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Effects of wearing a jaw-repositioning Intra-oral Device in synchronized swimming athletes

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ABSTRACT

Background/Aims: The effects of wearing an intra-oral device on several ventilatory and fatigue markers have been reported for a variety of sports. The quality of the figures performed in synchronized swimming is directly affected by fatigue and can be monitored during training sessions (TS). The aim of the study was to investigate the acute effects of wearing customized intra-oral devices on heart rate variability, rating of perceived exertion, blood lactate accumulation, and salivary cortisol production during a competitive training session.

Methods: Twelve highly trained elite female athletes (age: 21.0 ± 3.6 years, height: 1.69 ± 0.57 m, weight: 54.0 ± 6.0 kg) took part in the study. Swimmers' baseline HRV was monitored 3 times·week^{-1} across one week for consistency and were taken 30-min before the training session (TS). Fatigue markers [SC, BLa_{peak}, HRV during recovery (HRV_{Rec}), and RPE] were assessed at the beginning (SC) and at the end of the 3rd and 5th afternoon TS of that week (all the markers), once with a customized mouthpiece (M) and other without mouthpiece (NM), in random order. Student's paired *t* test was used for comparing the difference between conditions on paired mean values for SC, BLa_{peak} and RPE and a mixed model for repeated measures ANOVA for HRV.

Results: Salivary cortisol levels were higher in relation to the baseline in the intra-oral device condition ($P < 0.05$) but not in athletes without an intra-oral device. No differences between conditions were found in rating of perceived exertion ($P = 0.465$) and blood lactate ($P = 0.711$). No time or condition interactions or main effects were shown for heart rate variability.

Conclusions: There is no evidence that wearing a low-arch intra-oral device is a good recommendation for high-standard athletes performing long and stressful routines.

KEYWORDS:

mouthguard

ergogenic effects

sport performance

synchronized swimming

training load.

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1- INTRODUCTION

Beyond the preventive role of intra-oral devices, recent research has investigated their physiological effects and potential benefits in various parameters such as salivary cortisol (SC), blood lactate (BL) accumulation, and ventilatory function [1–5]. Certain evidence shows that jaw clenching, biting or the use of intra-oral devices affect lactate production and cortisol release in humans [1, 2, 6]. The study of such fatigue markers can provide valuable information about the possible benefits of wearing an intra-oral device in a sport characterized by long training sessions and stress-inducing technical routines. To the best of our knowledge, there is no research related to the effects of wearing intra-oral devices in synchronized swimming (SS). Synchronized swimming is an Olympic sport that requires not only a high level of technical and artistic skill but also aerobic and anaerobic fitness, strength, power and endurance [7]. The routines are characterized primarily by long underwater episodes that activate complex adjustment mechanisms for respiratory compensation in apnea situations while the limbs are moving to control body posture or to produce the maximal body emersion at maximal power [8].

Regarding physiological responses to SS, most studies have focused on heart rate or heart rate variability (HRV), VO2peak, and BL accumulation following the performance of a single figure or a routine program [7, 9–12]. Other research has focused on analyzing the relationships between SC, rating of perceived exertion (RPE), and training intensity in synchronized swimmers during pool-session training [13, 14]. In this vein, it is well-known that cardiac and metabolic output in SS athletes are highly affected by dynamic apnea, which not only can change the oxygen uptake but can also reduce sympathetic tone during intense exercise and induce a psychological stress factor to exercise [10, 15–17]. Dynamic apnea is developed when SS athletes dive their faces underwater, an action that comprises more than half of the total time for a routine. Apnea in SS is achieved by closing the mouth and blocking nasal air entry using diving nose clips [18]. Thus, the aquatic environment where the SS athlete is training, the need for apnea together with efficient ventilation, and the metabolic consequences of fatigue during technical routines can be affected by the use of an intra-oral device. There are several connections between the response of the autonomous nervous system and the stress variables. Some investigations have connected different acute fatigue markers with HRV [19–21]. Furthermore, Ishida et al. [22] studied the effects of wearing a mouthguard on the autonomic nervous system and found significant effects on pupillary flash response but not on HRV. The experiment involved simply wearing an unpleasant mouthguard without doing any other activity. In fact, comfortability is also connected to autonomic nervous system response [23], and this phenomenon could interfere with the relationship of wearing an intra-oral device and HRV changes.

