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The Effect of Wearing Mouthguards on VO2, Ventilation, and Perceived Exertion at Two Different Exercise Intensities

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THE EFFECT OF WEARING MOUTHGUARDS ON VO_2,

VENTILATION, AND PERCEIVED EXERTION AT

TWO DIFFERENT EXERCISE INTENSITIES

by

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GRADUATE COMMITTEE APPROVAL

of a thesis submitted by

Jeffrey S. Hurst

This thesis has been read by each of the following graduate committee and by majority vote has been found to be satisfactory.

Date	J. Brent Feland, Chair
Date	Pat Vehrs
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BRIGHAM YOUNG UNIVERSITY

As chair of the candidate's graduate committee, I have read the thesis of Jeffrey S. Hurst in its final form and have found that (1) its format, citations, and bibliographical style are consistent and acceptable and fulfill university and department style requirements; (2) its illustrative materials including figures, tables, and charts are in place; and (3) the final manuscript is satisfactory to the graduate committee and is ready for submission to the university library.

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ABSTRACT

THE EFFECT OF WEARING MOUTHGUARDS ON VO_2, VENTILATION AND PERCEIVED EXERTION AT TWO DIFFERENT EXERCISE INTENSITIES

Objective: To assess the effects of wearing a protective mouthguard during exercise on ventilation and oxygen consumption.

Design and Setting: All participants performed a graded maximal exercise test on a cycle ergometer to determine peak oxygen consumption (VO_2peak). Each participant also performed 6 submaximal exercise tests while wearing one of two facemasks (nasal or non-nasal breathing) and one of three mouthguard conditions (no mouthguard, boil and bite, custom-fit). Steady-state VO_2, rate of perceived exertion (RPE), and other ventilatory values were measured at 60% and 80% of VO_2max during each submaximal exercise test. All 6 submaximal exercise tests were completed within a 2-week period using a randomized 6x6 balanced Latin square design.

Subjects: Twenty-four subjects (age = 20.41 ± 1.99) who were members of the Brigham Young University lacrosse team participated in this study.

Measurements: Data were analyzed using a random coefficients growth curve. The full models for all variables included fixed effects for mask, work level, mouthguard, time, and all interactions of the above. Full models were also assumed to have random subject coefficients for the intercepts and slopes relative to time.

Results: For VO_2 there was a significant effect for facemask type ($p<.0001$, $F = 24.30$, $df = 1680$), mouthguard ($p = .0177$, $F = 4.04$, $df = 1680$), and work ($p<.0001$, $F = 5428.16$, $df = 1680$). For VO_2 there was also a significant interaction for mask*work ($p = .0280$, $F = 4.84$, $df = 1680$). For RPE there was a significant effect for facemask type ($p = .0005$, $F = 12.28$, $df = 1657$) and for work ($p<.0001$, $F = 4040.53$, $df = 1657$). For RPE there were also significant interactions for mask*mouthguard ($p<.0001$, $F = 11.82$, $df = 1657$) and for mask*work ($p<.0001$, $F = 18.88$, $df = 1657$). For VE there were significant interactions for mask ($p < 0.0001$, $F = 16.49$, $df = 1680$), mouthguard ($p < 0.0001$, $F = 19.98$, $df = 1680$), and work ($p < 0.0001$, $F = 9122.33$, $df = 1680$). For VE there were also significant interactions for mask*mouthguard ($p < 0.002$, $F = 6.25$, $df = 1680$), and mask*work ($p < 0.0001$, $F = 17.77$, $df = 1680$).

Conclusions: Although statistical significance was found for a number of effects, we speculate that the very small differences in the physiological responses to wearing a mouthguard are of little practical significance and would not effect performance. Wearing a mouthguard during exercise does not alter physiological responses and complaints of reduced ventilation are probably psychological.

Keywords: Protective equipment, VO_2, breathing.

