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Perceptually regulated training does not influence the differentiated RPE response following 16-weeks of aerobic exercise in adults with spinal cord injury

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Title: Perceptually regulated training does not influence the differentiated RPE response following 16-weeks of aerobic exercise in adults with spinal cord injury.

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Abstract

This study investigated the effect of prolonged familiarisation with ratings of perceived exertion (RPE) on the peripheral (RPE_P) and central (RPE_C) RPE responses to moderate-vigorous exercise in adults with spinal cord injury (SCI). RPE_P and RPE_C characterize the exertion of the working musculature and cardiorespiratory systems, respectively. Nineteen participants (41.4±11.4 years; 19.2±7.2 ml·kg⁻¹·min⁻¹) with chronic SCI were randomly assigned to RPE-guided (n = 11; EXP) or active control (n = 8; CON) groups. EXP performed 16-weeks of RPE-guided, supervised aerobic training for 20 mins, twice weekly, at RPE 3-6 (Category-Ratio 10 scale). CON had access to the same exercise equipment but received no specific advice on their exercise-training regime. Participants completed a graded exercise test, using an arm crank ergometer, pre- and post-training to determine peak oxygen uptake ($\dot{V}O_{2peak}$), with RPE_P and RPE_C recorded every minute throughout tests. Sixteen weeks training did not improve $\dot{V}O_{2peak}$. RPE decreased post-training at 50% ($p = 0.02$) and 70% $\dot{V}O_{2peak}$ ($p = 0.03$), though there was no effect of group at either intensity ($p = 0.54, 0.42$ respectively). At 70% $\dot{V}O_{2peak}$ RPE_P was greater than RPE_C (4.2±1.7 vs 3.4±1.8, $p < 0.005$). Training with RPE-guidance for 16-weeks had no additional effect on the differentiated RPE responses to moderate-vigorous exercise in adults with SCI.

Novelty:

- In adults with SCI, differentiated RPE responses were not different between those who did, and did not, perform 16-weeks RPE-guided training.
- This challenges whether familiarisation with RPE is necessary to be an effective regulator of exercise intensity in this population.

Key words: perceived exertion; familiarisation; differentiated; peripheral; central; paraplegia; tetraplegia.

Introduction

For adults with spinal cord injury (SCI), the use of ratings of perceived exertion (RPE) offers a feasible and cost-effective tool for monitoring exercise intensity prescription and training progression. Across a range of upper body exercise modes in persons with SCI, RPE has been used to control the exercise intensity during both exercise testing (Muller et al. 2004, Al-Rahamneh and Eston 2011) and exercise prescription (Goosey-Tolfrey et al. 2010, Paulson et al. 2013). However, there is currently very low confidence in the evidence regarding the reliability and validity of using RPE with community-dwelling adults with SCI during a training intervention (van der Scheer et al. 2018), and as such this is an area that warrants investigation.

Previous research has identified a requirement to implement the RPE scale appropriately (readers are directed to the review by Pageaux (2016)). Briefly, effective use of RPE centres on cues that participants are instructed to focus on when rating their exertion. One definition of RPE asks participants to consider the effort, strain and discomfort experienced during the exercise (Noble and Robertson 1996). This definition, however, includes sensations within the construct of RPE that are, in fact, independent of RPE. For example, it has been shown that “discomfort” (Christian et al. 2014), and “pain” (Gros Lambert et al. 2006, Astokorki and Mauger 2017) can be dissociated from RPE. Therefore, when asking participants to rate their RPE, it is recommended to instruct them to focus simply on how hard, heavy or strenuous the physical task is (Marcora 2010). In order to successfully dissociate the sensation of exertion from those of pain and discomfort, a familiarisation or learning trial is recommended prior to either rating, or prescribing, exercise intensity with RPE (Eston et al. 2015, Pageaux 2016). It has been shown that a learning trial, prior to prescribing a training programme using RPE, improves its validity in able-bodied individuals (Wegner et al. 2007, Soriano-Maldonado et al. 2014). Furthermore, a recent meta-analysis in able-bodied persons reported that a second trial

