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ORIGINAL ARTICLE

Pacing strategies during repeated maximal voluntary contractions

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Abstract
Purpose Pacing strategies have been reported to occur during continuous cyclical exercises. However, currently no studies have examined if pacing takes place during repeated maximal voluntary muscle contractions (MVCs). Accordingly, the purpose of this study was to examine if informing subjects on the number of MVCs they would perform would affect force and root mean squared electromyography (EMG), during similar fatiguing protocols.
Methods Thirty well-trained male subjects completed three fatiguing protocols in a randomized order. In the control condition participants were informed they would perform 12 MVCs, and then completed all 12. In the unknown condition they were not told how many MVCs they would perform, but were stopped after 12. Lastly, in the deception condition they were initially told they would perform only 6 MVCs, but after the 6 contractions they were asked to perform a few more repetitions and were stopped after 12.
Results Compared to the unknown condition, subjects demonstrated greater forces ($p < 0.05$, ES $= 0.35$–1.14, 2–7.5 %) and biceps EMG ($p < 0.05$, ES $= 0.6$, 6 %) in the deception condition during the first six MVCs. Additionally, under all conditions subjects applied greater forces in the last repetition (#12) relative to the previous one (#11) ($p < 0.06$, ES $= 0.36$–0.5, 2.8–3.8 %).
Conclusions The anticipation of performing a certain number of MVCs led the subjects to utilize different pacing strategies. The results also question the assumption that subjects followed the instruction to exert maximal effort during repeated MVCs.

Keywords Fatigue · Electromyography · Deception

Abbreviations

ANOVA	Analysis of variance
EMG	Electromyography
ES	Effect size
Hz	Hertz
ICC	Intraclass correlation coefficient
MVC	Maximal voluntary contraction
RMS	Root mean square
SD	Standard deviation
VO_2	Volume of oxygen (measure of aerobic capacity)

Introduction

Pacing strategies refers to the conscious and/or subconscious neural mechanisms involved with the distribution of energy resources during physical effort (De Koning et al. 2011; Roelands et al. 2013; Tucker and Noakes 2009). The goal of such a strategy is to optimally utilize energy stores to enhance performance without fully depleting them prior to the end of the task leading to premature fatigue or injury (Gibson and Noakes 2005; Noakes 2012). It has been suggested that pacing strategies are established before the initiation of exercise based on various factors such as intramuscular substrate availability (Lima-Silva et al. 2011; Rauch et al. 2005), core temperature (Tucker et al. 2006b; Tucker et al. 2004), motivation (Blanchfield et al. 2013; Stone et al. 2012), and knowledge of end point (Ansley et al. 2004; Billaut et al. 2011). Furthermore, the pacing strategy

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chosen is thought to be continuously regulated throughout the exercise based on external and internal environmental changes (Noakes 2011; Roelands et al. 2013; Tucker and Noakes 2009).

Research has shown that different pacing strategies are employed in a range of exercises and competitions. In activities lasting between 2 min to several hours competitors typically employ a pacing strategy in which effort is exerted in a U-shaped pattern (Roelands et al. 2013; Tucker et al. 2006a). That is, athletes will initiate the race in a fast manner, slow down during the middle part, and speed up towards the end (known as the “end sprint”). The ability to speed up towards the end of the race, a state in which subjects are suppose to be the most fatigued, strengthens the concept of planned pacing strategies that regulate performance (Roelands et al. 2013; Tucker and Noakes 2009). In addition, it also questions the classical model of fatigue in which one or more of the peripheral physiological systems limits performance due to reaching an upper limit of the working muscles or the cardiovascular system (Gibson and Noakes 2005; Noakes 2011). In contrast, during high-intensity, short-duration activities an “all out” positive pacing strategy is mostly utilized in which the speed/power output gradually declines as a function of the length of the activity (Chidnok et al. 2013; Ferro et al. 1999). These findings could be explained as the inability of the muscular and/or cardiovascular systems to produce the necessary force, or supply enough oxygen, despite the will of the athlete to do so (Chidnok et al. 2013; Shephard 2009).