In recent years, the literature has focused on studying the acute effects of wearing intra-oral appliances on performance in various sports. Although airflow resistance is increased by wearing mouth- guards [24] and peak expiratory flow is reduced [25], no negative effects were found in heart rate increments, RPE, minute ventilation, or VO2max in a maximal cycle ergometer test in physically active women [26], and using a mouthguard did not represent a significant interference in normal breathing [24]. In SS, the maximal oxygen intake manoeuvers are just after the apnea periods. Thus, wearing intra-oral devices could influence breathing conditions in this crucial phase during routines. Furthermore, jaw-clenching could decrease cortisol release in humans in a psychologically stressful situation. During a 20-min mental stress activity, subjects displayed a decreased cortisol response

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when they could clench their teeth or bite down on paraffin wax, thereby using the masticatory muscles [6]. It has been suggested that the activity of these muscles activates the motor area of the cerebellum, decreasing the hypothalamic-pituitary response and its cortisol release [6, 27]. Furthermore, the use of a mouthpiece during intensive training had similar SC levels in both mouthpiece and no-mouthpiece conditions in collegiate football players. However, 10 minutes post-exercise, the mouthpiece condition displayed baseline levels of cortisol, while without the mouthpiece, cortisol levels were found to increase [1]. Other authors observed that wearing a custom-made mouthpiece reduced blood lactate levels after performing the Win- gate anaerobic test [5]. Additionally, in the same study, researchers found similar mean airflow values at maximal intensities when comparing the values of forced expiration with and without a mouthpiece. In contrast, no significant differences were observed when comparing the effects of two different mouthguards on BL in a Wingate Test [4].

To the best of our knowledge, there are no studies about the effects of wearing customized intra-oral devices on HRV, RPE, BL ac- cumulation, and SC production during competitive training in elite SS. Thus, the aim of this study was to investigate the acute effects of wearing an intra-oral device on the mentioned variables after competitive technical team TSs in elite SS. It was hypothesized that, for the same training load, the athletes would demonstrate lower BL accumulation, lower SC levels, lower RPE, and higher HRV when using the intra-oral device.

2- MATERIALS AND METHODS

Participants

Twelve highly trained, elite female athletes, comprising the Senior Spanish Synchronized Swimming Team, participated in the study one month before the important international championship (mean ± SD age: 21.0 ± 3.6 years; height: 169.0 ± 5.7 cm; body mass: 54.0 ± 6.0 kg; BMI: 19.3 ± 1.0 kg/m2). All subjects were asked to refrain from participating in any activity that would negatively impact the outcome of the assessments and were free of temporomandibular joint disorders. Subjects were also asked not to drink alcohol or use any other type of drug or stimulant before testing and to refrain from abnormal eating or sleeping habits. Ethical approval was obtained from the Research Ethics Committee of Ramon Llull University (Barcelona, Spain), and the study was conducted in accordance with ethical standards in sports and exercise science research [28]. Swimmers were provided with oral and written in- formation about the study procedures before giving their informed consent, with parental permission for athletes under 18 years of age.

Protocol

The study was conducted over the course of one week during the competitive phase of training and one month before the FINA World Championships, the most important competition of the sea- son, suggesting that they were close to or at peak performance. Swimmers' baseline HRVs were monitored 3 times · per week-1 across the week for consistency [29] and during the same menstrual phase to avoid hormone disturbances [30]. Baseline HRV measurements were interspersed by 48h and taken 30 min before the TS. The

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averaged HRV during that week was considered the basal HRV value (Rest), assessed in the supine position for 10 min. Fatigue markers [SC, La, HRV during recovery (HRVRec) and RPE] were assessed on the 3rd and 5th afternoon TS of that week, once with an intra-oral device (I-OD) and once without an intra-oral device (NI- OD), in random order. All exercises and routines were performed in SS habitual training facilities at a 50-m indoor pool (water temperature: 25–26 °C).

