Pacing strategies during repeated voluntary maximal contractions

by

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A thesis submitted to the

School of Graduate Studies

in partial fulfillment of the

requirements for the degree of

Master of Science (Kinesiology)

School of Human Kinetics and Recreation

Memorial University of Newfoundland

May 2014

St. John's Newfoundland & Labrador

Acknowledgements

The creation of this thesis required the support of colleagues, friends and family.

First of all, I am truly thankful to my supervisor Dr. David Behm for his invaluable guidance, patience, trust, and knowledge. Without his assistance this work would not have been possible.

Secondly, I would like to thank the faculty of Human Kinetics and Recreation, Memorial University of Newfoundland, for sharing their wealth of knowledge, and their willingness to answer all of my many questions.

Thirdly, I am grateful to all my friends and fellow graduate students who contributed valuable assistance in the preparation and completion of this thesis. Notably, I would like to thank Dr. Majid Aboodarda for his countless hours of help and assistance.

Lastly, I would like to thank my parents, Lilly and Avi Halperin, for their support and encouragement throughout this Master's degree in Canada.

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List of abbreviations

ANOVA: analysis of variance

EMG: electromyography

ES: Effect sizes

F100: force produced in the first 100 milliseconds of a maximal voluntary contraction

Hz: Hertz

ICC: Intraclass correlation coefficient

MIVC: Maximal isometric voluntary contraction

M-wave: muscle action potential wave

RPE: rating of perceived exertion

VO_2: Aerobic capacity

Kg: Kilogram

Min: Minute

mV: Millivolts

s: Second

1. Introduction

1.1 Background of study

Although substantial literature exists on the topic of exercise related fatigue, it is still difficult to state with certainty why an individual becomes fatigued under different conditions (Enoka et al., 2008). One possible option, which explains this difficulty, is the lack of a clear definition of fatigue and its location (Marino and Drinkwater, 2011). Conveniently, the literature typically divides the origin of fatigue to central and peripheral sites. Central fatigue is defined as the ability of the muscles to produce a greater output than what the central nervous system is willing or able to request (MacIntosh et al, 2002). Peripheral fatigue is defined by the inability of the muscles to respond in the same fashion as they were prior to the exercise that elicited fatigue (MacIntosh et al., 2002). Understanding the mechanisms leading to fatigue is important for many reasons. First, many sports and activities have an endurance component to them. That is, athletes will need to repeatedly apply force and generate power for certain periods of time. It has been demonstrated that fatigue resulted in physical and technical decrements (Gabbett et al., 2008, Royal et al, 2006). Additionally, exercise related fatigue is strongly correlated with injury inducing behavior (Lee et al, 2003, McLean et al, 2007). Accordingly, developing a deeper understanding of what effects and leads to exercise related fatigue is of great importance. One way to study fatigue and exercise regulation is through the study of pacing strategies which refers to the conscious and/or subconscious distribution of energy during physical effort (Noakes, 2012). Indeed, 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 the energy recourses prior to the end of the activity. By doing so premature fatigue and injuries can be avoided (St Clair Gibson and Noakes, 2004). Furthermore, the chosen pacing strategy is continuously regulated throughout the exercise based a various of factors such as as knowledge of end point, motivation, and core temperature (De Koning et al, 2011Noakes, 2012, St Clair Gibson and Noakes, 2004). For example, it has been shown that during most races lasting longer than 2 minutes athletes will tend to increase their speed/power output towards the end of the race (Roelands et al, 2013), suggesting a planned strategy in which energy is conserved until the end point. Also, slower than normal pacing strategies have been recorded during exercises performed in extreme environments such as hypoxic and hyperthermic conditions (Tucker et al, 2004, Tucker etl al, 2009, Noakes, 2012). Interestingly, the slower reserved pacing strategies began before the extreme conditions affected any of the peripheral systems (Tucker et al, 2004, Tucker etl al, 2009, Noakes, 2012). These findings suggest an anticipatory response in which the pace is decided before the initiating of exercise, and regulated throughout.

1.2 Purpose

Despite the growing number of studies on this topic, most studies to date have examined and characterized pacing strategies in cyclic exercises such as cycling and running lasting over 2 minutes. Considering that many sports and physical efforts in daily life require the application of force in a non-cyclical fashion and are shorter than 2 minutes, it is of interest to learn if subjects unitize various pacing strategies as they do during longer cyclical activities. This is of particular interest as physical fatigue during short and intense activities is mostly attributed to peripheral aspects which are independent of pacing strategies (Weir et al, 2006). Therefore, the goal of the present study is to examine if various pacing strategies will be adopted by trained males subjects during repeated maximal muscle contractions. This will be done by exposing the subjects to 3 fatiguing protocols in which the subjects will be receive knowledge of repetitions range prior to performing the protocols. Despite the fact that during all protocols subjects would be performing the exact same number of maximal muscle contractions with their elbow flexors, they will be incorrectly informed about the repetitions ranges prior to the initiation of the protocol. Accordingly, if the prior knowledge will have any effect on their force production it will be safe to conclude that pacing strategies are employed during non cyclical maximal muscle contractions as well. In contrast, if no effects will be recorded then it may indicate that pacing strategies do not take place during such activities, and they may be limited to cyclical and longer duration exercises.