The few studies that have examined pacing strategies during short and intense forms of exercise found mixed results (Ansley et al. 2004; Billaut et al. 2011; Chidnok et al. 2013; Wittekind et al. 2011). Wittekind et al. (2011) had subjects perform four all out cycling bouts lasting 5, 15, 30 and 45 s on different days. Despite being asked to pedal as hard as they could, during the 5- and 15-s trials the mean and peak power output were higher relative to the first 10 s of the 45-s trial. Ansley et al. (2004) had subjects perform six Wingate tests lasting 30 s, 32 or 36 s once a week. Participants were informed they would perform four trials lasting 30 s, one 32-s trial, and one 36-s trial. However, in reality they performed two trials of 30, 32, and 36 s. It was found that power output was significantly higher during the last 6 s of the 36-s informed trial compared to the 36-s deception trial in which subjects expected to pedal for just 30 s. Since the participants were asked to pedal as hard as they could on each trial, there should have been no difference in power output during the last 6 s of the informed and deception trials. Interestingly, the subjects were not able to detect the extra 6 s in the deception trials. Billaut et al. (2011) tested subjects on three different occasions in a randomized manner. Each session consisted of performing ten sets of 6-s maximal sprints with 24 s of rest between each set. In the control condition, subjects were told they would perform the ten sets before beginning the activity. In the unknown condition, the subjects were not told how many sets they would be performing, but were stopped after ten sets. Lastly, in the deception condition subjects were told they would only perform five sets, but were asked to perform five extra sets once they completed the first five. It was shown that during the deception condition subjects accumulated more work, generated more power, and had higher overall lower body EMG during the first five sprints relative to the two other conditions. During the unknown condition, subjects demonstrated a relative early decrease in work and EMG. Collectively, the results of these three studies solidify the concept of a subconscious planned pacing strategy in which the distribution of energy stores was based on the expected duration of exercise (Ansley et al. 2004; Billaut et al. 2011; Wittekind et al. 2011). However, Chidnok et al. (2013) found that exhaustion during high-intensity exercise was based on known peripheral physiological processes, which were unaffected when pacing strategies were self-selected. Subjects performed two cycling tests: a ride to exhaustion at a high-intensity constant work rate which was expected to result in exhaustion in 3-min, and a self-paced 3-min cycling time trial. Exhaustion during both rides was correlated with the same peak VO_2. Accordingly, more studies are needed to verify if and what type of pacing strategies take place during high-intensity exercises.

Despite the fact the pacing strategies have been found in cyclic activities (i.e., running, cycling), it is still not clear if such strategies are employed during exercises that require maximal muscle contractions (Shephard 2009; Weir et al. 2006). Accordingly, the goal of this study was to determine if pacing strategies were utilized during repeated maximal muscle contractions (MVC). Using a similar research design to Billaut et al. (2011), the hypotheses were as follows: (1) the anticipation of performing fewer repetitions would lead to higher values of force and EMG; (2) not knowing how many repetitions are to be carried out 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

Thirty males (23 ± 4 years, 178 ± 7 cm, 78 ± 9 kg) participated in this study. Subjects were healthy and performed resistance training at least twice a week for a minimum of 1 year prior to participation in the study. Subjects were asked to avoid a heavy meal and caffeinated drinks 3 h before the test. Furthermore, they were asked avoid upper body training a day before the testing day, and avoid training on testing days. All subjects signed a written consent form prior to participation. Memorial University of Newfoundland Human Research Ethics Authority approved this study (File number 14.411).

Experimental design

Subjects visited the laboratory on three occasions. During the first testing session they were also familiarized with the equipment and testing procedures. They were told that the goal of the study was to examine the effects of different fatiguing protocols on the electrical activity of the arm muscles. Consequently, subjects performed one of three conditions (control, unknown and deception) in a randomized fashion with 3–5 days of rest between testing days.

For all conditions, subjects initially performed a warm-up consisting of ten isometric contractions with their elbow flexors with their wrist maintained in a supinated position. The work-to-rest ratio was 2/2 s at an intensity level equating to approximately 50 % of their perceived maximum. One minute after the warm-up, subjects performed three pre-test maximal voluntary contractions (MVC) lasting 5 s each with 2 min of rest between each repetition. Only after the completion of the pre-test MVC, participants were told which fatiguing protocol they would perform that day.

