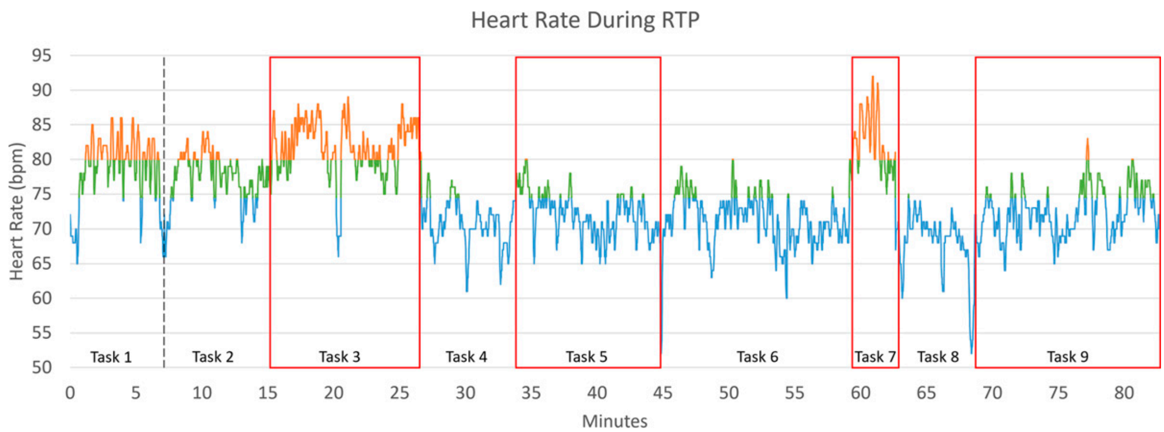
Intervention and Outcomes

After completion of a baseline cardiopulmonary exercise test and assessment of baseline UE–FMA, participants attended 24 therapy sessions over 8 wk, completing 90 min of UE RTP per session. Each session aimed for 450 repetitions. Heart rate was continuously monitored (Figure 1) with a Wahoo chest strap (Wahoo Fitness, Atlanta, GA). Each task was annotated within the Wahoo app. Mean HRR for each task was calculated with the Karvonen formula (American College of Sports Medicine, 2021). Outcomes obtained included time spent completing RTP (minutes), repetitions completed, mean HRR during each task (%), and the following task descriptors: (1) task position (standing or sitting), (2) target height (below shoulder height or at or above shoulder height), and (3) task type (gross, fine motor, or a combination of gross and fine motor). After completing the intervention, participants completed another cardiopulmonary exercise test and UE–FMA to quantify change in aerobic capacity and UE impairment.

Statistical Analysis

Summary statistics were calculated for demographic characteristics and RTP outcomes. A linear mixed effects model was conducted with HRR as the dependent variable and the following independent variables as fixed effects: task position (standing or sitting), baseline UE–FMA, target height (below shoulder height or at or above shoulder height), percentage of age-predicted VO_{2peak} achieved at the baseline stress test, and task type

Figure 1. Representative heart rate data from a repetitive task practice (RTP) session.



Note. Heart rate data are from a 69-yr-old man who had experienced a subarachnoid hemorrhage affecting his dominant side 10 mo before study enrollment. The color of the line indicates aerobic intensity (blue = very light intensity, <30% heart rate reserve [HRR]; green = light intensity, 30%–39% HRR; orange = moderate to vigorous intensity, ≥40% HRR; American College of Sports Medicine, 2021). Red boxes indicate tasks in which the participant was standing. The vertical dashed line separates two consecutive seated tasks. Although all sessions were 90 min in length, collection of heart rate data was paused while the participant was resting or instructions were being given. bpm = beats per minute.

(fine motor, gross motor, or a combination). Random intercepts per subject were included in the model. Tests of significance were conducted with the Kenward–Roger approximation on the results of the linear mixed effects model. Relationships between time spent in a moderate or vigorous intensity aerobic zone, change from baseline to end of treatment UE–FMA, and change from baseline to end of treatment percentage of age-predicted VO_{2peak} were assessed visually with scatterplots.

Results

Demographic, session, and task characteristics are shown in Table 1.

Position, $F(1, 2947) = 270.03$, $p < .0001$; target height, $F(1, 2946) = 13.80$, $p < .001$; and task type, $F(2, 2947) = 8.66$, $p < .001$, were significant predictors of aerobic response. On the basis of coefficients from the model (Table 2), targets at or above shoulder height, standing position, and gross motor tasks were associated with a higher HRR, with a standing position being the strongest predictor of higher HRR. Baseline UE–FMA, $F(1, 16) = 0.31$, $p = .584$, and percentage of predicted VO_{2peak}, $F(1, 16) = 1.45$, $p = .246$, were not significant predictors.

Of tasks that were moderate to vigorous intensity, 54.1% were performed in standing, 79.7% were gross motor, and 27.9% had targets at or above shoulder height. Among sessions that elicited an aerobic response, a median of 15.2 (Quartile 1 = 8.7, Quartile 3 = 43.5) total minutes were spent in moderate to vigorous intensities. Visual assessment of scatterplots revealed no relationship between time spent in an aerobic zone and change in aerobic capacity or UE–FMA.