1.3 Significance of study

Information acquired from this research will deepen our understanding of physical fatigue, particularly during short and intense maximal muscle contractions. Furthermore, the results acquired from this study may have relevant practical applications for coaches and athletes. That is, if previous knowledge of repetition range has an effect on performance then under some circumstances coaches could use this information as part of the training process, or during competitions. For example, cuing the athlete that less distance is to be covered towards the end of a race may enhance performance.

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1. Literature review

2.1 Introduction

Definitions of fatigue differ depending on the task. Some types of fatigue may be characterized by externally measurable impairments in force, torque, power, or performance. This type of fatigue, which may be associated with repeated or sustained high intensity or maximal contractions, has been defined as a transient decrease in working capacity (Asmussen and Mazin, 1978), a loss of force output leading to reduced performance (Fitts and Metzger, 1993), or a decline in the force generating capacity of the muscle (Degens and Veerkamp, 1994). The mechanisms of fatigue are often divided into peripheral (muscle) and central (neural) influences (Behm, 2004). It is now suggested that neither system works in isolation (Behm, 2004). There is an interplay of influences with peripheral responses (e.g. metabolic responses such as increased intracellular acidity, lactate accumulation or mechanical such as tension exerted on the fibre) modulating central responses (e.g. chemoreceptor and mechanoreceptor afferent impulse activity). Conversely, conscious or subconscious central responses from spinal (typically reflex mediated) and supraspinal (long loop reflex or conscious events such as diminished motivation) centers can alter peripheral or muscle performance. However the predominance of a top down (central modulating peripheral) or opposite (peripheral modulating central) approach to fatigue is still controversial.

Fatigue may be also described as an increase in the perceived effort needed to exert a desired force and an eventual inability to produce this force (Enoka and Stuart, 1992). Researchers also disagree upon whether the perception of fatigue is primarily a feedback or feed forward (anticipatory) mechanism. According to Noakes' central governor model (CGM), fatigue is not a physical event but rather an emotion (Noakes, 2012a, Gibson and Noakes, 2004, Baron et al, 2011). The model assumes that the brain, or central governor, continuously gathers information from the internal and external environment during and prior to the activity. Accordingly, it creates the sensation of fatigue to preserve homeostasis by eliminating or down regulating the exercise before harm is done to the muscles or organs (Noakes, 2012a, Gibson and Noakes, 2004, St Clair et al, 2001).

Indeed, it has been shown that fatigue can develop before complete muscle recruitment (Gibson and Noakes 2004, St Clair et al, 2001), maximal muscle lactate accumulation (Baron et al, 2008), ATP depletion (Allen et al, 2008), and before reaching the upper limits of blood lactate, oxygen consumption, heart rate and ventilatory rates (Swart et al, 2008).This supports the notion that fatigue can happen without reaching the upper limits of peripheral changes leading to physical fatigue. In addition, Swart et al. (2008) found that ingestion of amphetamines, a drug that primarily affects the brain, had the subjects ride longer and faster when tested in a cross over placebo ride to exhaustion while maintaining a constant RPE of 16 (corresponding to verbal cue of between 'hard' and 'very hard' on Borg scale (Borg, 1982)). Peripheral measurements were significantly higher during the amphetamine trial, which suggests that performance was not limited by peripheral fatigue during the placebo trial.

One of the corner stone's supporting the CGM is the study of human pacing strategies. This research field offers a unique perspective on how humans consciously and subconsciously down regulate performance.

2.2 Pacing Strategies

During different activities such as running, cycling and rowing, humans will decide either consciously or subconsciously on a certain speed or intensity in which the activity will be performed (St clair Gibson et al, 2001, Noakes 2011a). The decision starts from the very beginning of the activity, and changes throughout the race according to the constant feedback from both the external and internal environment (Swart et al, 2009, Noakes 2011a). Interestingly, it has been found that towards the end of most races the speed and intensity will increase (Naokes, 2012a). In other words, the competitors will typically run or cycle faster in the last portion of the race. This finding is not in accordance with the classical peripheral theories of fatigue as they would assume that in later stages of the race, metabolic and biochemical byproducts would have accumulated resulting in slower speeds and less intense physical exertions. For example; an analysis of 32 world mile record performances found that in only two records (6%) was the final lap the slowest, whereas in 24 records (76%), it was either the fastest (38%) or the second fastest (38%) lap (Noakes et al, 2008). Another analysis (Tucker et al, 2006) of pacing strategies during the men's world-record performances in track athletics, found that in the 5k and 10k events, the first and final kilometers were significantly faster than the middle kilometer. However, in the second lap during the 800-m it was slower than the first. These results clearly demonstrate that fatigue is more complex than simply the accumulation of byproducts in the muscles; however, it is still not completely clear exactly how pacing strategies work in shorter and more intense activities such as the 800-m sprints. Additionally, the question if the competitors decide on the pacing strategies in a conscious manner before the race or change it in a subconscious manner remains to be answered. In the following sections research on this topic will emphasize the important concepts in the field of pacing strategies.