All intra-oral devices were provided and fitted by CleverBite (CleverBite SL, Terrassa, Spain). The device fabrication was performed by an expert dentist on a digital model made of Pearlstone VisiJet Plastic Material (Urethane Acrylate and Phenylbis [2, 4, 6-trimethylbenzoyl] phosphine oxide) obtained using the technique of scanning the dentoalveolar maxillary and mandibular environment using the 3Shape Trios System (3Shape, Inc., Copenhagen, Den- mark). This method simplifies manufacturing and reduces the appliance final cost. No familiarization session was paired with the intra-oral device prior to the testing session. Devices were designed to promote a stabilization of the mandibular arch in a long centric position. The athletes performed different sets of head movements in order to neutralize any postural neuromuscular disorder that might influence the position of the mandible with respect to cranial and cervical muscle activation. The intra-oral devices were built with minimal dentoalveolar discrepancy regarding the morphology of the mouth structure of each subject. The scanning system provided precise models that were made specifically for the lower mandibular arch to avoid swimmers exhibiting it when smiling during competition (Fig. 1). A shortened version (5 of 11 questions) of the Athletic Mouthguard Attitude Questionnaire (AMAQ) [31] was administered to the subjects.

*** Fig. 1 approx here***

The training session comprised a standardized warm-up, followed by a 4-h specific training that ended with execution of the technical team routine (TT) simulating the competitive performance. Baseline salivary cortisol was taken at 4:00 pm, which was 30 min before the TS, and the basal HRV (Pre) assessment was per- formed. Then, the specific 4-h training, ending with the TT execution, started, during which heart rate (HR) was continuously monitored. After that, capillary blood lactate samples were taken from the swimmers' earlobes at 2-, 4-, and 8-minute time points post-TS. Then, swimmers were asked to walk to a quiet room next to the pool where mats and blankets were prepared so that their salivary cortisol samples could be collected between 8:00 and 8:30 pm, which was 15 min after the TT completion (stimulated SC), and HRVRec assessments were repeated during recovery from minute 20 to minute 35. The participants were asked about their RPE when completing the recovery assessments (~35 min post TT). The TS is summarized in Fig. 2

*** Fig. 2 approx here***

HRV was assessed in the supine position and measured using waterproof Suunto Memory Belt HR monitors (Suunto Oy, Vantaa, Finland), which record HR beat by beat. These devices were placed on each swimmer's chest 15 min before the testing session and re- moved when the HRV assessment during recovery was completed. HRV was assessed from R-R intervals and transferred to the Suunto Movescount App (Suunto Oy, version 2.4.5), which interpolated the data every 2 s and reported the square root mean of the sum of the squared differences between adjacent normal R-R intervals (RMSSD). Kubios software (version 2.0) was used for HRV analysis, and the natural logarithm of the RMSSD (LnRMSSD) was calculated. The recovery period lasted 35 min. LnRMSSD was assessed during the last 20 min of the recovery period, with the first 5 min excluded from the analysis due to the mechanism of modulation of the autonomic transition from sympathetic to parasympathetic activation [32]. The HRV measurements were averaged every 5 min: Rec20–25, Rec25–30, and Rec30–35 in the recovery phase.

Capillary blood samples were obtained from the earlobe using a portable device (Lactate Pro LT-1710, Arkray, Kyoto, Japan). Sam- pling took place at 2, 4, and 8 min following the execution of the TT, with and without mouthpieces. The highest value of blood lactate concentration (BL, mmol·L-1) was considered for statistical analysis.

The effects of wearing a mouthpiece on endocrine responses to training were measured by salivary cortisol (SC, nmol·L-1). Two saliva samples (4 mL) were collected using Salivettes (Sarstedt Ltd Nümbrecht, Germany). For SC sampling, all swimmers were in- structed to avoid the use of dental floss or toothpaste and to not to eat a large meal (60 min) or use alcohol or caffeine (24 h) before testing. Basal and stimulated cortisol were considered for statistical analysis. Samples were centrifuged at 3000 rpm for 10 min and stored at −20 °C until analyzed. SC levels were determined using an automated electrochemiluminescence immunoassay (Modular E, Roche Diagnostics GmbH Mannheim, Germany); the analytical sensitivity of the assay was 0.054 µg/dL and the inter-assay CV was 4.5 %.

