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Research article

Knowledge of Repetitions Range Affects Force Production in Trained Females

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Abstract
Most studies have examined pacing strategies with cyclical activities (running and cycling). It has been demonstrated that males employ different pacing strategies during repeated maximal voluntary contractions (MVCs) dependent upon a known endpoint. Since different fatiguing mechanisms have been identified between the genders, it is not known if females use comparable pacing strategies. The purpose of this study was to examine if informing female subjects regarding the number of MVCs to perform would affect force and electromyography (EMG). Twenty well-trained females completed 3 fatiguing protocols in a randomized order. In the control condition participants were informed they would perform twelve MVCs and then actually completed twelve. In the unknown condition they were not told how many MVCs to perform but were stopped after twelve. In the deception condition they were initially informed to perform 6 MVCs, but after the 6th MVC they were asked to perform a few more MVCs and were stopped after twelve. During the first 6 MVCs, forces in the deception condition were greater compared to the unknown ($p = 0.021$, ES = 0.65, 5%) and control ($p = 0.022$, ES = 0.42, 3%) conditions. No differences were found between conditions in the last 6 MVCs. A main effect for repetitions showed force deficits during the first 6 MVCs ($p = 0.000$, ES = 1.81, 13%) and last 6 MVCs ($p = 0.05$, ES = 0.34, 3%). No differences were found between conditions in biceps and triceps EMG. However, EMG decreased during the first 6 MVCs for biceps ($p = 0.001$, ES = 1.0, 14%) and triceps ($p = 0.001$, ES = 0.76, 14%) across conditions. No differences were found in the last 6 MVCs. The anticipation of performing fewer MVCs led to increased force, whereas no endpoint led to decreased force production.

Key words: Fatigue, electromyography, deception, pacing.

Introduction

Pacing strategies refers to the conscious and/or subconscious distribution of energy during physical effort (De Koning et al., 2011; Gibson and Noakes, 2005; Tucker and Noakes, 2009). It has been suggested that such strategies are regulated, and established before the initiation of exercise in order to enhance performance and to avoid depletion of energy resources. By doing so, premature fatigue and injuries can be avoided (Gibson and Noakes, 2005; Noakes, 2012). Furthermore, the chosen pacing strategy is continuously regulated throughout the activity based on external and internal environmental changes such as knowledge of end point (Billaut et al., 2011; Halperin et al., 2014), motivation (Blanchfield et al., 2013; Stone et al., 2012), and core temperature (Tucker et al., 2004; 2006). Despite the growing number of studies of this topic, most have characterized pacing strategies in cyclic activities such as cycling and running utilizing activities lasting over two minutes. More so, it is currently not clear if pacing strategies differ between the genders.

The few studies to date that have measured pacing strategies during short and intense activities found mixed results (Ansley et al., 2004; Billaut et al., 2011; Chidonk et al., 2013; Morton, 2009; Wittekin et al., 2011). Chidnok et al. (2013) compared two repetitions of three-minute high intensity cycling bouts: self-paced and constant work. Exhaustion with both trials was correlated with the same peak VO_2 and thus was highly dependent on peripheral physiological processes, rather than a self selected pacing strategy. In contrast, Wittekin et al. (2011) used four maximal cycling sprints of 5 s, 15 s, 30 s and 45 s durations. Power was significantly higher during the five and 15 s bouts compared to the first 10 s of the 45 s bout supporting an anticipatory response. Ansley et al. (2004) asked subjects to perform four 30 s, one 33 s and one 36 s cycling tests. However, they were deceived about the duration and actually completed two bouts each of 30 s, 33 s, and 36 s. Power was lower during the last six seconds of the 36 s deception test compared to the actual 36 s test supporting an anticipatory response. By manipulating a clock to run 10% faster or slower than the control condition, males cycled significantly longer when the clock ran slower, but not the females (Morton, 2009). Billaut et al. (2011) implemented three fatiguing protocols consisting of ten sets of six-second maximal cycling sprints. On the control day, subjects were told they would complete ten sets. On the unknown day, participants were not told how many sets they would complete but were stopped after ten sets. On the deception day participants were told they would complete five sets, but were then asked to perform five additional sets. Power and work were higher during the first five sets in the deception day compared to both control and unknown days. Halperin et al. (2014) were the first to examine if pacing strategies are employed during maximal voluntary contractions (MVCs) using a similar methodology to Billaut et al. (2011). In the control day subjects were asked to perform twelve MVCs and were stopped after twelve. In the unknown day subjects were not told how MVCs they would perform but were stopped after twelve. In the deception day subjects were told to perform six MVCs, but after the sixth contraction were asked to perform a few more repetitions and