2.3 Pacing strategies during short duration activities (<2 min)

Despite the fact that fewer studies to date have examined short duration and higher intensity activities (<2 min), it seems as if anticipation plays an important role in such activities. In a study by Wittekin et al. (2011) 9 active male subjects performed four maximal cycling bouts lasting 5, 15, 30 and 45s on different days. Despite being asked to pedal as fast and hard as they could during the 45s trial, a pacing strategy was noticed in which the peak and mean power output decreased during the first 10s compared to the 5s and 15s trials. This finding supports the notion of a central governor anticipating the length of the activity as otherwise there should have been no difference between the trials during the initial 10s. A study by Ansley et al. (2004) also supports the concept of a central governor during short and intense activities. Eight physically active subjects performed six Wingate tests lasting 30s, 32s or 36s once a week. Subjects were informed they would perform four 30s trials, one 32s trial and one 36s trial. However, in reality they performed two of each. It was found that power output was significantly lower during the last 6s of the 36s deception trial in which subjects expected to just last 30s, compared to the informed trial lasting 36s. Interestingly, the subjects were not able to detect the extra 6s on the deception trial, which could be explained by a subconscious plan portioning out the energy based on previous knowledge and experience, and based on expectations of the activity. Otherwise, there should have been no difference in the last 6s between the informed and deception trial as subjects were asked to pedal as hard as they could.

Billaut et al. (2011) found that pacing occurs with repeated sprints exercises. Subjects were tested on three different occasions in a randomized manner performing ten sets of 6s maximal sprints with 24s of rest between each set. In the control trial subjects were told they would perform the ten sets before beginning the activity. In the unknown trial, the subjects were not told how many sets they would be performing but were stopped after ten sets. During the deception trial, subjects were told they would only perform 5 sets, but were asked to perform additional 5 sets once they were complete the first 5. It was shown that during the deception trial, subject's accumulated more work, generated more power, and had higher overall lower body EMG during the first five sprints relative to the other two trials. Also, during the unknown trial, subjects demonstrated a relative early decrease in work and EMG. The authors suggested that the anticipation of performing fewer sprints led the subjects to consciously or subconsciously recruit more muscles in the deception trial, which resulted in higher power and work outputs. In contrast, the unknown trial led subject to be more economical with their physiological resources as they were not sure about the amount of sets they would be performing. This resulted in decreased EMG and work performed. According to the authors, this was the first study to demonstrate that pacing occurs during repeated all-out sprints which is influenced by prior knowledge of the sprint number. The results of these studies demonstrate that despite the short duration and high intensity of the activities, which are typically associated with a predominant emphasis on peripheral fatigue (Weir et al, 2006), subjects still apply various pacing strategies in an anticipatory manner.

2.4 Pacing strategies during longer duration activities (>2 min)

Anticipatory responses to cycling exercises are also illustrated with longer duration cycling exercises. Mauger et al. (2009) randomly divided 18 competitive cyclists into two groups; constant feedback and no feedback regarding distance covered. Subjects were asked to perform 4 consecutive 4k time trials with 17 minutes of recovery between trials. The feedback group received distance feedback throughout each trial while the no feedback group, did not know the distance they were cycling. It was found that as the no feedback group gained experience performing the trial, they began to match the time to completion of the feedback group in a linear fashion despite not knowing the exact distance they cycled. Additionally, the RPE, power, and blood lactate progressively increased with consecutive trials nearly matching the control values. As more information was received throughout the trials, the pacing strategy in the no feedback group became more robust, leading to greater energy expenditure. This allowed greater RPE, blood lactate and higher EMG, which demonstrates that prior experience of an unknown distance, creates an internal, relative distance that is used to establish a pacing strategy. However, in a similar study by the same group (Willams et al, 2012) it was shown that the results from the previous study may not be relevant for untrained subjects. Twenty-two untrained subjects were assigned to an experimental and control group. Both groups performed two consecutive 4k time trials with 17 minutes of rest. The control group received distance knowledge and distance feedback where the experimental group did not. In contrast to the previous study, no significant differences in completion time were observed between the first and second trial in both groups. The results indicate that untrained individuals base their pacing strategies primarily on perception of fatigue rather than external exercise information in trained subjects.

Mauger et al. (2011) examined the affects of correct and incorrect feedback during two 4k time trials with five competitive cyclists. During the incorrect trial subjects received opposite information; when they cycled faster relative to their baseline they were told they were cycling slower and reverse feedback when they cycled slower. The aim was to confuse their past and present scheme comparisons. It was found that cycling with accurate feedback led to significantly faster times. Importantly, the subjects were unaware of the fact that they received incorrect feedback which supports the notion of a subconscious governor. The study does offer an interesting perspective to the importance of feedback and performance.