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Conclusions: Although statistical significance was found for a number of effects, we speculate that the very small differences in the physiological responses to wearing a mouthguard are of little practical significance and would not effect performance. Wearing a mouthguard during exercise does not alter physiological responses and complaints of reduced ventilation are probably psychological.

Keywords: Protective equipment, VO_2, breathing.

Introduction

Inherent risk accompanies participation in sports. Contact sports present an increase in the probability that a serious injury could occur. The use of protective equipment in sports, especially in contact sports, has dramatically increased over the last 30 years.[1] Rule changes, which require the use of adequate protection, have reinforced attempts to make athletics safer for the participant. One piece of equipment designed to protect athletes is the mouthguard. Historically, mouthguards were first used in boxing. Boxers in England began developing techniques for protecting their mouths in the early 1900s.[2] During the 1960s, football became the focus for much of the research done in this area. Today, it is common to see protective mouthguards used in lacrosse, soccer, baseball, softball, basketball, and many other sports where there is a possibility of injury to the mouth, teeth, or head.

Most injuries to the head and/or face occur by one of two mechanisms[2]: (1) a direct anterior impact (as in a straight punch), which can cause fractured, avulsed, damaged, or loose teeth, as well as lacerations to the lip and the gum surfaces; (2) impact to the mandible from below (as in an uppercut or kick), that can cause the teeth to be forced together, which could also damage teeth, fracture the mandible, or cause a concussion. Both mechanisms can cause injury to the brain through impact forces. Concussion, cerebral bleeding, or even death can result from impact depending on the force generated, and the transmission of that force to the head.[2] Wearing a protective mouthguard will decrease the forces transmitted to the teeth and surrounding tissue, and decrease the transmission of force to the brain.[3-6]

Use of mouthguards, often results in complaints of discomfort, inability to communicate, and difficulty breathing.[2-6] Some say mouthguards are a psychological disadvantage.[1,7,8] Studies have shown that if mouthguard use during practices and games begins at an early age, it is more likely that the common complaints of discomfort, difficulty breathing, and difficulty communicating are greatly reduced.[2,6,8]

If breathing is more difficult when using a mouthguard, then there may be an obstruction of airflow due to the mouthguard. While at rest, breathing is primarily accomplished through the nose. However, when a person begins to exercise, the breathing pattern changes and breathing occurs through both the nose and the mouth. The majority of inspired air enters the lungs via the oral route during exercise.[9] Unfortunately, there has been relatively little research looking at respiration and airflow dynamics while wearing a mouthguard during exercise. A mouthguard could present increased resistance to airflow during respiration.

Amis et al.[10] reported that, “While airflow resistance of the nasal airway (RN) is restricted to a relatively narrow range of values, oral resistance (RO) has the potential to vary from infinity (mouth closed) to something approaching zero (mouth widely open).”[10] This means that jaw position, widely open or nearly closed, has the potential to effect airflow. The degree that the oral route is obstructed may be a factor in ventilatory changes during exercise.

Only two published studies pertaining to airflow dynamics while wearing a mouthguard were found in the literature.[1, 9] Francis et al.[1] reported that the wearing of the different mouthguards did not significantly change VO_2 while exercising at low work loads, whereas VO_2 was significantly ($p < 0.05$) reduced at heavier workloads.[1] In a second study by Amis et al.[9] airflow dynamics, inspiratory volume and expiratory volume, were found to be decreased by mouthguard use. However, the subjects were not exercising during the testing. Both authors suggest that more research is needed to better understand mouthguards and how they affect ventilation.

Based on the limited findings of Amis et al.[9] and Francis and Brahser[1], changes in airflow dynamics when wearing a mouthguard can be expected. However, the effect of mouthguard use on ventilation and other physiological responses during exercise is still unclear. Knowledge of the effect of wearing a mouthguard on breathing dynamics, (i.e. respiratory rate, gas volumes, etc.), could help determine if the complaints of mouthguards affecting breathing are valid. If there is no effect, then these complaints are based solely on the perception that breathing is affected, and are purely psychological. Therefore, the purpose of this study is to explore the impact that wearing a mouthguard during activity could have on ventilation and perceived exertion.

