Motor cortex tDCS does not modulate perceived exertion within multiple-sets of resistance exercises

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Title: MOTOR CORTEX tDCS DOES NOT MODULATE PERCEIVED EXERTION WITHIN MULTIPLE-SETS OF RESISTANCE EXERCISES

Running head: Strength Exercise RPE and tDCS

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Abstract

BACKGROUND: Recent evidences have shown that the motor cortex (MC) may influence the rating of perceived exertion (RPE). Given the potential role of transcranial direct current stimulation (tDCS) in modulate cortical areas related to exercise performance, it is possible that tDCS applied on motor cortex (MC) could also influence the RPE during resistance exercises.

OBJECTIVE: This study analyzed the effects of transcranial direct current stimulation on the rating of perceived exertion during multiple sets of resistance exercises.

METHODS: Thirteen strength-trained men performed a resistance exercise session after either anodal tDCS or sham stimulation applied over the primary motor cortex. Resistance exercise sessions included 3 sets of 10 repetitions of 6 exercises performed with load equal to ~ 85% of 8-12 RM. The RPE was obtained using OMNI-Resistance exercise scale.

RESULTS: The RPE assessed at the end of the sessions was similar in tDCS vs. sham condition (6.78 ± 1.48 vs. 6.87 ± 1.49, respectively; $p = 0.56$). The RPE for each exercise was similar across conditions, except for the second set of bench press ($p = 0.04$) and first set of seated-row ($p = 0.03$).

CONCLUSION: In conclusion, the RPE during multiple sets of submaximal exercises was not modulated by tDCS applied upon MC.

Key words: *tDCS; Motor Cortex; Exercise; Perceived Exertion; Strength*

Introduction

It has been shown that the motor cortex (MC) may influence the rating of perceived exertion (RPE) via efferent motor command [1-4]. Morree et al. [5], using electroencephalography, showed a significant correlation (r = -0.64) between RPE and movement-related cortical potential. Thus, it is possible that motor areas modulate the activity of primary somatosensory cortex (corollary discharge theory) by copying the efferent command, thereby defining perceived exertion [6]. Probably, subcortical areas may also be involved in RPE formation due to the complexity of integration between the neuronal paths related to this system [7, 8]. In brief, interventions that modulate motor cortex can potentially affect RPE.

Transcranial direct current stimulation (tDCS), which involves application of an electrical current to the scalp, has been used safely and effectively [9, 10] to modulate brain activity of several areas [11] in patients with health adverse conditions, such as depression [12, 13], chronic pain [14], deficit of motor task [15, 16] and Parkinson's disease [13]. tDCS has also been proved to modulate cortical areas related to exercise performance, such as the prefrontal and motor cortex [17-19]. Cogiamanian et al. [20] observed an increased muscle endurance and decreased muscle fatigue following anodal tDCS. The mechanisms proposed to underlie this response include reduced supraspinal fatigue, increased activation of primary premotor areas and, possibly, decreased feedback inhibitory systems, which limit motor cortical output to ‘protect’ the motor system from overload, thereby increasing voluntary muscle activation and intermuscular coordination [20]. Furthermore, anodal motor cortex tDCS seems to be capable to increase both perception and pain thresholds by stimulating the dorsolateral prefrontal cortex. These results suggest that both MC and dorsolateral prefrontal cortex may be a potential target of stimulation for lessening pain perception [21, 22].

Recent evidence suggests that fatigue would be purely sensory, although expressed physically by an alteration in physical performance [23]. Such perceptive mechanism would take place to ensure homeostasis during strenuous effort [24]. Since fatigue might be considered as a type of pain sensation, it might be modulated by tDCS [25, 26]. In this sense, a previous study demonstrated that the increase in the RPE during maximal incremental cycling exercise test was slowed following the application of anodal tDCS [23].

The RPE has been used to monitor the intensity of resistance exercises [27, 28], due to its relationship with physiological markers of exercise stress, such as lactate and muscle electrical activity [29-31]. Given the potential effects of cortical and subcortical areas upon the sensory nature of RPE and considering the available evidence of the role of tDCS upon perceived exertion within dynamic endurance exercise, it is possible that tDCS applied upon cortical areas like MC could also influence the RPE during resistance exercises. However, we could not find previous research addressing this issue, which has evident practical implications, particularly in the context of motor rehabilitation programs.