In another study by Ansley et al. (2004), 9 highly trained cyclists performed 3 consecutive 4k time trials with 17 min of rest between each trial in which other than distance covered they received no feedback regarding their cycling speeds, power output, elapsed time or heart rate. It was found that the first and last trials were completed in similar times; however, the peak power output was significantly higher during the first trial. This may indicate that subjects adopted different pacing strategies to complete the trials. Also, this finding refutes the notion of peripheral fatigue playing a significant role in fatigue as it would be expected that the last trial would be slower relative to first one as more byproducts would have accumulated in the muscles. Furthermore, if peripheral fatigue was the main cause of decreased performance then higher EMG values would be expected from the lower limb muscles. If peripheral fatigue is to be reached, one would expect that a greater number of motor units would fire in order to recruit bigger, faster, and most importantly, fresher motor units. However, this was not the case in this study as EMG remained relatively constant and never reached more than 40% of MVC values. Lastly, a pattern of power output fluctuations was found in all subjects during all trials which indicate that absolute fatigue was never reached. Again, refuting the notion that peripheral fatigue was the central cause of fatigue.

Stone et al. (2012) had 9 trained cyclists perform four 4k time trials against a computer avatar. The first trial was for habituation, the second was considered a baseline, and in the next two trials, which were randomized, the subjects were told they would be racing against an avatar representing their own baseline. However, one of the trials had the baseline avatar cycle at a power output that was 2% greater. It was found that during the deception trial, subjects completed the distance significantly faster despite not being able to detect the deception. Based on the results, two main conclusions can be drawn; first, trained cyclists operate with a metabolic reserve even during maximal time trials which supports the adoption of a pacing strategy while not reaching the maximal levels of physical exertion. Second, deception of time may have an important role in improving performance, predominantly by accessing the metabolic reserve which allows greater energy production and better results. In a similar study, Corbett et al. (2012) had fourteen active subjects' initially complete three 2k cycling time trials and then complete two more trials in a counterbalanced order. The final two trials included another time trial and cycling against a computer generated avatar. Subjects were told the avatar represented another person which they will be competing against but in actuality it was the subject's best result out of the three time trials. Performance was found to be faster during the "head-to-head" trial compared to any of the time trials. Collectively, the results of these studies demonstrate that pacing strategies take place during longer duration activities lasting ~3 minutes. Particularly, knowledge of endpoints and accurate knowledge of speed and performance positively affects performance when it comes to trained and experienced subjects. In contrast, it seems the knowledge of end point and performance may not improve the results of untrained subjects, perhaps as they lack the needed experience to pace themselves throughout different activities.

2.5 Running Pacing Strategies

Despite that the cycling ergometer is the most common testing tool in pacing studies, similar results were found when running protocols were used. Eston et al. (2012) had twelve physically active participants perform 3 different running trials: 1) 20 min of running – stop after

20 min. 2) 10 min of running but in the 10^{th} min subjects were asked to continue for another 10 min. 3) Unknown time of running in which subjects were stopped after 20 min. The treadmill speed was based on previous VO_2max test and was set at 70% of peak oxygen uptake. It was found that the rate of perceived exertion increased during the 10^{th} min in which subjects were asked to run for another 10 minutes. This happened despite no changes in heart rate and oxygen uptake. This may point to a disruption to a feed-forward/feedback mechanism in which a governor anticipates and does not react as expected to the periphery. Interestingly, during the unknown trial the heart rate was lower compared to the two other trials, which suggest that the brain was attempting to conserve energy when the duration is not known. A study by Faulkner et al. (2011) had thirteen healthy active men complete four self paced 6k treadmill time trials with either accurate, inaccurate and no distance feedback during the runs. No differences were noted between the accurate and inaccurate trials. However, during the no distance feedback, subjects ran significantly slower. Additionally, subjects demonstrated lower heart rate and oxygen consumption. Similar to other studies, it was postulated by the authors that without feedback, subjects will adopt an economical energy strategy which strengthens the importance of feedback prior and during performance. Similar to the cycling studies, subjects were affected by knowledge of endpoint and performed better when receiving accurate feedback. Additionally, it seems as if the subjective feeling of effort (RPE) could increase despite no actual changes in the physical effort when the pacing strategy is abruptly altered. These findings point to the importance of the psychological aspects of fatigue.