Each of the three experimental conditions consisted of 12 elbow flexion MVCs with a work-to-rest ratio of 5/10 s. The work-to-rest ratio was chosen as it induced a moderate degree of fatigue (20–30 %) while allowing for sufficient rest to prepare the participants for the additional six MVCs during the deception condition. The conditions differed only by what the subjects were told they would be performing. In the control condition, subjects were informed they would perform 12 MVCs and then actually performed all 12. In the unknown condition, they were not told how many MVCs they would perform and were stopped after 12. For both these conditions subjects were informed immediately following the 11th contraction that their 12th contraction would be their last. In the deception condition, subjects were told that six repetitions would be done, however, after the sixth contraction they were asked to perform a “few more repetitions”. Although “a few more repetitions” was not defined, subjects were stopped after their 12th contraction. As subjects believed the sixth contraction would be their last they were informed after the fifth contraction that the next repetition would be their last. As was the case for control and unknown conditions, a similar reminder about their last forthcoming repetition was given after the 11th contraction. The importance of exerting maximum force with every contraction was emphasized to all subjects. The same investigator gave the same level of encouragement during all MVCs, which consisted of three shouts of the word “GO”.

Maximum voluntary contraction (MVC) force

Subjects were seated on a chair with their upper arm supported and elbow flexed at 90°. The wrist was inserted into a padded strap attached by a high-tension wire to a load cell (LCCA 500 pounds; sensitivity = 3 mV/V, OEI, Canada) that was used to measure elbow flexion forces. All force data were sampled at a rate of 2,000 Hz using a Biopac data collection system (Biopac Systems Inc. DA 100 Holliston, MA). Data were recorded and analyzed with a commercially designed software program (Acq-Knowledge III, Biopac Systems Inc.). Mean force was determined for all fatiguing contractions. The mean was determined over a 3-s 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 are reported as percentage of maximum pre-test values.

Electromyography (EMG)

Surface EMG recording electrodes were placed approximately 3 cm apart over the proximal, lateral segment of the biceps brachii and over the lateral head of the triceps brachii. The distance of the biceps electrodes from the acromion process and the distance of the triceps electrodes from the biceps electrodes were recorded to ensure accurate replacement for subsequent tests. A thorough skin preparation for all electrodes included shaving and removal of dead epithelial cells with sand paper around the designated areas, followed by cleansing with an isopropyl alcohol swab. EMG was collected using a Biopac (Biopac Systems Inc.) data acquisition system at a sample rate of 2,000 Hz [impedance = 2 MΩ, common mode rejection ratio >110 dB min (50/60 Hz), noise >5 μV]. A bandpass filter (10–500 Hz) was applied prior to digital conversion. Using the same 3-s 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. Once RMS was calculated the mean value was selected. These values were then normalized to the highest pre-test value and reported as a percentage.

Statistical analysis

Normality (Kolmogorov–Smirnov) and homogeneity of variances (Levene) tests were conducted for all dependent variables. If the assumption of sphericity was violated, the

Greenhouse–Geisser correction was employed. Intraclass correlation coefficients (ICC) were measured for mean force and EMG for the three pre-tests of each condition to assess consistency of this data. Firstly, a two-way repeated measures ANOVA test (3 conditions × 3 MVCs) was conducted to measure differences between conditions in raw mean force and EMG of the pre-tests MVCs. Secondly, a two-way repeated measures ANOVA test (3 conditions × 6 MVCs) 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 voluntary force and EMG of biceps brachii and triceps brachii. Paired *t* tests with Holmes–Bonferroni correction were used to decompose significant interactions and main effects. Significance was set at 0.05. Cohen's *d* effect sizes (ES) (7) were also calculated to compare mean force and EMG between conditions. Data are reported as mean ± SD.

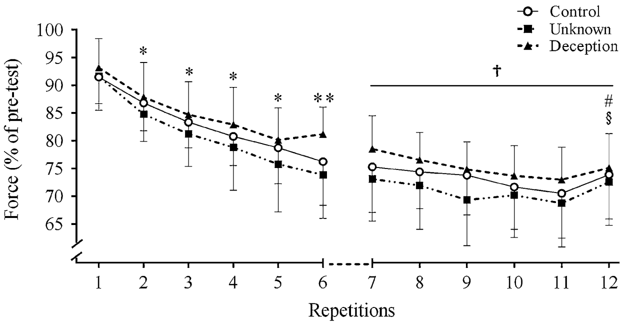

Fig. 1 Mean force profile over the 12 MVCs for the 3 trials. Data are presented in percentage relative to the highest value of the pre-test. *Asterisk* indicates that force was significantly higher ($p \leq 0.05$) in the deception condition relative to unknown condition. *Double asterisks* illustrates that force was significantly higher in deception condition relative to both unknown and control conditions. A *cross* represents a main effect of conditions with forces higher in the deception condition compared to the control and unknown conditions ($p = 0.024$). Number *hash tag* indicates that force was significantly higher in repetition number 12 relative to number 11 in both the control and unknown conditions. § Demonstrates that force is significantly higher in repetition number 12 relative to number 11 in the unknown condition. Means and standard deviations (*vertical bars*) are illustrated

Results

Pre-test

Irrespective of the condition, pre-test force production and EMG of the biceps and triceps did not differ significantly (Table 1). Correspondingly, the ICCs of the three pre-test values for each condition were highly correlated ($r \geq 0.94$) for absolute force measures and EMG of biceps and triceps brachii.