The Borg CR-10 scale was selected to rate the perceived intensity of exertion [33]. Swimmers were shown a colored, verbally anchored scale 35 min after the end of each tested training session. All athletes were given instructions regarding the scale interpretation and were assessed repeatedly during at least three training sessions to disclose learning effects and to improve the consistency of the measurements [34].

The testing protocol is summarized in Fig. 2. All ballets were performed in a high-performance synchronized-swimming pool, at a water temperature of 25–26 °C. Prior to the training session, baseline salivary cortisol samples were taken. All synchronized swimmers performed a standardized warm-up regimen that included a 15-min crawl swim combining apneas and sprints, 30 min of individual technical figures, and 15 min of small sections of the technical routine by couples. The training core included a total of 60 min of 15–20 sec of technical routine parts, with a resting time of 5–8 minutes between each part.

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Statistical analysis

Descriptive statistics were expressed as mean ± SD. To satisfy the normality assumptions, LnRMSSD was calculated. Departure from normality was assessed via Shapiro-Wilk test. Student's paired t test was used for comparing the difference between conditions on paired mean values of SC, RPE and BL. Comparison between the two different conditions for the heart rate variability variable (Ln- RMSSD) was conducted using a mixed model for repeated measures ANOVA before the TS (Pre) and during the three periods of the recovery phase (Rec20–25, Rec25–30, and Rec30–35). The statistical significance level was fixed at $P < 0.05$. Data were analyzed using the SPSS 22.0 (Armonk, NY: IBM Corp) statistical software package.

3- RESULTS

Subjects scored (1 to 5) 9.5 ± 1.3 points in the AMAQ (on a 1–5 Likert-type negative scale). The SC, RPE and BL scores (means ± SD) are shown in Table 1. Stimulated cortisol levels were higher in relation to the baseline in the I-OD condition ($p < 0.05$). No differences were found between basal and stimulated cortisol levels in the NI-OD condition ($p > 0.05$). No differences between conditions were found in RPE ($P = 0.465$) and BL ($P = 0.711$) (Fig. 3).

Table 1 approx here

*** Fig. 3 approx here***

Mean contrasts for LnRMSSD of HRV were tested using a mixed model of repeated measures ANOVA. A within-subject TIME factor was compared (Pre, Rec20–25, Rec25–30, and Rec30–35) × two between-subject conditions (I-OD and NI-OD). Pre- and recovery values for LnRMSSD are presented in Fig. 4. No time × condition interactions or main effects were shown for this variable.

*** Fig. 4 approx here***

4- DISCUSSION

The results in the present study showed that the acute effects of wearing custom-made intra-oral devices in SS during a high-intensity TS increased salivary cortisol levels but did not significantly affect either BL or RPE and LnRMSSD. Previous studies with SS athletes before the Olympic games found baseline cortisol levels of 15.2 ± 3.8 and 18.6 ± 4.5 nmol·L-1 after the training session without intra-oral device. Nevertheless, all the measurements were developed from 8:00 to 11:00 am [13], while the athletes of the present study were assessed in the evening (from 4:00 to 9:30 pm), when the cortisol levels are lower. There

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was a significant difference be- tween basal and stimulated cortisol with the use of an intra-oral device after completing 4 hours of intensified training. There are several explanations for these increased values. Cortisol has catabolic functions that have greater effects in fast-twitch muscle fibers, which have an intermittent participation when swimmers per- form powerful technical figures emerging from the water across the TS [14]. Furthermore, during the breathing phases, the SS athletes are required to smile, and the breathing mechanisms might be affected by the use of an intra-oral device partially obstructing the inhalation. Additionally, the athletes reported discomfort wearing the devices [31], although the intra-oral devices were built considering the 'long centric' position as an optimal mandibular position for dynamic movements [35]. Indeed, the mentioned mandible position contributes to the occlusal stability of the anterior part of dentition, and all the customized intra-oral devices should be designed regarding the 'long centric' occlusal position, especially for the athletes that are moving all the time, the head is continuously in motion and the mandible is twisting in lateral and anteroposterior planes [36]. Furthermore, the affection to breathing mechanisms, together with long periods of apnea during the TS with a new and uncomfortable device in the mouth, could cause an additional stress factor in the I-OD condition. Moreover, although it has been reported that an increased ability to clench jaw muscles leads to decreasing mandibular stress through the motor area of the brain, thus decreasing the hypothalamic-pituitary response and, thereby, resulting in a reduction in cortisol release, the presence of the stress factor of holding the breath appears to interfere with this mechanism [1, 37].