2.6 Pacing strategies during hyperthermic and hypoxic conditions

In addition to studies looking into pacing strategies employed during different durations and modalities, other studies have examined and characterized them in extreme environments such as hyperthermic (hot) and hypoxic (lower oxygen) conditions. Tucker et al. (2004) compared two self-paced 20k cycling time trials performed in hot (35C) and cool (15C) environments. Despite similar heart rate, RPE, and rectal temperatures under both conditions, there was an early decrease in power output and quadriceps EMG under the hot condition. Considering that the core temperature did not reach the "critical temperature" of 40C before a noticeable decrease in power output and IEMG, the authors speculate that an anticipatory response in the brain selectively recruited a limited amount of motor units (demonstrated by the lower EMG) to avoid potentially harmful temperatures. Since heat storages were not different between trials, it is suggested that the goal of the decreased power and EMG was to ensure similar heat accumulation (Tucker et al, 2004). Strengthening the brain anticipatory response theory, Tucker et al. (2006) had subjects cycle at a similar relative RPE in cool (15C), normal (25C) and hot (35C) conditions until power output decreased by 30% relative to initial value. Participants were allowed to increase and decrease power output throughout the trial provided they stayed at a subjective RPE of 16. Starting power outputs were similar between the three trials and declined in a linear fashion as a function of the completed percentage of the trials. The hot conditions resulted in significantly higher decline rate. Heat storage was similar under the three conditions other than the first 3 minutes of the hot condition in which a significant increase was recorded. EMG decreased the most under the hot condition, which happened before reaching the core critical temperature. EMG began to fall in the hot condition despite having similar rectal temperatures to the cold and normal conditions during that period of time. It was suggested that the regulation of exercise happened first in a feedback manner in which the sum of information from afferent receptors resulted in decreased power output and EMG. This feedback allowed the brain to calculate and anticipate which pace and intensity will result in a constant RPE and heat storage. This ensures protection of the thermal homeostasis by reducing heat accumulation (Tucker et al, 2006).In addition to hot temperatures; pacing strategies have been found to take place in other extreme environments such as high altitudes (hypoxic). Particularly, the "lactate paradox" is the finding that blood lactate concentrations are lower than expected while exercising in high altitudes. This is paradoxical as lactate levels are expected to be higher when oxygen levels are low (Hochachka et al, 2002). Noakes (2009b) explains the paradox in the following way: training in altitude results in decreased blood lactate levels, cardiac output, and muscle activation (measured with EMG), while the RPE increases gradually. Accordingly, Noakes infers that the brain regulates the extent of muscle recruitment to protect the brain from cerebral deoxygenation. This response can occur early into the activity, which highlights the anticipatory process in the brain considering that any peripheral changes leading to fatigue are unlikely at these stages (Noakes, 2009b). Noakes (2007b) interpreted the results from Amann et al. (2006) study to support this point of view. Subjects performed four cycling 5k time trials at four different levels of inspired O_2 fractions ranging from hypoxia to hyperoxia. They found that the participants decreased power output and activated less quadriceps muscle fibers when cycling under hypoxic conditions from the beginning of the trial, which supports the idea of an anticipatory response as peripheral fatigue is not likely at these early stages. Additionally, subjects showed an "end sprint" towards the end of the trial, which, again, demonstrates a preconceived plan (Noakes, 2007b). Taking together, the results support the notion of pacing strategies in which subjects either consciously or subconsciously decide on a pace depending of many factors which include the relative temperature and oxygen availability at a given point in time. These results demonstrate that peripheral fatigue could not be the sole reason for decreases in performance as otherwise significant decreases in speed/power output would not be noticeable from the very beginning of the activity, before peripheral changes take place.

2.7 Free vs. constant pace exercises

Despite the fact that many studies exist on the topic of pacing, it is still not clear if optimal pacing strategies are set/constant or free/self selected. Few studies to date have examined different physiological and performance related variables when comparing self paced and constant pace exercise. Lander et al. (2009) had nine well trained subjects perform three 5k rowing trials. Two of the trials were submaximal and one was a maximal test, which was added to disguise the true purpose of the study. In the first submaximal test, subjects were asked to row at a constant RPE of 15. In the second test subjects were asked to row at a constant power output which was the mean power output of the first trial. Subjects were blinded to this fact and were told the constant pace was calculated based on their maximal trial. No significant differences in performance times were found between the conditions. However, despite the similar power outputs, during the constant pace trial, core temperature, blood lactate and EMG were significantly higher. That is, despite similar performance, during the self pace trial the surrogate measurements associated with efficiently were improved relative to the externally controlled trail. In contrast, Thomas et al. (2012) had trained subject's complete three 20k cycling time trials: a self paced, even paced trial in which the mean work and time of the self paced were used, and a variable paced trial (142/72% of power calculated from the self paced trial performed in a 1:1.5 ratio). It was found that blood lactate and RPE were significantly lower in the even paced trial relative to the other two conditions. However, no differences were found between for respiratory variables. The discrepancies in results between Thomas et al. (2012) and Lander et al. (2009) may be explained by the type of activity (rowing vs. cycling) and length of activity (20k vs. 5k). Garclin et al. (2008) had ten subjects complete a run to exhaustion test at a constant speed (90% of their maximal velocity associated with their VO_2max). On the second test subjects were asked to run the same distance they were able to achieve in their first exhaustion test at a self paced speed. The results did not show any significant differences in oxygen uptake between free and constant paces runs.

One of the most common fitness tests is the VO_2 max test in which subjects are asked to run or cycle for as long as they can while the intensity gradually increases. However, if subjects do not receive any idea of an end point it might negatively affect the results. Maguer and Sculthorpe (2012) listed three significant problems with the way in which common VO_2 max tests are performed:

1- Subjects are unaware of the endpoint creating an 'open loop' form of exercise which rarely happens in sports.

2- The fixed progressive intensity of the protocols produces a form of exercise which does not replicate reality.

3- The only way to down regulate the work rate is to stop exercising.

Accordingly, in a novel study by Maguer and Sculthorpeb (2012) a new way to measure VO_2max was compared to a traditional test, which was based on the findings of the previous pacing studies. Sixteen untrained subjects performed two VO_2max tests on different days in a counterbalanced order:

1) A self paced test lasting 10 minutes in which the RPE was controlled for in such a way that subjects were asked to cycle faster and harder every 2 minutes. In contrast- external intensity such as speed and power were not controlled for.