Treatment

Force: There was a significant interaction for normalized mean force during the first six MVCs ($p = 0.017$). Post hoc paired *t* tests revealed that forces during the deception condition were significantly higher than those during the unknown condition (Figs. 1, 2). The *p* values, effect sizes and percentage differences for the deception versus unknown repetitions were as follows: #1 ($p = 0.062$, ES = 0.34, 1.8 %); #2 ($p = 0.012$, ES = 0.52, 2 %); #3 ($p = 0.003$, ES = 0.58, 3.7 %); #4 ($p = 0.009$, ES = 0.57, 4.2 %); #5 ($p = 0.008$, ES = 0.63, 4.7 %) and #6 ($p = 0.000$, ES = 1.14, 7.5 %). Additionally, forces in the deception condition were significantly higher than those of the control condition only for repetition number #6 ($p = 0.004$, ES = 0.78, 5 %). No significant interactions were found for normalized mean force of the last six MVCs ($p = 0.135$). However, a main effect of conditions ($p = 0.024$) and repetition numbers ($p = 0.000$) were found. Average forces were significantly higher in the deception condition compared to the unknown condition ($p = 0.003$, ES = 0.63, 4.3 %) and slightly but not significantly higher than control ($p = 0.09$, ES = 0.3, 2.3 %). A further examination of the last two repetitions using paired *t* tests revealed that force was significantly higher in repetition #12 compared to #11 within conditions for the unknown ($p = 0.001$, ES = 0.49, 3.8 %) and control conditions ($p = 0.004$, ES = 0.42, 3.5 %), and higher but not significant for the deception condition ($p = 0.06$, ES = 0.36, 2.3 %) (Fig. 1).

Table 1 Average ± SD absolute values of the three pre-tests

	Mean force (N)	Biceps EMG (mV)	Triceps EMG (mV)
Control	415 ± 108	0.82 ± 0.32	0.18 ± 0.09
Unknown	421 ± 91	0.74 ± 0.32	0.17 ± 0.05
Deception	420 ± 93	0.8 ± 0.35	0.17 ± 0.07

Force is presented in units of Newton (N) and EMG in units of millivolts (mV)

EMG: No significant interactions were found for normalized biceps brachii EMG during the first six ($p = 0.735$) or last six ($p = 0.523$) MVCs. However, a main effect of conditions was found for the first six MVCs ($p = 0.026$), indicating that EMG amplitude in the deception condition was higher than the unknown ($p = 0.000$, ES = 0.6, 5.8 %) and control ($p = 0.000$, ES = 0.65, 6.8 %) conditions. Non-significant effects were found for the last six contractions ($p = 0.07$). Although not statistically significant, EMG amplitude in the deception condition was numerically higher (moderate magnitude effect sizes) than the unknown

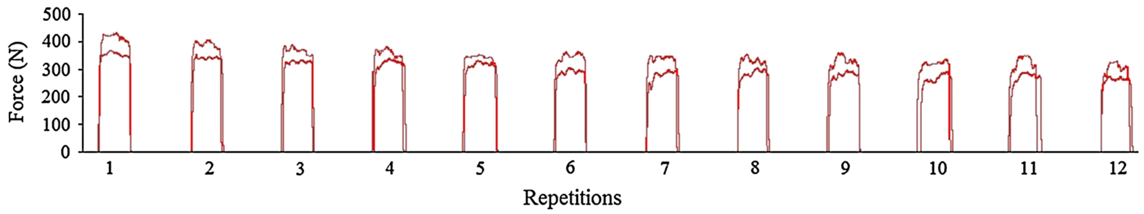

Fig. 2 An original MVC force trace recording from one subject in which the deception and unknown conditions are superimposed on each other. Forces are higher in each MVC during the deception relative to the unknown condition