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were stopped after twelve. Greater forces and higher biceps electromyography (EMG) activity were demonstrated during the deception compared to the unknown condition starting from the first repetition. It was also found that under all conditions the force applied in the last repetition (#12) were significantly greater than the previous. These findings suggest that the anticipation of performing a certain number of MVCs led the subjects to utilize different pacing strategies.

Unfortunately, only two of the above studies included female subjects. Billaut et al. (2011) found that females were susceptible to deception, whereas Morton (2009) found the opposite. Therefore, similar studies using female subjects are warranted. Additionally, other than Halperin et al. (2014) all of the studies used cycling. Hence, it is of interest to examine if females employ similar pacing strategies as males while performing the repeated MVCs protocol (Halperin et al. 2014). Indeed, it has been reported that female fatigue profiles differ from males during repetitive or sustained muscle contractions (Hunter, 2009), and during multiple sprint exercises (Billaut and Bishop, 2009). Females are reported to be more fatigue resistant than males by approximately 23% during sustained isometric contractions of different intensities (Hunter 2009). Suggested factors to explain the gender muscle fatigue differences include differences in central drive (Russ et al., 2003) distribution of muscles fiber types (Miller et al. 1993) and muscle metabolism (Russ et al., 2005).

Therefore, the aim of this study was to determine if females utilize similar pacing strategies to males during repeated MVCs. Using a similar design to Halperin et al. (2014), it was hypothesized that 1) prior knowledge of performing fewer repetitions would lead to greater force and EMG. 2) Not receiving any repetition endpoint would lead to lower values of force and EMG. 3) Informing the participants about their forthcoming last repetition will lead to higher force and EMG values.

Methods

Participants

Twenty females (22 ± 4 years, 1.68 ± 0.05 m, 60 ± 8 kg) participated in this study. Subjects were healthy and performed resistance training a minimum of twice a week for at least a year prior to participation in the study. Subjects were asked to avoid a heavy meal and caffeinated drinks three hours before the test. Furthermore, they were requested to avoid upper body training a day prior to testing days, and avoid all types of training on testing days. McLester et al. (2003) demonstrated that a single rest day was sufficient to fully recover between two similar strength training sessions consisting of three sets of 10 repetitions to failure among trained males. Before participation subjects signed a written consent form. The study was approved by the institution's Human Research Ethics Authority (File number 14.411).

Experimental design

Subjects attended the laboratory on three occasions. Initially the participants were familiarized with the equipment and testing procedures. To avoid bias, they were told that the goal of the study was to inspect the effects of three fatiguing protocols on the electrical activity of their arm muscles. Afterwards subjects completed one of three conditions (control, unknown and deception) in a randomized fashion with three to six days of rest between days. Three to six days were allocated between testing days to alleviate possible delayed onset muscle soreness with the performance of a novel activity (repeated isometric MVCs) (Cheung et al., 2003), under relatively stressful conditions (in laboratory while receiving heavy motivation) (Smith, 1992).

At first, subjects executed a warm up consisting of ten isometric contractions with their elbow flexors with their wrist in a supinated position. Intensity level was equal to ~50% of their perceived maximum with a work to rest ratio of 2/2 s. A minute after the warm up, participants performed three pre-test maximal voluntary contractions (MVCs) lasting five seconds each with two min of rest between the trials. Immediately after performing the three pre-test MVCs subjects were told which fatiguing protocol they would perform.