2) The classical test was done in an incremental design in which every 2 minutes the intensity

was increased by 30 Watts until failure. Subjects achieved significantly higher VO_2 and peak power output values during the self paced test. Interestingly, the higher VO_2 values were found even when a plateau was reached in the classical test.

In contrast, Chidnok et al. (2013) examined the differences between performing a high-intensity cycling test at a constant work rate which was expected to result in exhaustion after 3 minutes and a 3 min self paced ride. It was found that exhaustion under both conditions was based on known peripheral physiological processes, which were unaffected when pacing strategies were self-selected. Exhaustion during both rides was correlated with the same peak VO_2.

No clear and decisive answers arise from these studies. The mixed findings may results from using different protocol performed at different intensities. Currently more studies are needed to pinpoint which exercise protocols would benefit from using a self selected pacing strategy and which would benefit from a constant one.

2.8 Conclusion

Collectively, the results of the studies strengthen the notion that fatigue is an output of the brain and not just an input from the periphery affecting the muscles. This was demonstrated by the repeated findings in which trained subjects improved their performance when receiving accurate feedback on either the distance traveled or speed during the physical task (Maguer et al, 2009, Billaut et al, 2011).Hence, according to previous knowledge received about the activity they were about to perform, or contentious/inaccurate information, subjects altered the speed and power output, at times without any periphery changes (Lander et al, 2009). However, it should be noted that performance of untrained subjects who may have a lack of knowledge about the activity to perform was unaffected by endpoint knowledge (Willams et al, 2012).In some studies RPE was increased when the endpoint was manipulated despite no changes in the periphery

(Lander et al, 2009). This shows that subjective sense of effort is also influenced by psychological aspects and not just based on peripheral changes. The findings of different pacing strategies during extreme environments strengthen the CGM in which down regulating the level of effort prior to any peripheral changes indicates an anticipatory response. However, it is currently not clear which pacing strategies positively affect performance in different activities, as some studies found improved performance and physiological responses with constant pacing, while others found the opposite with free pacing strategies. The practical application of these results are as follows: withholding information about endpoints in cyclical type of activities such as running and cycling will hinder performance, and therefore if optimal performance is the goal then coaches should consider proving detailed feedback during and prior to practice/race. The opposite is also true. That is, a lack of feedback or providing inaccurate feedback typically leads to suboptimal results. However, under certain situations it may still be beneficial to do so. For example, soldiers do not always know of the end point of a given mission and therefore training without one might better prepare them to deal with the metal burden.

2.9 Future Studies

Most studies to date have mostly examined cycling and running to a lesser degree, yet to the best of our knowledge, there are currently no studies looking at strength related pacing strategies. It could be of interest to study if subjects will vary their power outputs during a power movement such as a jump squat based on the knowledge of how many repetitions they are asked to perform. Knowledge of such pacing strategies may influence training methods for the power and strength athlete, and not just the endurance athlete.

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Pacing strategies during repeated maximal voluntary contractions

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Accepted with minor revisions to European Journal of Applied Physiology.

The following manuscript is the revised version.

Author Contributions

I. Halperin collected the data, analyzed the results, and wrote the manuscript.

S.J. Aboodarda assisted in collecting the data and analyzed the results.

F.A. Basset assisted in analyzing the results and with the statistical analysis.

J.M. Byrne assisted with the data collecting and analysis.

D.G. Behm assisted in planning the study, analyzing the results, and writing the manuscript.

RUNNING TITLE: MVC Pacing Strategies

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 3 fatiguing protocols in a randomized order. In the Control condition participants were informed they would perform twelve MVCs, and then completed all twelve. 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^{th} contraction they were asked to perform a few more repetitions and were stopped after twelve. **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 6 MVCs. Additionally, under all conditions subjects applied greater forces in the last repetition (#12) relative to the previous one (#11) ($p< 0.05$, 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

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 et al. 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 (Balnchfield et al. 2013; Stone et al. 2012), and knowledge of end point (Ansley et al. 2004; Billaut et al. 2011). Furthermore, the pacing strategy 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 (Chidonk et al. 2013; Ferro et al. 2001). 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 (Chidonk 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; Chidonk et al. 2013; Wittenkind et al. 2011).Wittekin et al. (2011) had subjects perform 4 all out cycling bouts lasting 5s, 15s, 30s and 45s on different days. Despite being asked to pedal as hard as they could, during the 5s and 15s trials the mean and peak power output were higher relative to the first 10s of the 45s trial. Ansley et al. (2004) had subjects perform six Wingate tests lasting 30s, 32s or 36s once a week. Participants were informed they would perform 4 trials lasting 30s, one 32s trial, and one 36s trial. However, in reality they performed 2 trials of 30s, 32s, and 36s. It was found that power output was significantly higher during the last 6s of the 36s informed trial compared to the 36s Deception trial in which subjects expected to pedal for just 30s. 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 6s of the informed and Deception trials. Interestingly, the subjects were not able to detect the extra 6s in the Deception trials. Billaut et al. (2011) tested subjects on 3 different occasions in a randomized manner. Each session consisted of performing ten sets of 6s maximal sprints with 24s 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 5 sets, but were asked to perform 5 extra sets once they completed the first 5. 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 5 sprints relative to the 2 other conditions. During the Unknown condition subjects demonstrated a relative early decrease in work and EMG. Collectively, the results of these 3 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; Wittenkind 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 2 cycling tests: a ride to exhaustion at a high intensity constant work rate which was expected to result in exhaustion in 3min, and a self-paced 3min 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, given that most studies thus far have employed cyclical exercise protocols that were longer than 30s, the goal with 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±7cm, 78±9kg) participated in this study. Subjects were healthy and performed resistance training at least twice a week for a minimum of one year prior to participation in the study. Subjects were asked to avoid a heavy meal and caffeinated drinks 3h before the test. Furthermore, they were asked to 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 (HREA) approved this study (File number 14.411).