Thus, the purpose of the present study was to investigate the effects of anodal tDCS applied over MC on the RPE during a multiple-set session of resistance exercises. Since the anodal tDCS could increase the MC excitability [10, 32], it has been hypothesized that this non-invasive technique might be utilized for inducing a decrease in RPE during the resistance exercise session.

Methods

Subjects

Subjects were recruited from local community via advertisement. Before enrollment, all volunteers provided written consent and the experimental protocol was approved by institutional Ethics Committee. Subjects completed a detailed health history questionnaire and were included in the study if they had no signs or symptoms of disease, were not under medication or using ergogenic substances, had no orthopedic injuries. In addition, subjects were asked about their previous participation in resistance training by the following questions: "Have you ever practiced recreationally resistance training?", if the answer was "yes", they answered the following question "How long did you practice resistance training?". Subjects were included if they have been performing regular resistance exercise three times a week for at least 4 months in order to avoid problems in their strength assessment [33] and provide adequate perceived exertion during resistance exercise.

Procedures

Familiarization Sessions - All subjects underwent two familiarization sessions on different days, to standardize the positioning and technique of the resistance exercises. The sessions included three sets of 10 repetitions of six exercises performed with the minimum load allowed by each machine, in the following order: leg press 45°, bench press, unilateral knee extension, seated row, knee curl and frontal raise.

Anchoring Procedures - All subjects were provided with scaling instructions and anchoring procedures for the OMNI-Resistance exercise scale (OMNIRES) [34]. The scaling instructions define the perceived exertion as the subjective intensity of effort, strain, discomfort or fatigue experienced during the exercise in the active muscle. The instructions covered explanations of the use of the scale, how to differentiate ratings, and how to use the low and high numerical categories as scale anchor points. Memory anchoring was used during the experimental session. To assess RPE, subjects were required to answer the question "*How hard is the exercise?*" while looking at the RPE scale. The participants were invited to experience two opposite loads corresponding to the RPE number 1 (extremely light) and number 9 (extremely hard).

8-12 Repetitions Maximum (RM) Test - After 48 hours following the anchoring procedures, subjects performed 8-12 RM tests in order to determine the workload used in the experimental sessions [35]. After warming-up at a comfortable load subjects attempted each exercise once (leg press 45°, bench press, unilateral knee extension, seated row, knee curl, and frontal raise) with a workload estimated to elicit 8-12 RM. If the target load was not obtained in the first attempt (number of repetitions below or above 8-12 RM), the load was progressively readjusted and subjects were allowed to perform a second attempt after 10-min rest intervals, until the 8-12 RM could be determined. An interval of 5 min was respected between tests for each exercise. If the load was not obtained in the second attempt, another test session in another day was scheduled.

Experimental Sessions - In Figure 1 is shown a time-line with the procedures used in the two experimental sessions (anodal tDCS or sham condition). The whole experimental sessions lasted ~90 min. Before the experimental sessions, subjects were instructed to have a light meal, to avoid physical exercise in the prior 24 h and ingestion of alcohol or caffeine in the prior 12 h, and to maintain their routine of sleeping hours and daily activities. Before the exercise sessions, the participant remained at rest for instrumentation and then randomly received either anodal tDCS which is thought to facilitate neuronal membrane depolarization [10, 32] or sham condition on the left primary MC (M1).

The anodal tDCS followed the configuration proposed by Fregni et al. [36]. For the anodal tDCS, the anode was positioned over M1 and the cathode was positioned over the contralateral supraorbital area (Fp1), in accordance with the International Electroencephalography (EEG) 10-20 system [37]. A direct electrical current with 2 mA of intensity was applied for 20 min. With regard to the sham condition, the electrodes took place in the same positions used for the anodal tDCS. However, the electrical current was turned off after two min of stimulation; this time is considered to cause no prolonged changes in neuronal excitability [10]. Hence in the sham condition, subjects felt an initial itching sensation, but no electrical current was provided for the rest of the stimulation period. Direct current was transferred via a saline-soaked pair of surface sponge electrodes (35 cm^2) and was delivered using a battery-driven constant current stimulator developed for this study. The current delivered by the stimulator was confirmed using a digital multimeter (ICEL™, Manaus, AM, Brazil). The exercise sessions performed after both anodal tDCS and sham condition were identical. In both sessions, the subjects initiated with a warm-up set of 10 repetitions at 50% of 8-12 RM. Subsequently, three sets of 10 repetitions of each exercise with load corresponding to 85% of 8-12 RM were performed, with the same order described for the 8-12 RM testing. Resting intervals between sets and exercises were set at 2 min and 1 min, respectively. At the end of each set, the RPE was assessed using the OMNIRES. Both subjects and instructors that assessed the RPE and supervised the exercise sessions were blinded with regards to the tDCS condition previously applied (anodal tDCS or sham condition). A wash-out period of 48-72 h between experimental sessions was respect to avoid tDCS carryover effects.