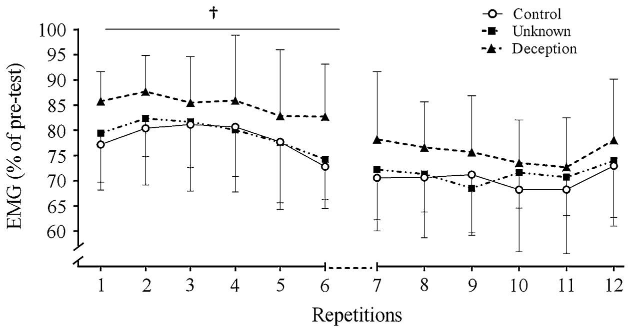

Fig. 3 EMG amplitude profile of biceps brachii over the 12 MVCs for each of the 3 conditions. Data are presented in percentage relative to the highest activation recorded during the pre-test for each condition. A *cross* represents a main effect of condition with the deception condition being higher than the unknown and control condition ($p = 0.024$). Means and standard deviations (*vertical bars*) are illustrated

(ES = 0.45, 4.5 %) and control (ES = 0.5, 5.4 %) conditions (Fig. 3). Also, a main effect for repetitions was found for the first six MVCs ($p = 0.011$) and last six MVCs ($p = 0.008$). There were no significant differences in normalized triceps brachii EMG during the first and last six contractions.

Discussion

The main finding of the present study was that subjects employed different pacing strategies in each of the three conditions. Despite being asked to perform the same maximal intent fatiguing protocol, subjects displayed higher forces and biceps brachii EMG during the deception condition compared to the unknown condition beginning from the first contraction. In contrast, when subjects were unaware of the number of contractions they were about to perform, a pacing strategy was adopted in which subjects produced less force and EMG. This conclusion is supported by the fact that no significant differences were found between groups during the pre-test trials. This finding suggests that the identified differences were a result of the intervention.

Statistically significant and meaningful differences were found when comparing forces between the deception and the unknown conditions during the first six MVCs. Subjects increased the force produced with each subsequent contraction by 2–7.5 % in the deception condition relative to the unknown condition. In addition, in contraction #6 during the deception condition subjects produced more force than both the unknown (7.5 %) and control (5 %) conditions. Interestingly, they also applied more force compared to their previous contraction (#5). Although subjects were instructed to produce maximal force with each contraction, these findings suggest that the participants were not applying true maximal forces. Instead, the suppression of maximal forces until the expectation of a final repetition suggests a planned pacing strategy (Jones et al. 2013; Tucker and Noakes 2009). Similar to the current study, Billaut et al. (2011) found higher power and work in the deception trial in the first half of a repeated cycling sprints protocol. The findings are also similar to Wittekind et al. (2011) who reported higher mean and peak power output during sprints lasting 5 and 15 s, compared to the first 10 s of a 45-s sprint. As previously described, Ansley et al. (2004) found higher power output during the final 6 s of the accurate 36-s trial compared to the 36-s deception one. These results are comparable to the present study demonstrating a planned pacing strategy in which prior knowledge of the exercise end point influenced the effort subjects were willing to apply.

Average forces were also found to be higher in the last six MVCs in the deception condition relative to the unknown (4.3 %) and control (2.3 %) conditions. This finding could be explained by the fact that subjects were informed they would only perform "a few more repetitions" and not six more repetitions. Since "a few more" was not clearly defined, perhaps subjects thought they would only perform 2–3 more repetitions and not an additional 6. Interestingly, when subjects were informed about their last repetition, they applied more forces relative to the previous repetition irrespective of the condition. Specifically, repetition #12 was higher than #11 by 3.8, 3.5, 2.3 % in the unknown, control and deception conditions, respectively. Similar to the sixth repetition in the deception condition, these results strengthen the concept of planned pacing strategies. That is, despite being asked to apply as much force as possible on each contraction, and despite receiving vocal encouragement, subjects apparently did not express their true maximal forces until their last contraction. Other studies have found comparable results (Hunter et al. 2004, 2008; Neyroud et al. 2012; Marcora and Staiano 2010). Hunter et al. (2004, 2008) had subjects perform a time to exhaustion test against a load that was equal to 20 % of their MVC with either the elbow flexors or dorsiflexors. Despite the participant's apparent exhaustion, an immediate post-test MVC revealed that subjects were able to apply ~3 times as much force compared to that applied during the test. Likewise, Marcora and Staiano (2010) found that participants were able to apply ~3 times as much power in a 5-s maximal cycling test performed immediately after an exhaustive cycling test done at 80 % of peak aerobic power. Lastly, Neyroud et al. (2012) asked subjects to hold an isometric knee extension contraction until exhaustion at a target force equal to 20 % of their MVC. Once reaching exhaustion, the knee extensors were electrically stimulated for 1 min which involuntarily elicited comparable levels of force (20 % of MVC). Collectively, these results challenge the assumption that peripheral muscle fatigue is the main reason of performance decrements. Particularly, peripheral muscle fatigue cannot account for the observation that subjects applied higher levels of force/power at the point in which they were supposed to be the most fatigued (Hunter et al. 2004, 2008; Marcora and Staiano 2010). Also, peripheral muscle fatigue cannot account for the extended duration in which the muscles were able to produce involuntary force after reaching complete voluntary exhaustion (Neyroud et al. 2012).