improved the validity of using an RPE-guided exercise test to predict peak oxygen uptake ($\dot{V}O_{2peak}$; Coquart et al. 2016). The need to distinguish the perception of exertion from alternate sensations when using RPE is of particular importance for adults with SCI who are reliant on upper body exercise, and who experience a high prevalence of neuropathic (Siddall et al. 2003, Finnerup et al. 2014), and musculoskeletal shoulder pain (Bossuyt et al. 2018, Kentar et al. 2018). Therefore, given the practical role that RPE could have for prescribing the intensity in an exercise programme for people with SCI, more needs to be known regarding how familiarisation with RPE may improve its validity in this population. This could then inform subsequent community-based exercise interventions in participants with SCI.

In addition to the potential importance of RPE familiarisation, it is unclear whether using differentiated RPE may be more appropriate in comparison to overall RPE (RPE_O ; van der Scheer et al. 2018). The RPE_O encompasses a summation of exertional cues from the exercising muscles and cardiovascular and respiratory systems (Borg 1998), while differentiated RPE requires reporting both a peripheral (RPE_P) and central (RPE_C) RPE, focusing on the degree of heaviness of physical work in the working musculature, and cardiorespiratory systems, respectively. An acceleration of RPE_P compared to RPE_C has recently been shown during ramp-incremented exercise in community-based adults with tetraplegia (Au et al. 2017).

Consequently, the aim of the present study was to investigate a period of prolonged familiarisation with RPE on the differentiated RPE responses at moderate (50% $\dot{V}O_{2peak}$) to vigorous (70% $\dot{V}O_{2peak}$) exercise intensities in adults with SCI. Based on previous research, it was hypothesised that individuals provided with a period of familiarisation with RPE would exhibit an altered relationship between RPE and exercise intensity, compared to those who received no familiarisation.

Materials and methods

Participants

Data were obtained as part of a previously published randomised controlled trial (Pelletier et al. 2015, Totosy de Zepetnek et al. 2015). Consequently, the exercise intervention, potential participant pool, and exercise characteristics are identical to those studies. The Hamilton Health Sciences Research Ethics Board approved the study, and informed, written consent was obtained from each participant before any testing began. We certify that all applicable institutional regulations concerning the ethical use of human volunteers were followed during the course of this research. Participants were originally recruited if they complied with the following inclusion criteria: chronic SCI (> 1-year post-injury), 18-65 years old, and relied on a manual wheelchair for mobility. An additional inclusion criterion for this specific study was having complete RPE records during exercise testing sessions. Exclusion criteria were the progressive loss of neurological function within the six months prior to recruitment. Of the original participant pool (n = 23), nineteen participants (age: 41.4 ± 11.4 years, body mass: 84.4 ± 17.8 kg, $\dot{V}O_{2\text{peak}}$: 1.6 ± 0.5 L.min⁻¹; 19.2 ± 7.2 ml⁻¹.kg⁻¹.min⁻¹) who were untrained in using RPE during exercise met the present study requirements. Participants performed an exercise testing session pre and post a 16-week exercise intervention period. Following the pre-intervention test the participants were randomly allocated into an RPE-based exercise (EXP) or active control (CON) group (Table 1). Levels of leisure time physical activity were assessed at commencement of the study using the Physical Activity Recall Assessment for People with Spinal Cord Injury (Table 1; Ginis et al. 2005).

Peak aerobic capacity

Participants completed a maximal, graded exercise test (GXT) using an arm crank ergometer (Angio, Lode B. V., Groningen, Netherlands) pre- and post-training intervention. Prior to the test participants completed a 5 min warm-up at 0 W. The GXT began at 0-15 W

and was increased by 5-10 W·min⁻¹ until participants reached volitional exhaustion or could not maintain a cadence of 40 rpm. Starting power output (PO) and PO increments were modified to ensure tests lasted 8-12 min. Breath-by-breath gas exchange and ventilatory variables (Moxus Metabolic System, AEI Technologies, Pittsburgh, PA, USA), along with heart rate (HR; Polar Electro, Lachine, QC, Canada), were collected throughout the test. In the final 10 s of each one minute stage, RPE_P and RPE_C were recorded using Borg's Category-Ratio 10 (CR-10) scale (Borg 1998). To rate their RPE, participants were asked to focus on how hard, heavy or strenuous the physical task was and to ignore sensations of pain and discomfort (Marcora 2010), with a specific focus on the exercising musculature for RPE_P, and the cardiorespiratory system for RPE_C (Borg 1998).