*** Insert Figure 1 here ***

Statistical Analyses

The sample size was estimated considering previous study that analyzed RPE during submaximal exercise and identified an *Cohen's d* effect size of 1.02 between anodal tDCS and sham condition [23]. Considering a similar effect size with a power of 80% and α error of 5%, the sample size was estimated in 10 subjects. Normality of data was ratified by the Shapiro-Wilk test and the homogeneity of variances by the Levene test. Therefore, the RPE in anodal tDCS vs. sham condition was compared using a paired t-test. The significance level was set at $p \leq 0.05$ and all calculations were performed using the Statistica® software.

Results

In Table 1 summarizes participants' anthropometric characteristics and strength performance during the 8-12 RM tests. Thirteen subjects participated voluntarily of the present study. None of them reported any adverse events during tDCS procedures.

*** Insert Table 1 here ***

Figure 2 shows means ± standard deviation of the RPE chosen by participants during the resistance exercises after anodal tDCS and sham condition. There was no difference between the overall RPE assessed during the resistance exercises following anodal tDCS or sham condition (tDCS: 6.78 ± 1.48, Confidence interval 95% [CI 95%] 6.22-7.35; sham condition: 6.87 ± 1.49, CI 95% 6.36-7.38; $p = 0.56$).

*** Insert Figure 2 here ***

Figure 3 shows the RPE obtained in the last repetition of each set of the 6 resistance exercises, following anodal tDCS and sham condition. The RPE was similar across tDCS conditions for all exercises, except for the second set of the bench press (anodal tDCS: 7.54 ± 1.34, CI 95% 6.69-8.37; sham condition: 8.15 ± .77, CI 95% 7.67-8.63; $p = 0.04$) and the first set of the seated-row (anodal tDCS: 7.85 ± 1.10, CI 95% 7.15-8.53; sham condition: 8.46. ± 1.21, CI 95% 7.69-9.22; $p = 0.03$).

*** Insert Figure 3 here ***

Discussion

The main finding of the present study was that 20 min of anodal tDCS over primary motor cortex was not sufficient to modulate the RPE during multiple-sets of resistance exercises performed with submaximal workload, at least in subjects with previous experience in resistance training. There is evidence that anodal tDCS might induce an ergogenic effect, increasing the physical performance in healthy and motor impaired subjects [20, 23, 38]. Three mechanisms have been proposed to explain such acute effect: (i) Modulation of supraspinal fatigue or fatigue-related muscle pain [20]; (ii) Attenuation of perceived exertion at a given submaximal workload [23], (iii)

Augmentation of motor cortical excitability with concomitant increase in recruited motor units due to a greater descending drive to the spinal motor pool [39].

Based on these potential mechanisms, it has been hypothesized that anodal tDCS upon motor cortex could modulate the RPE during resistance exercises. However, the RPE was not affected by anodal tDCS during the presently applied submaximal resistance exercise protocol. A possible explanation to our findings is proposed by previous study appointing that the tDCS may be innocuous when the amount of volitional drive is sufficient to activate the spinal motor pool necessary for the task performance [39]. In brief, there would be a "ceiling effect" of tDCS upon the cortex excitability for the spinal pool and consequently to the muscle electrical activation, as well as the muscular torque and RPE modulation in neurologically non-affected subjects [40, 41]. A potential increase in cortical activity due to external electrical sources, would not reflect on fatigue or perceived exertion attenuation due to the presence of already neuronal hyper-excitability in the dominant MC [41, 42]. Previous studies have suggested an increase responsiveness of intracortical inhibitory interneurons during dynamic exercise performed under conditions of increased RPE [28, 43]. In addition, there is a close relationship between a submaximal exercise-induced high excitability of the intracortical inhibitory interneurons and the considerable increases in psychological stress [44, 45].