Experimental Design

Subjects visited the laboratory on 3 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 2/2s at an intensity level equating to approximately 50% of their perceived maximum. One minute after the warm up, subjects performed 3 pre-test maximal voluntary contractions (MVC) lasting 5s 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 3 experimental conditions consisted of twelve elbow flexion MVC with a work to rest ratio of 5/10s. 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 6 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 twelve MVC and then actually performed all twelve. In the Unknown condition, they were not told how many MVCs they would perform and were stopped after twelve. For both these conditions subjects were informed immediately following the 11^{th} contraction that their 12^{th} contraction would be their last. In the Deception condition, subjects were told that 6 repetitions would be done, however after the 6^{th}contraction they were asked to perform a "few more repetitions". Although "a few more repetitions" was not defined, subjects were stopped after their 12^{th} contraction. As subjects believed the 6^{th} contraction would be their last they were informed after the 5th 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 3 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 degrees. The wrist was inserted into a padded strap attached by a high tension wire to a load cell (LCCA 500 pounds; sensitivity = 0.0017 MV/V, OEI, Canada) that was used to measure elbow flexion forces. All force data was sampled at a rate of 2000Hz using a Biopac data collection system (Biopac Systems Inc.DA 100Holliston, 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 3s window defined as 1.5s before and following the peak force of each contraction. To account for variability in force production between the 3 testing days, all mean force data was normalized to the highest mean force recorded during the 3 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 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 2000Hz (impedance = 2MΩ, common mode rejection ratio > 110 dB min (50/60 Hz),noise> 5 µV). A band pass filter (10-500Hz) was applied prior to digital conversion. Using the same 3s window as applied to the force analysis mean root mean square (RMS) EMG was used. RMS values were determined using a window width of 50ms. 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 Sphericiy was violated, the Greenhouse-Geisser correction was employed. Intraclass correlation coefficients (ICC) were measured for mean force and EMG for the 3 pre-tests of each condition to assess consistency of this data. Firstly, a two-way repeated measures ANOVA test (3 conditions x 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 x 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 means ± SD.

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 3 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 6 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 (Figure 1). 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 6 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%) (Figure 1).

EMG: No significant interactions were found for normalized biceps brachii EMG during the first 6 (*p*= 0.735) or last 6 (*p*= 0.523) MVCs. However, a main effect of conditions was found for the first 6 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 6 contractions (*p*= 0.07). Although not statistically significant, EMG amplitude in the Deception condition was numerically higher (moderate magnitude effect sizes) than the Unknown (ES=0.45, 4.5%) and Control (ES=0.5, 5.4%) conditions (Figure 2). Also, a main effect for repetitions was found for the first 6 MVCs (*p*=0.011) and last 6 MVCs (*p*=0.008). There were no significant differences in normalized triceps brachii EMG during the first and last 6 contractions.

DISCUSSION

The main finding of the present study was that subjects employed different pacing strategies in each of the 3 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 reserved 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 6 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 Wittekin et al. (2011) who reported higher mean and peak power output during sprints lasting 5s and 15s, compared to the first 10s of a 45s sprint. As previously described, Ansely et al. (2004) found higher power output during the final 6s of the accurate 36s trial compared to the 36s 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 6 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 6 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 6th 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; Netroud 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 5s 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 minute which involuntary 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 seventeen minutes. 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 4 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 traveled distance, 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 underperform. 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 6 contractions (Figure 2). Despite the limitation of surface EMG such as crosstalk (Frina et al. 2004) and amplitude cancelation (Keenan et al. 2005), it is still considered to be associated with neural drive (Gibson and Noakes 2005; Frina 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 6 MVCs. Although not statistically significant, EMG had moderately higher magnitudes in the Deception condition (Figure 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; Hickes 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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ABBREVIATIONS