The three conditions consisted of twelve-elbow flexion MVCs with a work to rest ratio of 5/10 s. The only difference between the conditions was what the subjects were told they would be performing. In the control condition, subjects were asked to perform twelve MVCs and then they actually completed all twelve. In the unknown condition, they were not told how many MVCs they would perform and were stopped after twelve. In the deception condition, subjects were asked to perform six MVCs, but after the sixth MVC they were asked to perform "a few more repetitions". Although "a few more repetitions" was not described, subjects were stopped after their 12^{th} MVC. Since the subjects assumed that the sixth contraction would be their last, they were informed after the fifth MVC that the next repetition would be their last. Under all three conditions subjects were informed immediately following the 11^{th} contraction that their 12^{th} contraction would be their last. The same researcher provided similar level of encouragement during all MVCs, which consisted of four shouts of the word "GO". Prior to the initiation of each trial, the importance of applying maximum force with each MVC was emphasized.

Maximum Voluntary Contraction (MVC) Force

Subjects were seated on a chair with their upper arm supported and elbow flexed at 90^0. The wrist was inserted into a padded strap attached by a high-tension wire to a load cell (Omega Engineering Inc., LCCA 250, Don Mills, Ontario, Canada) that was used to measure elbow flexion force. Data was collected and analyzed in a similar fashion to Halperin et al. (2014). The mean force for each MVC was determined over a three second window defined as 1.5 s before and following the peak force of each contraction. To account for variability in force production between the three testing days, all mean force data was normalized to the highest mean force recorded during the three pre-test trials. As such, all force data is reported as percentage of maximum pre-test values.

Electromyography (EMG)

Surface EMG recording electrodes were placed approximately three cm apart over the proximal, lateral segment of the biceps brachii and over the lateral head of the triceps brachii. Placement of electrodes, skin preparation, and data collection and analysis were done in a similar fashion to (Halperin et al, 2014). Using the same three-second window as applied to the force analysis mean root mean square (RMS) EMG was used. RMS values were determined using a window width of 50 ms. The mean amplitude of the RMS EMG was calculated, and used for analysis. These values were then normalized to the highest pre-test value and reported as a percentage.

Statistical analysis

Normality and homogeneity of variances tests were conducted for all dependent variables. Greenhouse-Geisser correction was used if the assumption of sphericity was violated. Absolute intraclass correlation coefficients (ICC) were measured for mean force and EMG of the three pre-tests of each condition to assess consistency of this data. First, a two-way repeated measures ANOVA test (three conditions x three repetitions) was conducted to measure differences between conditions in raw mean force and EMG of the pre-tests MVCs. Second, a two-way repeated measures ANOVA test (three conditions x six repetitions) was conducted to determine differences between conditions in the first six (1-6) and last six (7-12) MVCs. The following variables were compared between conditions: normalized mean and EMG of biceps brachii and triceps brachii. Paired *t*-tests with Holmes-Bonferroni correction were used to decompose significant interactions and a post hoc Bonferroni was used to compare means if main effects were found. Significance was set at 0.05. Cohen's *d* effect sizes (ES) (1988) were also calculated to compare mean force and EMG between conditions if significance was reached. Data are reported as means ± SD.

Results

Pre-test

No significant differences were found across conditions for pre-test force production, and EMG of the biceps and triceps (Table 1). Likewise, the ICCs of the three pre-test values for absolute force and EMG of biceps and triceps brachii were highly correlated ($r \geq 0.96$) for each condition. Additionally, no significant differences were found between conditions in terms of absolute force, EMG of biceps and triceps brachii ($p \geq 0.423$).

Table 1. Average (± SD) absolute values of the 3 pre-tests.

	Mean Force (N)	Biceps EMG (mV)	Triceps EMG (mV)
Control	246 (30)	.65 (.22)	.11 (.08)
Unknown	236 (25)	.58 (.29)	.14 (.05)
Deception	237 (31)	.61 (.31)	.12 (.01)

Treatment

Force: Significant main effects were found for conditions (p = 0.000) and repetitions (p = 0.000) for normalized mean force during the first six MVCs. Deception condition forces were greater compared to the unknown (p = 0.021, ES = 0.65, 5%) and control (p = 0.022, ES = 0.42, 3%) conditions (Figure 1). Repetition #1 was also significantly greater than #6 (p = 0.000, ES = 1.81, 13%) across conditions. No significant differences were found between conditions during the last 6 MVCs. However, a main effect for repetitions was found (p = 0.018). Repetition #7 was higher than #11 (p = 0.05, ES = 0.34, 2.8%). Interestingly, no significant differences were found between repetition #7 and #12. Paired sample t-test did not reveal significant differences between repetition #11 and #12 within the three conditions. Overall, the forces and SD of the first six MVCs for the Control (86.5 ± 6.4%), unknown (82.2 ± 7.7%), and deception (89.5 ± 7.5%) were greater than the last six MVCs (Control (78.8 ± 7.4%), unknown (76.5 ± 9.3%), and deception (79.3 ± 8.8%)).