The training status of subjects enrolled in the study is another issue that may have affected the present findings. In fact, Shibuya and Kuboyama [43] demonstrated that the activation of MC is greater in non-athletes compared to athletes, suggesting that the activation of primary motor cortex during physical exercise is higher in non-trained individuals. Since our sample was composed by well trained participants with large previous resistance training experience, the effects of tDCS on RPE may have been soothed. Interestingly, a reduction in intracortical inhibition has been reported after either single session of anodal tDCS or 4-weeks of heavy load squat strength training [46, 47]. It suggests that anodal tDCS associated with strength training may have induced a cumulative effect increasing the “ceiling effect” contribution on spinal pool activation, thereby inducing no changes in RPE responses during the all sets of resistance exercises. Additional research is warranted to ratify the present findings and to verify these possibilities.

In order to identify whether tDCS occurred only at the onset of resistance exercise session, we analyzed the RPE at the end of each set. The results indicated that differences between conditions were observed during 2 out of 18 evaluated sets, and that these sets were spread during the middle of the resistance exercise protocol. Thus, it is feasible to believe that the duration of the exercise session did not affect the present findings, since no tDCS effect was observed from the first resistance exercise. Williams et al. [39] have shown that the performance and RPE during a sustained submaximal contraction until volitional fatigue could be improved by anodal tDCS. It is therefore possible that aiming to modulate the RPE during resistance training, the tDCS should be applied during and not immediately before the resistance exercise sessions. This possibility certainly warrants future research to be ratified and has evident practical implications.

Cortical areas, such as the insular cortex and the anterior cingulate cortex, have been associated with fatigue [48] and regulatory mechanisms involved in processing judgments and feelings [49]. Recently, studies using tDCS applied over the temporal cortex targeting the insular cortex demonstrated a decrease in RPE and an improved peak performance on an exhaustive cycle ergometer test suggesting that brain areas beyond the motor cortex may modulate fatigue and, consequently the RPE [23]. Since in the present study the anodal tDCS was applied upon MC and not on the temporal cortex, it is possible that the low spatial focality of tDCS may have interfered in the present obtained results. Further research is necessary to determine the best configuration of electrodes to optimize the tDCS effects on central or peripheral fatigue and perceived exertion during resistance exercises.

This study has limitations that should be considered. Despite the fact that brain related areas related to motor control and perceived effort have been well described, we were not able to verify the specific cells actually stimulated by the tDCS. For instance, the size of electrodes (35 cm^2) might have resulted in stimulation of other surrounding areas of motor cortex [36]. Furthermore, it is well know that RPE is also affected by psychological and emotional factors, which were not controlled in this study [50]. Finally, it is worthy to highlight that our sample was composed exclusively by resistance trained practitioners which prevents extrapolation of the present findings to general population.

Conclusion

The results of the present study suggest that tDCS applied over the motor cortex immediately before multiple sets of submaximal resistance exercises had no influence on the RPE during the exercise session, in subjects with prior experience in resistance training. Thus, this technique of neuromodulation appears not to be effective to attenuate the effort perception during resistance training and should not be recommended with this purpose in well trained individuals.

Acknowledgment

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Conflict of Interest

None.

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TABLE LEGEND

Subject anthropometrics and performance measurements for the 8-12 repetitions-maximum test (n=13)

FIGURE LEGENDS

Figure 1. Experimental protocol.

Figure 2. Ratings of perceived exertion during the resistance exercise sessions following Transcranial direct current stimulation (black bars) or sham stimulation (white bars). tDCS - Transcranial direct current stimulation. Values denote the mean ± standard deviation.

Figure 3. Ratings of perceived exertion obtained during the last repetition of the first, second and third series of resistance exercise sessions following Transcranial direct current stimulation (tDCS; black bars) or sham stimulation (white bars). A - Leg press 45°; B - Bench press; C – Unilateral knee extension: right leg; D – Unilateral knee extension: left leg; E - Seated row; F – Knee curl; G - Frontal raise. *Significantly different from the tDCS session. Values denote the mean ± standard error.