The present study found no significant differences in BL between conditions, in contrast with previous studies that found significantly lower BL accumulations for subjects wearing an intra-oral device and indicated that its use might create an advantage for sports where fatigue and lactate accumulations influence athletic performance [2, 5, 38]. Furthermore, the aforementioned studies reported performance testing comparisons (between mouthguard and no-mouthguard conditions), and the present study evaluated an entire training session. Similar BL peak values (5.91 ± 2.03 mmol·L-1) than Bante et al. [7] (5.7 mmol·L-1) were found in the athletes studied without intra-oral device after technical routine. However, higher values (8.5 ± 1.6 and 7.52 ± 1.6 mmol·L-1) were found during a Japanese Championships [12] or those obtained in inter-regional and national synchronized competitions over the season after a team routine [9]. These differences might be caused by the maxi- mal intensity and short duration of the exercise in a competition, in contrast with the intermittent intensity and longer duration of the training session analyzed in the present study. Moreover, it could be speculated that the intermittent breath pattern of these swimmers would lead to progressive lactate accumulation during TS and the routine equally in both conditions. The increased O2 sup- ply, due to the combination of intense exercise and apneic bouts, leads to prolongation of oxidative metabolism in parallel with anaerobic glycolysis [39], and the possible beneficial effects of wearing the intra-oral device might be attenuated. The present results are in line with those reported by Rodriguez-Zamora et al. [10], who suggested that, in SS during apneic work, part of the lactate produced in the working muscles is rapidly catabolized by the less-active muscles and other tissues or used during recovery to resynthesize glycogen. Moreover, wearing an intra-oral device did not cause any effects during the TS because the swimmers opened their mouths to breathe, and therefore, there was no jaw-clenching that could promote ergogenic effects [40] and, thus, a reduction in lactate levels during the I-OD condition. Additionally, there were no effects of wearing the intra-oral device, probably because SS athletes were not familiarized with the device and were not confident about clenching their jaws underwater.

Although differences between basal and stimulated SC were significantly higher in the I-OD condition, no significant differences were found in RPE with or without the intra-oral device. The duration of the TS and the exhaustive character of the effort in this sport did not contribute to showing differences between perceived exertion for either condition. In fact, the RPE was not affected by the use of intra-oral devices in other studies of this sport [5, 26, 38], which also was probably because the devices used in the present study did not affect ventilatory flows [5].

The impact of wearing an intra-oral device during the training session on HRV was not significant in regard to the NI-OD condition. A possible important factor that may have influenced the un- changed LnRMSSD was the effect of the training practice: a lower HR during recovery is a specific adaptation in trained SS athletes [15]. The increased LnRMSSD at low HR is linked to the fact that vagal-related HRV indices more strongly reflect the magnitude of modulation in parasympathetic outflow rather than an overall parasympathetic tone per se. Therefore, it appears that the decreased HRVRec of our swimmers might explain the similar LnRMSSD values obtained across the entire recovery period in both conditions and the lack of significant differences.

The main strengths of the present study are the inclusion of elite SS athletes in a study about the acute effects of wearing customized repositioning intra-oral devices in a sport like SS, where the functionality of the mouth enabling proper ventilation and proper clenching in the different apneic and surface phases is crucial. Although no significant effects were found in the major part of the variables studied, this investigation constitutes a first step in studying the ergogenic effects of wearing a repositioning intra-oral device in highly trained women and in a sport like SS. Furthermore, research on this topic focused on the effects of wearing repositioning intra-oral devices or mouthguards on performance tests instead of on fatigue indicators after an entire training session. Regarding the comfort level reported by the athletes, the lack of a familiarization process before the study might be a limitation for observing the effects of wearing the device. Although it is very difficult to observe, the use of jaw-clenching during apnea is unknown in the present study. Thus, one does not know the particular use of the intra- oral device made by the athletes during the session. Future studies are needed to investigate the effects of wearing different types of repositioning intra-oral devices in different sports and competitive standards. Moreover, its effects on isolated actions (height of water emersion, height on assisted jumps, or the technical execution of powerful figures) during the SS routines, as demonstrated by different studies using intra-oral devices and jaw-clenching, should be considered. In addition, longitudinal studies of longer duration wearing intra-oral devices to check the long-term effects should be conducted.