ANOVA Analysis of variance

EMG Electromyography

ES Effect size

MVC Maximal voluntary contraction

SD Standard deviation

Figures

1

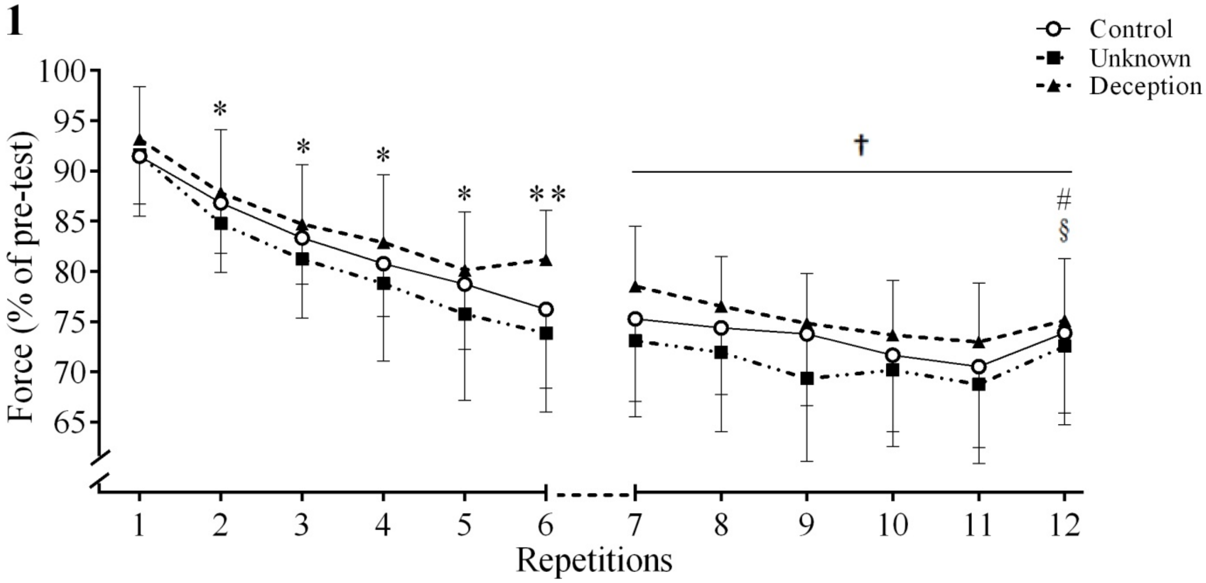

FIGURE 1: Mean force profile over the 12 MVCs for the 3 trials. Data is presented in percentage relative to the highest value of the pre-test. * indicate that force was significantly higher ($p \leq 0.05$) in the Deception condition relative to Unknown condition. ** illustrates that force was significantly higher in Deception condition relative to both Unknown and Control conditions.† represents a main effect of conditions with forces higher in the Deception condition compared to the Control and Unknown conditions (p=0.024). # 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.

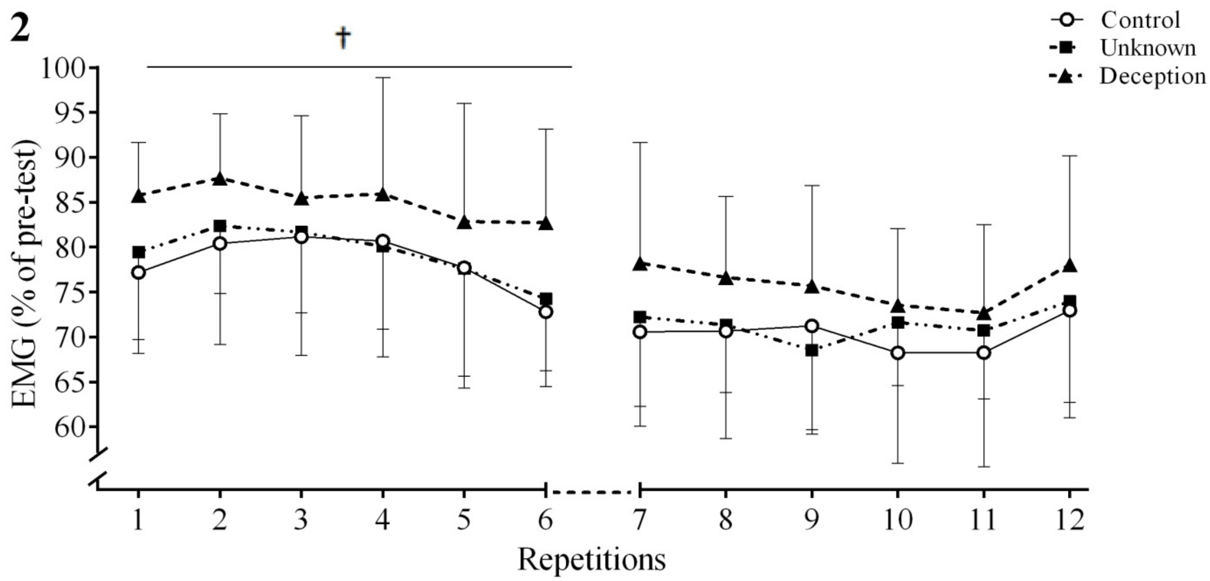

FIGURE 2 –EMG amplitude profile of biceps brachii over the 12 MVCs for each of the 3 conditions. Data is presented in percentage relative to the highest activation recorded during the pre-test for each condition. † represents a main effect of condition with the Deception condition being higher than the Unknown and Control condition (p= 0.024). Means and standard deviations (vertical bars) are illustrated.

Tables

Table 1

Average ± SD absolute values of the 3 pre-tests. Force is presented in units of Newton (N) and EMG in units of millivolts (mV).

	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