Exercise training intervention

All participants underwent a 16-week exercise training intervention. Participants in the EXP group completed a supervised, progressive exercise programme that consisted of 20 min of RPE-guided aerobic exercise, twice weekly, at 3-6 on the CR-10 (Borg 1998). Aerobic exercise training sessions were performed using an arm ergometer (Monark Rehab Trainer 881E, Patterson Medical Supply), hybrid recumbent stepper with combined upper body exercise (T5XR Recumbent Cross Trainer, NuStep Inc., Ann Arbor, MI, USA), or VitaGlide (Miami, FL, USA). Prior to each training session participants were instructed to focus on how hard, heavy or strenuous the physical task was (Marcora 2010), and to adjust the workload accordingly in order to maintain the required RPE. In addition to the aerobic exercise, the EXP participants completed resistance exercise (three sets of 10 repetitions at 50-70% 1 repetition maximum) of each major upper body muscle group. The CON group had access to the same exercise equipment as the EXP group, but received no guidance on the type, amount or intensity of exercise training to perform.

Data collection and processing

For determination of peak data, $\dot{V}O_2$, respiratory exchange ratio (RER) and minute ventilation ($\dot{V}E$) were computed as rolling 15-breath averages throughout the tests with the greatest single value taken as the peak response (Robergs et al. 2010). For each participant the reported RPE_P and RPE_C were independently fit against $\% \dot{V}O_{2peak}$ using a quadratic function (Au et al. 2017). The RPE_P and RPE_C corresponding to 50 and 70% $\dot{V}O_{2peak}$ were then calculated. Furthermore, for EXP, the $\% \dot{V}O_{2peak}$ equating to RPE_P and RPE_C of 3 and 6 were also calculated.

Statistical analyses

Mean and standard deviation (SD) were computed for all variables, and normality was checked with the Shapiro Wilk test. Differences in peak exercise responses between groups were assessed using two-way analysis of variance (ANOVA) with between-measures factor of group (EXP vs CON) and within-measures factor of time (pre vs post-training). To compare the differentiated RPE responses at 50 and 70% $\dot{V}O_{2peak}$, three-way mixed measures ANOVA were used. The between-measures factor was group (EXP vs CON), whilst the within-measures factors were type of RPE (RPE_P vs RPE_C) and time (pre- vs post-training). Effect sizes (ES) were calculated to determine the magnitude of differences, and were classified as trivial (≤ 0.19), small (0.20-0.49), medium (0.50-0.79) and large (≥ 0.80 ; Cohen 1992). Statistical analyses were performed using SPSS 23.0 statistical package (SPSS Inc., Chicago IL, USA), with a level of significance of $p < 0.05$.

Results

The original investigation (Pelletier et al. 2015) reported EXP ($n = 12$) and CON ($n = 11$); the current study differed due to the exclusion of four participants (1 EXP and 3 CON) as they did not have complete differentiated RPE records during exercise testing. Nevertheless, group demographics and characteristics remain similar (Table 1 and 2).

Peak exercise responses

The pre- and post-training peak physiological responses for EXP and CON are displayed in Table 2. Following the exercise training intervention there was no difference, for either EXP or CON, in any measured variable. There was no main effect of group for the peak RPE_P and RPE_C responses ($F_{(1,00)} = 0.01, p = 0.93$). However, there was a main effect of type of RPE, with peak RPE_P significantly greater than peak RPE_C ($F_{(1,00)} = 23.97, p < 0.005$).