Methods

Participants

Twenty-four college age males (mean = 20.41 ± 1.99) from the Brigham Young University men's lacrosse team participated in this study. This study was approved by the Brigham Young University Institutional Review Board for Human Participants prior to the collection of data. All participants were informed of the risks associated with participating in this study and gave informed consent prior to participation. Based on self-reported information gathered from a Pre-Exercise Test Screening Questionnaire, participants' risk for cardiovascular, metabolic, or pulmonary events during exercise was classified according to the American College of Sports Medicine three tier risk stratification. Only participants classified as "low risk" and were free of ankle, knee, or hip injury and pain were accepted for participation in this study.

Research Design

All participants performed a maximal graded exercise test (GXT) on a Lode cycle ergometer (Lode Medical Technology, Netherlands) to determine peak oxygen consumption (VO_2peak). Participants also performed six submaximal exercise tests using one of two facemask conditions and one of three mouthguard conditions. All testing was performed in the Human Performance Research Center at Brigham Young University. The maximal GXT was performed one week prior to performing the six submaximal exercise tests. The submaximal exercise tests were performed on an every-other-day basis over a two-week period.

Maximal Graded Exercise Testing

Participants were instructed to abstain from vigorous exercise for 12 hours prior to testing; abstain from diuretic agents, including caffeine; and abstain from eating for at least 4 hours prior to testing. Participants were fitted with a mouthpiece and a nose clip to facilitate the measurement of ventilation, expired gases, and oxygen consumption (VO_2) using Parvo-Medics TrueMax 2400 metabolic cart (Consentius Technologies, Sandy, UT). Prior to testing, the oxygen and carbon dioxide analyzers were also calibrated using medical grade gases of known concentrations. The flow meter of the metabolic cart was also calibrated prior to each test using a 3.0 L syringe. Heart rate was continually monitored using a radiotelemetry heart rate monitor (Polar, Inc.). Rating of perceived exertion (RPE) was monitored using the Borg 15 point scale.

The GXT was performed on an electromagnetically braked cycle ergometer (Lode Medical Products, The Netherlands) using a standard protocol used in our labs designed to elicit a VO_2peak within 15 minutes. Subjects pedaled at 50 W for 60 seconds. Workload was then increased to 75 W for 90 seconds and then to 100 W for 90 seconds. The workload then progressively increased in 20 W increments every minute until the participant voluntarily terminated the exercise test due to fatigue, despite verbal encouragement. Participants were allowed to pedal at a self-selected cadence, but were encouraged to maintain minimal cadences of 60-70 rpm. Immediately following volitional termination of the test, participants performed an active cool down period at 50 W. The test was considered a valid maximal exercise test if at least three of the following four requirements were met:

1. Maximal respiratory exchange ratio (RER) $\geq$ 1.1,
2. Maximal HR no more than 15 bpm below age predicted (220-age) HR max,
3. Leveling off of VO_2 despite an increase in workload,
4. RPE or physical signs suggesting exhaustion.

VO_2 was defined as the highest VO_2 value recorded over any 30-second time period during the test, provided RER was greater than or equal to 1.1. Maximum HR was defined as the highest HR value recorded over any 30-second period same-day test.