Discussion

Most RTP in this study was performed at <40% HRR, which is in alignment with previous studies reporting low aerobic response during physical or occupational therapy (Barrett et al., 2018; MacKay-Lyons & Makrides, 2002a; Polese et al., 2014). Although time spent in an aerobic zone was not associated with improvement in UE impairment or aerobic capacity, in this observational study, the goal of RTP was to provide appropriate motor challenge for functional recovery. The administration of RTP was not manipulated to elicit a cardiovascular response. In traditional physical or occupational therapy, therapists similarly prioritize skills such as movement quality and ADL independence over aerobic training (Connell et al., 2018; Latham et al., 2006); additionally, aerobic exercise itself is not reimbursable as skilled therapy. Given that aerobic exercise is beneficial for poststroke recovery, it is important to consider methods that can combine aerobic training with traditional goals for stroke rehabilitation.

Our results suggest that although it is possible to administer UE rehabilitation in a manner that simultaneously taxes the cardiovascular system, therapists must be intentional about the mode of training. In our study, higher aerobic response was elicited by tasks performed in standing, where the target was at or above shoulder height, and with gross motor movements, regardless of the participant's UE impairment or aerobic capacity. A standing position was the strongest predictor of higher HRR. Standing increases postural demands and utilization of large bilateral muscle groups, contributing to an increased aerobic response. The effects of using large UE muscle groups for gross motor RTP tasks and the added balance challenge of reaching overhead complement the beneficial effects of standing.

These findings can be translated to clinical practice, allowing therapists to intentionally design sessions that elicit higher aerobic response by incorporating standing and gross motor tasks with targets at or above shoulder height. Modifying RTP activities with these

Table 1. Participant Demographic Characteristics of RTP Sessions and Tasks

Variable	Outcome
Demographic Characteristics (*N* = 19 Participants)	
Age, *M* (*SD*)	59.3 (9.0)
Male sex (vs. female), *n* (%)	10 (53)
Race, *n* (%)	
White	15 (79)
African American	3 (16)
Asian	1 (5)
Hispanic	0 (0)
% of age-predicted VO_{2peak}, *M* (*SD*)	76.3 (23.2)
Months since stroke, *Mdn* [Quartile 1, Quartile 3]	32.0 [13.0, 64.0]
Right side affected, *n* (%)	11 (58)
Dominant side affected, *n* (%)	9 (47)
Ischemic etiology, *n* (%)	13 (68)
Baseline UE Fugl-Meyer score (of 66), *M* (*SD*)	35.7 (12.2)
RTP Session Characteristics (*N* = 405 Sessions)	
Average repetitions per session, *M* (*SD*)	427 (38)
Average tasks per session, *M* (*SD*)	8 (1)
Average minutes spent actively performing RTP per session, *M* (*SD*)	75 (4)
RTP Task Characteristics (*N* = 2,968 Tasks)	
Average aerobic intensity of tasks, %	
Very light (<30% HRR)	79.5
Light (30%–39% HRR)	10.2
Moderate to vigorous (≥40% HRR)	10.3
Task position, %	
Sitting	69.2
Standing	30.8
Target height, %	
Below shoulder	78.0
At or above shoulder	22.0
Task type, %	
Gross motor	61.8
Fine motor	11.8
Combination of gross and fine motor	26.4

Note. Summary statistics are presented as *M* (*SD*) for normally distributed data, *Mdn* [Quartile 1, Quartile 3] for skew data, or *n* (%) for categorical data. Heart rate reserve (HRR) ranges are based on American College of Sports Medicine (2021) guidelines. RTP = repetitive task practice; UE = upper extremity; VO_{2peak} = peak volume of oxygen consumption.

characteristics will facilitate efficient poststroke rehabilitation that simultaneously targets improved motor function and elicits a robust cardiopulmonary response.

Limitations

This study was a secondary analysis of a larger randomized clinical trial that used a subset of the participants. The primary aim of this study was not to elicit an aerobic response during RTP. In future studies, researchers should examine the effects of fusing aerobic activity with traditional therapy on stroke outcomes using a larger sample size.

Implication for Occupational Therapy Practice

The results of this study have the following implication for occupational therapy practice:

- Training in standing, with targets at or above shoulder height and with an emphasis on

Table 2. Effect of Variable on HRR in Linear Mixed Effects Model

Variable	Effect on HRR[a]	*p*
% of age-predicted VO_{2peak}	−0.2	.25
Baseline UE Fugl-Meyer score	−0.2	.58
Sitting (compared with standing)	−8.9	<.0001
Target at or above shoulder (compared with below shoulder)	2.2	<.001
Gross motor task (compared with fine motor task)	2.2	<.001
Combination of gross and fine motor (compared with fine motor)	0.1	<.001

Note. HRR = heart rate reserve; UE = upper extremity; VO_{2peak} = peak volume of oxygen consumption.
[a]The model prediction of average point change in HRR based on the given variable. For categorical variables, this value is in reference to a comparison category. For example, the model predicts that repetitive task practice performed in standing results in an HRR 8.9 points higher than the same activity performed in sitting.

incorporating gross motor tasks, will maximize aerobic response to poststroke upper extremity repetitive task practice.

Conclusion

Monitoring heart rate response during stroke rehabilitation may increase awareness of training elements that provoke a higher aerobic response. To elicit a cardiovascular response during UE RTP, therapists should consider training in standing, with targets at or above shoulder height, and with an emphasis on incorporating gross motor tasks into UE functional rehabilitation.

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