Post-training differentiated RPE at moderate and vigorous exercise intensities

The differentiated RPE responses for moderate (50% $\dot{V}O_{2peak}$) and vigorous (70% $\dot{V}O_{2peak}$) exercise intensities are shown in Figure 1a and 1b, respectively. At 50% $\dot{V}O_{2peak}$ there was no main effect of group (EXP: 1.7 ± 1.0 vs CON: 2.1 ± 2.1 ; $p = 0.54$; ES = 0.25) or type of RPE (RPE_P: 2.0 ± 1.6 vs RPE_C: 1.7 ± 1.6 ; $p = 0.11$; ES = 0.16). Though there was a main effect of time with medium ES (Pre: 2.4 ± 2.0 vs Post: 1.3 ± 0.8 ; $p = 0.02$; ES = 0.59), there was no group by time interaction ($p = 0.17$). At 70% $\dot{V}O_{2peak}$ there was a main effect of type of RPE (RPE_P: 4.2 ± 1.7 vs RPE_C: 3.4 ± 1.8 ; $p < 0.005$; ES = 0.49) and of time (Pre: 4.3 ± 2.0 vs Post: 3.4 ± 1.3 ; $p = 0.03$; ES = 0.47), both with a small ES. There was, however, no main effect of group (EXP: 3.6 ± 1.5 vs CON: 4.1 ± 2.1 ; $p = 0.42$; ES = 0.27), or group by time interaction ($p = 0.14$). In the EXP group, it was found that during post-training GXT, a RPE of 3 equated to $64 \pm 8\%$ and $70 \pm 13\%$ $\dot{V}O_{2peak}$ and RPE of 6 to $83 \pm 7\%$ and $90 \pm 15\%$ $\dot{V}O_{2peak}$ for RPE_P and RPE_C, respectively.

Discussion

The principle finding of this study was that 16-weeks of familiarisation with RPE did not alter RPE_P and RPE_C responses to moderate-vigorous exercise in adults with SCI compared to those who received no familiarisation. This finding challenges the assertion that familiarisation with the RPE scale is needed prior to using RPE for exercise testing or

prescription in community-dwelling individuals with SCI. However, further studies are required in order to corroborate the present finding and strengthen this conclusion. Previous studies have used one (Wegner et al. 2007), and three (Soriano-Maldonado et al. 2014) learning trials to familiarise able-bodied participants with RPE, whilst the current study provided 32 sessions of RPE-guided training over 16-weeks ($98 \pm 3\%$ adherence). The rationale behind familiarisation with RPE is to avoid under- or over-estimation of RPE by ensuring participants can dissociate perceived exertion from other sensations, such as pain and discomfort (Pageaux 2016). Given the length of the present intervention it would therefore be expected that those individuals in the EXP would be more familiar with exercise-related exertional cues, would provide more valid ratings of RPE, and would have reduced variation in their RPE compared to CON. However, there were no differences in RPE_P and RPE_C at moderate ($50\% \dot{V}O_{2peak}$) or vigorous ($70\% \dot{V}O_{2peak}$) intensities between groups.

The present observations lead to an interesting question of why familiarisation in adults with SCI did not lead to a difference in RPE responses compared to those who were not familiarised? One potential explanation comes from considering that RPE principally reflects the central motor command emanating from pre-motor areas of the brain that is copied to sensory areas (Marcora 2009). This is based on the postulation that RPE is independent of afferent feedback from working muscles and cardiorespiratory systems and that a change in RPE is caused by altering the level of central motor command. That RPE reflects central motor command is supported by experimental evidence showing an increase in RPE when exercising a pre-fatigued muscle (de Morree et al. 2012), and a decrease in RPE with caffeine ingestion (de Morree et al. 2014). Given that familiarisation with RPE will not lead to an altering of central motor command, could explain the present finding of no change in differentiated RPE with prolonged familiarisation.