5- CONCLUSIONS

The use of custom-made intra-oral devices in swimmers' sets of lower teeth increased SC levels in elite SS athletes. No significant changes were found for BL and RPE between conditions or for in LnRMSSD of HRV. The use of a customized repositioning intra-oral device does not affect the above-mentioned physiological markers in a highly demanding training session because of the competitive standard and the physiological adaptations exhibited by the athletes. The performance was not enhanced, and an indicator of stress, for instance, salivary cortisol, showed increases when the athletes wore a repositioning intra-oral device. Nevertheless, perceived exertion and HRV were similar in the I-OD and NI-OD conditions.

Thus, the intra-oral device used in the present study (lower arch) is uncomfortable and had no beneficial effects considering the studied variables. Although SC levels indicate that the use of intra-oral device might constitute a stressor, the fact that the use of the devices had no detrimental effects on Lactate and RPE does not allow us to say that its use should be avoided only based on the results of this study. Thus, further studies are needed to affirm that the use of intra-oral devices should be avoided by SS athletes.

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FIGURES

Figure captions

Figure 1. Lower arc intra-oral device used in the present study.

Figure 2. Flowchart of the study

Figure 3. Mean of the increment of salivary cortisol, blood lactate and rating of perceived exertion between the two conditions (NI-OD and I-OD)

** Expresses significant differences between basal and stimulated salivary cortisol p < 0.05.*

Figure 4. Mean LnRMSSD between the two conditions (NI-OD and I-OD) before and at different moments after the training session.

Figure 1.

Figure 2.

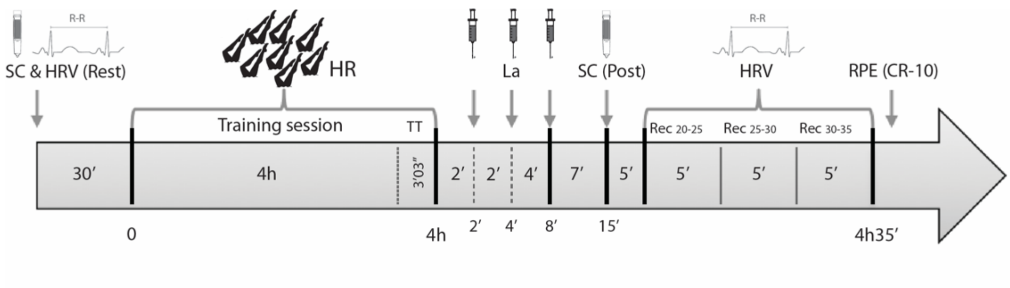

Figure 3.

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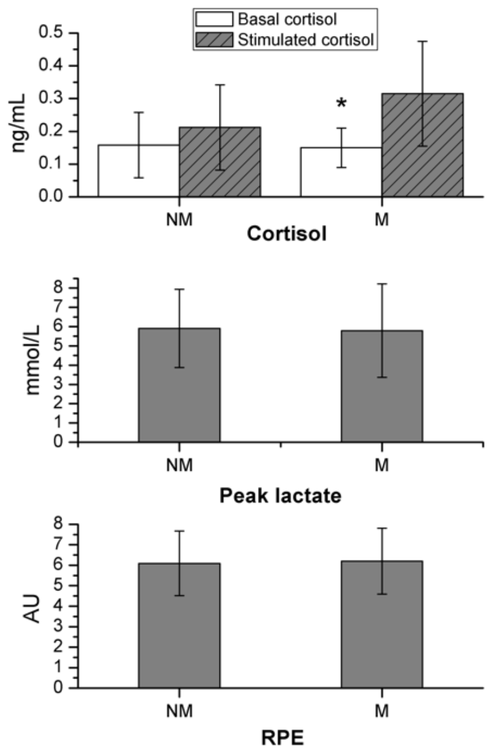

Figure 4.