Table 1. Subject anthropometrics and performance measurements for the 8-12 repetitions-maximum test (n=13)

Anthropometric characteristics	*Values*
Age (year)	20.8±3.9
Weight (kg)	72.1±9.9
Height (m)	1.74±0.04
Body mass index (kg/m^2)	23.6±2.5
Experience in resistance training (months)	18.8 ± 13.3
Exercises	*Weight lifted (kg)*
Leg press 45º	211.2±55.0
Bench press	62.2±9.5
Knee extension – right leg	24.7±6.1
Knee extension – left leg	25.0±5.3
Seated row	72.8±10.0
Knee curl	33.6±6.0
Frontal raise	18.4±2.7

Figure 1

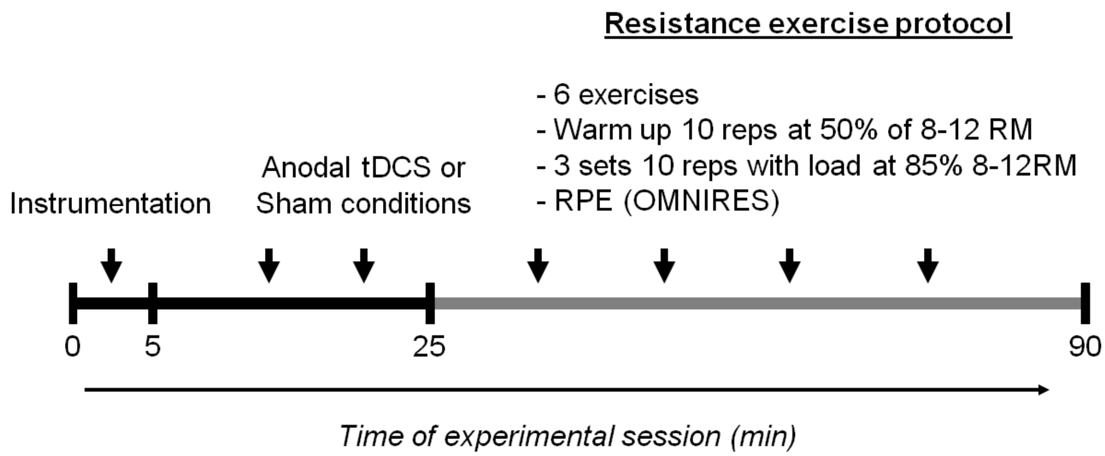

Resistance exercise protocol
- 6 exercises
- Warm up 10 reps at 50% of 8-12 RM
- 3 sets 10 reps with load at 85% 8-12RM
- RPE (OMNIRES)
Anodal tDCS or
Sham conditions
Instrumentation
0
5
25
90
Time of experimental session (min)