Another potential explanation could be the participant population that was studied. Pain, both neuropathic (Siddall et al. 2003, Finnerup et al. 2014) and musculoskeletal (Bossuyt et al. 2018, Kentar et al. 2018), is highly prevalent in persons with SCI. Although pain was not measured in the current study, it is likely that participants were familiar with the sensation of pain given the duration of their SCI (EXP vs CON: 15.7 ± 10.7 vs 7.8 ± 5.7 years). It is possible that familiarity with the sensation of pain would allow people with chronic SCI to successfully dissociate it from exertion, thus increasing the validity of their RPE. Lastly, it is possible that that incorporation of proper instructions for participants with SCI on how to use the RPE scale rendered a familiarisation period as unnecessary. Participants were instructed to focus on how hard, heavy or strenuous the task was (Marcora 2010), and to ignore sensations of discomfort and pain when rating RPE. This clear instruction may have allowed participants in CON to rate their RPE similarly to EXP and both groups to rate their RPE at pre-training similarly to post-training. This is a significant theoretical advancement from the present study and highlights the importance of providing adequate instruction on, rather than necessarily familiarisation with, the use of RPE. The practical application of this is that clinicians or researchers working with people with SCI can utilise RPE scales with their participants and be confident of the validity of the response, irrespective of the participant's previous experience with the scale. This can aid the subsequent implementation of RPE for exercise prescription purposes within a real-world, community-based exercise programme.

Of note in this study was that for the cohort included in the current analysis, 16-weeks of training with, or without, RPE-guidance did not result in improvements in cardiorespiratory fitness. This finding is different from the original study that reported increases in peak aerobic capacity in the EXP group, although this is likely due to different final participant sample sizes (Pelletier et al. 2015). The EXP group in the present study exercised at an RPE of 3-6 on the CR-10 scale. Based on RPE responses to the post-training GXT, this intensity should have

resulted in training being performed at 64-90% $\dot{V}O_{2peak}$. One would have expected this moderate to vigorous exercise intensity to be sufficient to induce changes in cardiorespiratory fitness with the exercise prescription used by this study. The lack of aerobic fitness improvement is surprising, given that the aerobic capacity of all participants was typical of an untrained cohort (Simmons et al. 2014), and the high volume of literature reported by van der Scheer et al. (2017) showing the beneficial effects of exercise programmes on fitness in adults with chronic SCI. For example, one previous exercise training study reported that when the intensity is anchored to an RPE of 4-7 using the same CR-10 scale, that handcycle and/or hybrid cycling showed improvements in aerobic capacity following a twice weekly 16-week training programme (Bakkum et al. 2015). That said, the present study was restricted to a duration of 20 mins twice a week, while the study by Bakkum et al. (2015) increased the exercise duration from 18 to 32 mins over the course of the 16-weeks. The fact that the EXP and CON groups showed no changes in fitness in the present study suggests that the volume (intensity x duration) of the exercise training did not provide a sufficient enough training stimulus to increase aerobic fitness.

The present study also has important implications for using RPE to guide the intensity of an exercise training intervention. Training was prescribed at an RPE of 3-6 on the CR-10, however given the variation in response at these RPE, a narrower target RPE could have resulted in a more homogenous training load across the EXP group. Furthermore, that RPE_P was significantly greater than RPE_C (Figure 1b) at 70%, but not 50% $\dot{V}O_{2peak}$ must be considered if indeed differentiated RPE are utilized to guide training at a specific intensity. Greater RPE_P at 70% $\dot{V}O_{2peak}$ corroborates previous research in recreationally-active participants with tetraplegia (Au et al. 2017), but contrasts findings regarding peak differentiated RPE in those with paraplegia (Al-Rahamneh and Eston 2011) and tetraplegia (Paulson et al. 2013). This conflicting evidence has led to very low confidence in the use of

differentiated RPE for measuring exercise intensity in participants with SCI (van der Scheer et al. 2018). Though the present study does not resolve the disparate findings regarding differentiated RPE, it does suggest that, if used for exercise prescription in participants with SCI, the same value for RPE_P and RPE_C could be used for moderate intensities, but that a greater RPE_P would be required at vigorous intensities.

A limitation of the current study is that some training was performed using a different exercise mode (hybrid recumbent stepper with combined upper body exercise) in comparison to the peak exercise testing exercise mode (arm crank). It has been found that persons with SCI performing hybrid exercise incorporating lower limb functional electrical stimulation-induced cycling combined with handcycling report lower RPE_P, RPE_C and RPE_O during 30 mins of moderate exercise at 60% $\dot{V}O_{2peak}$ when compared to handcycling alone (Paulson et al. 2014). Specificity of RPE to the exercise modality (e.g., differences in the size of active muscle mass being employed), and associated $\dot{V}O_2$, is a factor to consider for future studies, particularly as the choice and availability of exercise modalities is increasing within community and rehabilitation settings.