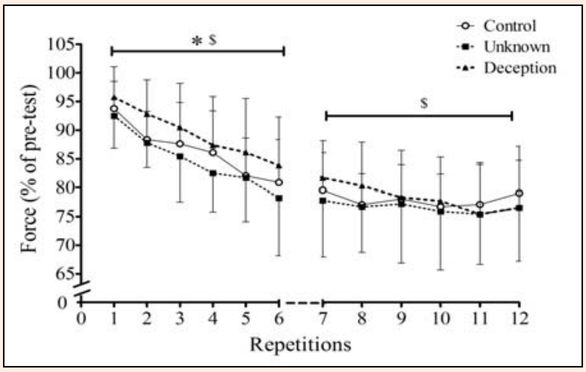

Figure 1. Mean (SD) force profile over the 12 MVCs for the 3 trials. Data is presented in percentage relative to the highest value of the pre-test. Asterix (*) indicate that was significantly higher ($p \leq 0.05$) in the Deception condition relative to Unknown condition. Dollar sign ($) represents a main effect for repetitions in which force decreases across conditions ($p \leq 0.05$).

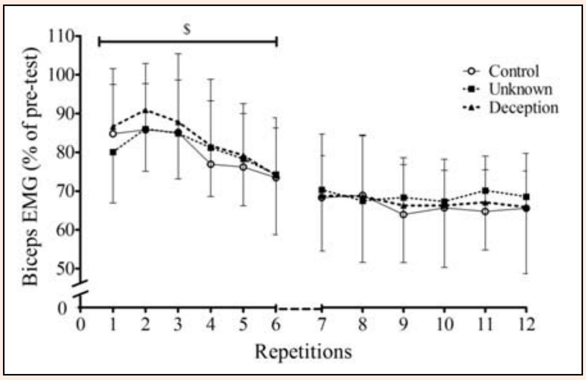

Figure 2. Mean (SD) EMG amplitude of biceps brachii over the 12 MVCs. Data is presented in percentage relative to the highest activation recorded during the pre-test. Dollar sign ($) represents repetitions effect in which EMG amplitude decreased over time across conditions ($P \leq 0.05$).

EMG

No significant interaction or main effect for conditions were found for normalized biceps brachii EMG during the first six or last six MVCs (Figure 2). A main effect of repetitions was found for the first six MVCs (p = 0.000). Significantly higher RMS EMG was found for repetition

#2 versus #5 ($p = 0.000$, ES = 0.78, 9.5%) and #6 ($p = 0.001$, ES = 1, 13.5%). No significant effects were found for the last six MVCs ($p \geq 0.6$). No significant interactions or main effect for conditions were found for triceps EMG. However, a main effect for repetitions was found ($p = 0.001$) for the first six MVCs in triceps EMG. Post hoc Bonferroni demonstrated significantly greater activity for repetition #3 versus #5 ($p = 0.011$, ES = 0.4, 8%) and #6 ($p = 0.001$, ES = 0.76, 14%). No significant effects were found for the last six MVCs ($p \geq 0.3$).