Figure 2

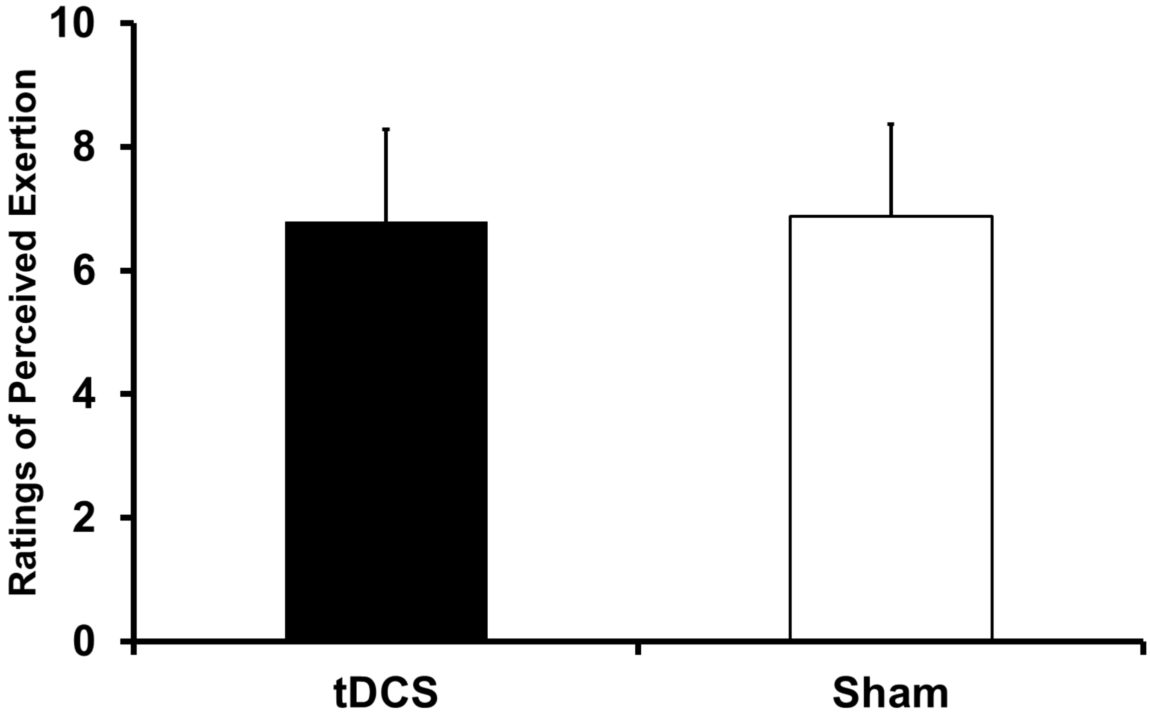
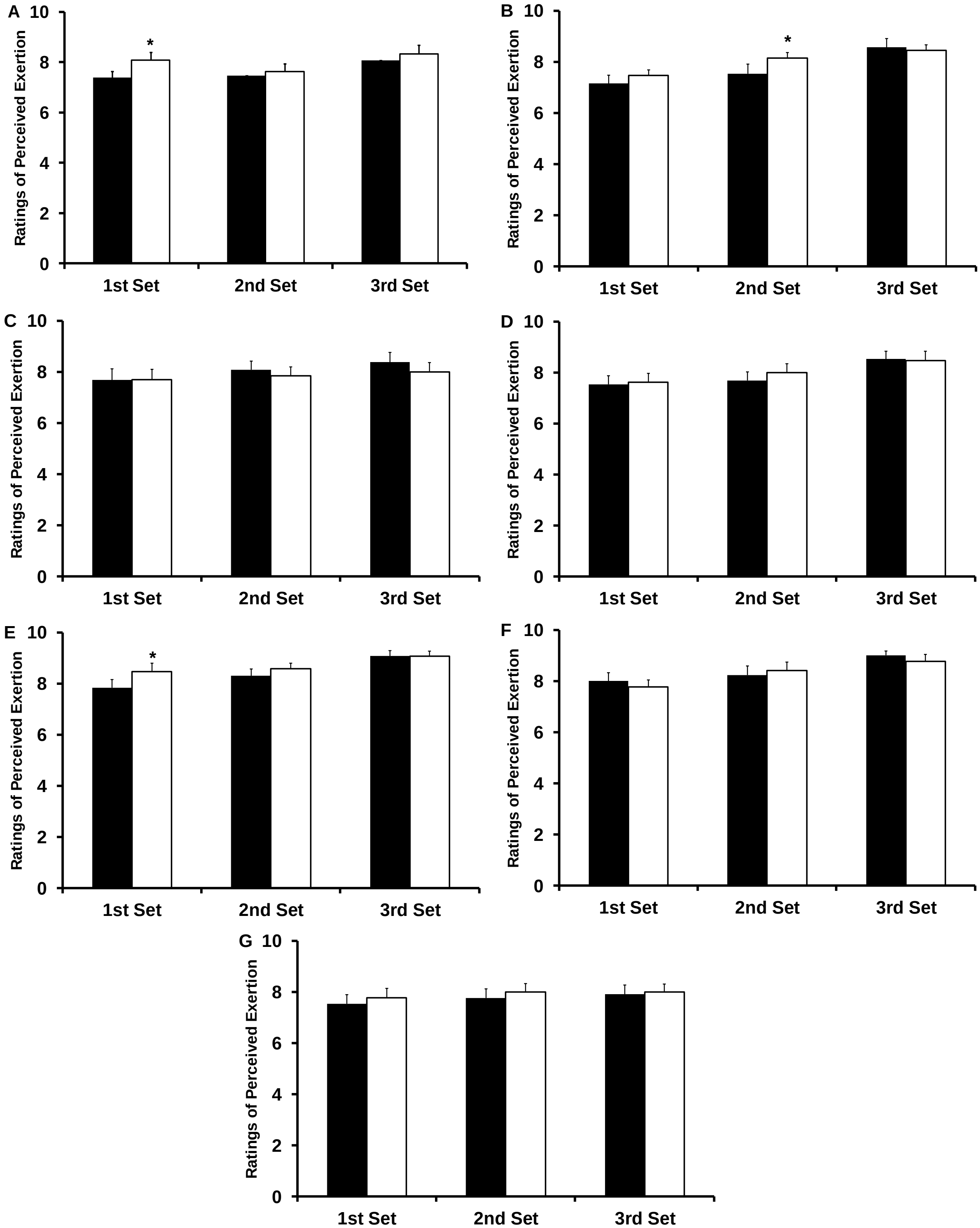


Figure 3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Ratings of Perceived Exertion
0
2
4
6
8
10
1st Set
2nd Set
3rd Set
*