It could be suggested that the inclusion of people with paraplegia and tetraplegia, as well as complete and incomplete lesions in the same groups also serves as a limitation. Previously a dominance of RPE_P over RPE_C has been found in people with tetraplegia, but not paraplegia (Au et al. 2017). However, the present findings show a significantly greater RPE_P compared to RPE_C at a vigorous intensity (70% $\dot{V}O_{2peak}$), even with the inclusion of a mixed group with both paraplegia and tetraplegia. Furthermore, although no research has compared RPE between people with complete and incomplete lesions, again as significant findings were found, the mixed groups used do not seem to have been a limitation. That said, an interesting avenue for future research could be to investigate the impact of injury completeness on differentiated RPE responses.

291 In conclusion, training with RPE-guidance for 16-weeks had no effect on the
292 differentiated RPE responses to moderate-vigorous exercise in adults with SCI compared to
293 those who did not train based on RPE. These data challenge whether familiarisation with RPE
294 is necessary for effective use of differentiated RPE for regulating exercise intensity in the SCI
295 population. However, given the difference between RPE_P and RPE_C at vigorous, but not
296 moderate, intensities, attention must be paid to how use of differentiated RPE is implemented
297 as a tool for regulating exercise intensity in adults with SCI.

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303

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406

407 **Table 1.** Participant characteristics as measured pre-intervention.

Parameter	ALL (n = 19)	EXP (n = 11)	CON (n = 8)	<i>p</i>
Body mass (kg)	84.4±17.8	88.3±18.9	79.1±15.8	0.28
Age (years)	41.4±11.4	40.9±10.7	42.1±12.9	0.83
Neurological level of injury	C3-T11	C3 – T10/11	C4 – T11	--
ASIA classification	A = 5, B = 2, C = 11, D = 1	A = 2, B = 1, C = 7, D = 1	A = 3, B = 1, C = 4	--
Time since injury (years)	12.4±9.6	15.7±10.7	7.8±5.7	0.08
Total LTPA (min·day ⁻¹)	39±45	27±34	53±54	0.23

408 Data are presented as mean±SD. ASIA, American Spinal Injury Association; LTPA, leisure
409 time physical activity.

410 **Table 2.** Pre and post-exercise training peak physiological responses to arm crank ergometry.

Parameter	EXP (n=11)		CON (n=8)	
	Pre	Post	Pre	Post
$\dot{V}O_{2peak}$ (L·min ⁻¹)	1.6±0.4	1.7±0.4	1.4±0.4	1.4±0.5
$\dot{V}O_{2peak}$ (mL·kg ⁻¹ ·min ⁻¹)	18.6±6.2	19.8±7.3	18.7±6.0	18.3±7.3
Peak RER	1.06±0.09	1.13±0.10	1.14±0.11	1.15±0.13
Peak $\dot{V}E$ (L·min ⁻¹)	67.7±20.0	69.3±15.3	65.9±31.7	60.3±22.6
Peak HR (beats·min ⁻¹)	135±33	137±27	152±21	142±24
Peak PO (W)	72±24	78±29	70±34	70±35
Peak RPE _P *	9±1	9±1	9±1	9±2
Peak RPE _C	7±2	7±2	7±2	7±2

411 Data are presented as mean±SD. HR, heart rate; PO, power output; RER, respiratory
 412 exchange ratio; RPE_C, central rating of perceived exertion; RPE_P, peripheral rating of
 413 perceived exertion; $\dot{V}O_{2peak}$, peak oxygen uptake. *, RPE_P significantly greater than RPE_C, p
 414 < 0.005.

415 **Figure legends**

416 **Figure 1.** RPE_P and RPE_C responses at a) 50% and b) 70% $\dot{V}O_{2peak}$ during incremental arm
417 crank ergometry, pre and post 16-weeks training for RPE-guided (EXP) and control (CON)
418 training groups. *, main effect of time as RPE greater pre- compared to post-training; †, main
419 effect of type of RPE as RPE_P greater than RPE_C at 70% $\dot{V}O_{2peak}$, $p < 0.05$.

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