Similar to the unknown condition in the current study, others have demonstrated that when subjects are deprived of information allowing them to develop a pacing strategy they tend to underperform (Faulkner et al. 2011; Mauger et al. 2009). Mauger et al. (2009) had subjects carry out four consecutive 4-km cycling time trials separated by 17 min. In contrast to the control group, subjects in the experimental group did not know the distance they would cycle during each time trial, only that the distance would be the same for all four trials. The experimental group was significantly slower than the control group during the first time trial, and with each consecutive trial the differences between the groups decreased. The authors suggested that this improved performance was a consequence of subjects developing a better approximation of the distance traveled, allowing them to cycle with greater intensity. Faulkner et al. (2011) found that when subjects did not receive distance feedback during a self-paced 6-km time trial, they ran slower and displayed lower VO_2 and heart rate values compared to both the accurate and inaccurate distance feedback trials. Taken together, these findings indicate that when subjects are unaware of the exercise endpoint they will under perform. The inability to employ a pacing strategy during exercises without a known endpoint may lead to decreases in motivation and a psychological strain, and consequently hinder performance (Smirmaul et al. 2013; Marcora et al. 2009).

Similar to the force differences between conditions, biceps brachii EMG activity in the deception condition was higher than the unknown (5.8 %) and control (6.8 %) conditions in the first six contractions (Fig. 2). Despite the limitation of surface EMG such as crosstalk (Farina et al. 2004) and amplitude cancelation (Keenan et al. 2005), it is still considered to be associated with neural drive (Gibson and Noakes 2005; Farina et al. 2004). This suggests that pacing strategies are centrally driven. No significant differences were found between conditions in biceps brachii EMG in the last six MVCs. Although not statistically significant, EMG had moderately higher magnitudes in the deception condition (Fig. 2). These magnitude-based outcomes are in agreement with Billaut et al. (2011) who reported higher quadriceps EMG in the deception condition, and lower activation in the unknown condition in the first half of a repeated cycling sprints protocol, with no difference in the second half. Additionally, a significant decrement in triceps EMG activity was found over time; however, it did not differ between conditions.

Limitations

EMG activity was only measured from one of the prime movers (biceps brachii), while elbow flexion force is produced by other muscles as well. Although there were significant differences between conditions for force for repetitions #6 and #12, the lack of significant EMG differences might be attributed to the contribution of synergistic muscles such as the brachialis and brachioradialis. Furthermore, EMG may not have been sensitive enough to reflect slight changes in force production, as is the case in this study.

Since subjects in the present study were resistance-trained males, further research is needed to examine if untrained and endurance-trained subjects will employ a similar pacing strategy. Likewise, considering that fatigue-related gender differences have been reported (Billaut and Bishop 2009; Hicks et al. 2001), additional research is needed to verify if females utilize similar pacing strategies during repeated maximal muscle contractions.

Conclusion

To the best of our knowledge, the present study is the first to demonstrate different pacing strategies during repeated MVCs as a function of pre-exercise end point expectations.

This novel finding is surprising considering the short duration of the protocol and that the intent of each contraction was to produce maximal force. Accordingly, the fatiguing nature of such a task is typically attributed to peripheral aspects of fatigue (Shephard 2009; Weir et al. 2006). Hence, the request for maximal force production should not allow for pacing strategies. However, despite these unique variables, pacing still occurred. The implications of this study are as follows: incorrectly informing the participants that they will perform fewer repetitions than they actually will, may lead to a higher level of effort as a result of adopting a more vigorous pacing strategy. In contrast, withholding information from the subjects about the number of repetitions they will need to perform will reduce their ability to consciously or subconsciously plan a precise pacing strategy. Accordingly, subjects will employ a reserved pacing approach in which less force will be applied. Therefore, knowledge of the exercise endpoint has an important role in pacing strategies.

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