Discussion

The most notable finding of this study was that females employed different pacing strategies depending on the number of MVCs they expected to perform. When subjects expected to perform fewer MVCs (deception condition), greater forces were applied during the first six MVCs compared to both unknown (5%) and control (3%) conditions. Considering that the pre-test values were similar between and within conditions, it is safe to assume that the differences were a result of the interventions. The greater forces applied during the first six MVCs in the deception condition is relatively comparable to the male subjects in Halperin et al. (2014). Similarly, Billaut et al. (2011) reported that both males and females applied greater power and work in the deception conditions in which subjects anticipated performing only five sprints and not ten. Further support to the existence of such pacing strategies can be derived from Wittekind et al. (2011) and Anesly (2004). Wittekind et al. (2011) found that subjects generated greater mean power during cycling sprints lasting five and 15 s than the first 10 s of a 45 s sprint. Similarly, Ansley (2004) showed that subjects generated less work and power in a Wingate sprint test, which lasted six seconds longer than they expected (30 vs. 36 s). Despite the fact that they were not able to detect the extra six seconds, they still underperformed. Collectively, the results of these studies point to the existence of pacing strategies during high intensity exercises that are influenced by an anticipatory response to the exercise duration. Specifically, the anticipation to perform less sprints or repetitions led subjects of both genders to apply greater power/work and force.

Whereas both genders applied greater force during the deception condition in the first six MVCs (present study and Halperin et al., 2014), only males demonstrated greater force during the last six MVCs in the Halperin et al. (2014) study. Nevertheless, both genders demonstrated a similar pattern of force decrements. A large decline in force was evident during the first six MVCs, whereas a negligible decline in force was found during the last six MVCs across conditions. Both genders displayed a similar pattern in force decrements, which suggests comparable fatigue resistibility during intense muscle contractions. For example, Yoon et al. (2007) found that females were more fatigue resistant than males during sustained contractions of lower intensity (20% of MVC), but not during higher intensity contractions (80% of MVC). This suggests that during higher intensity muscle contractions gender differences tend to diminish. However, males and females differed in their responses when informed about their forthcoming last MVC. In the present study females did not apply greater forces in their last MVC relative to the previous contractions whereas males did (Halperin et al, 2014). These findings could be explained by three possibilities. First, it is possible that in contrast to males, females did not preserve as much energy during the repeated MVC protocol. Second, females are affected to a greater extent by cognitive load during fatiguing tasks. Indeed, it was found that females reached exhaustion earlier than males when performing a fatiguing task and a cognitive demanding assignment at the same time (Yoon et al., 2009). Third, it could be that in the present study females had less attention reserves to act upon when feedback concerning their last repetition was provided.

Biceps EMG activity did not differ between the conditions which could be explained by a number of possibilities. First, despite asking the participants to keep their wrist in a supinated position throughout the protocol, minor shift towards mid positions (towards pronation) with the wrist could have influenced biceps EMG readings (Buchanan et al., 1989). Second, it has been demonstrated the force-EMG relationship in not always linear (Lawrence and De Luca, 1983). This is particularly the case at the high force portion of the EMG-force relationship (Kamen and Gabriel, 2010). Lastly, it could be that the surface EMG was not sensitive enough to capture the differences between conditions, which were relatively small (5%) (Dideriksen et al., 2010). However, despite the fact that EMG of the biceps did not differ between conditions, it followed a similar pattern to that of force across conditions. That is, a decline in the first six MVCs was noticed, whereas a plateau was found in the last six MVCs (Figure 2). A similar pattern was found for triceps, in which no differences were found between conditions, but it decreased during the first six MVC, and plateaued in the last six MVCs (Figure 2).

Conclusion

The present study reinforces the finding that pacing strategies occur during repeated MVCs as a function of end point expectations. The results may be considered surprising given that fatigue resulting from short and intense activates is typically attributed to peripheral aspects of fatigue (Shephard, 2009; Weir et al., 2006). Also, despite the fact that gender differences exists in exercise related fatigue, females in the current study used similar pacing strategies as those of males collected in a similar study. The implications of this study are as follows: providing subjects with incorrect information about the number of repetitions they will have to perform may lead to different responses: expecting to perform fewer repetitions than they actually will, may lead to a greater force production, whereas withholding an endpoint in terms of repetition number will result in under performance. Accordingly, knowledge of the exercise endpoint has an important role in pacing strategies.

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Key points

- Pacing strategies occur during repeated (fatiguing) MVCs as a function of end point expectations.
- Females use similar pacing strategies as previously published results with males.
- Without a known end point, females will tend to pace themselves by decreasing force output even when asked to perform maximal contractions.

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