Submaximal Exercise Tests

Six submaximal exercise tests were performed with the six treatment conditions described above. The intensities for the six submaximal exercise tests were based on percentages of individual VO_2peak values determined from the maximal GXT. Each submaximal exercise test began with a 5-minute warm-up period. Following the warm-up period, workload was gradually increased over a 2-minute period to a work load which elicited VO_2 values equivalent of 60% of VO_2peak. After cycling at 60% of VO_2peak for 3 minutes, participants were allowed to cool down at 50 W for 2 minutes. The workload was again gradually increased over a 3-minute period to a workload which elicited VO_2 values equivlanet to 80% of VO_2peak. Participants cycled at 80% of VO_2peak for 3 minutes and were then allowed to cool down while pedaling at 50 W. Steady state values of VO_2, V_E, tidal volume (VT), breathing frequency (BF), respiratory exchange ratio (RER), rate of perceived exertion (RPE), and HR were measured every 10 seconds during the final minute while cycling at 60% and 80% of VO_2peak.

Facemasks

There were two different facemasks (Hans Rudolf Inc., Kansas City, MO) used for testing in this study. Facemask 1 was an adult size Hans Rudolf rubber facemask with a partition between the nose and the mouth, allowing for oral breathing only. Facemask 2 was an adult size Hans Rudolf rubber facemask with no partition between the nose and mouth, allowing for oral and nasal breathing to occur. Both facemasks used adjustable straps to assure an airtight seal around the face. The masks and valve attachments were sterilized after each use by soaking in MadaCide-FD germicidal solution (Mada Medical Products, Inc., Mada Equipment Co., Carlstadt, NJ) for 10-15 minutes. After soaking, the masks and valve attachments were thoroughly rinsed with water and dried before the next use.

Mouthguards

Three different mouthguard conditions were tested in this study. Mouthguard A was a "boil and bite" or stock mouthguard (Mueller Strapguard SG-50, Mueller Sports Medicine, Inc., One Quench Drive, Prairie du Sac, WI) that can be purchased at almost any sporting-goods store. Each participant heated the mouthguard and formed it in their mouth. To minimize problems with fit, participants formed the mouthguard in the lab under the supervision of the investigator. The strap was trimmed off at the anterior portion of the mouthguard to facilitate wearing the facemask that was used during testing. Mouthguard B was a custom fit, single laminant ethyl-vinyl acetate (EVA) mouthguard (Proform, Dental Resources, Delano, MN) fabricated using a stone model made from an impression of the subjects upper teeth. The models of the teeth were poured from an impression taken using dental alginate (Patterson, Algitec, St. Paul, MN), common in any dental laboratory. The EVA material, prior to deformation, was 4 mm thick, which is standard for most custom fitted mouthguards. The material was heated and then vacuum-formed over the stone model of the subject's upper teeth. Once formed, the mouthguard was separated and trimmed to the appropriate size and the mouthguard was placed in the subject's mouth to assure a comfortable and correct fit. Any rough edges were buffed to maximize comfort. The lead investigator fabricated all the custom-fit mouthguards. The third condition (Mouthguard C) was the control condition or no mouthguard. Each participant drew a number in order to determine their sequence of treatment conditions for each of the six submaximal exercise tests. The six treatment conditions that were randomized in a 6x6 balanced Latin square design were:

1. Mouthguard C/Facemask 1
2. Mouthguard A/Facemask 1
3. Mouthguard B/Facemask 1
4. Mouthguard C/Facemask 2
5. Mouthguard A/Facemask 2
6. Mouthguard B/Facemask 2

Statistical Analysis

Data were analyzed using a random coefficients growth curve model (SAS 9.0) for VO_{2}, V_E, and RPE. The full models for all variables included fixed effects for mask, work level, mouthguard, time, and all interactions of the above. Full models were also assumed to have random subject coefficients for the intercepts and slopes relative to time. For the three variables there were no significant interactions involving time, so the final models included fixed effects for mask, work level, and mouthguard, and interactions involving these terms, and only a main effect for time. For VO_{2}, the random coefficients for subjects involving slopes with respect to time were found to be non-significant. So, the final model for VO_2 included only a random effect for intercepts. The final model for RPE and V_E had significant random coefficients for both intercepts and slopes.

Results

For VO_2 there were significant main effects for facemask type ($p < 0.0001$, $F = 24.30$, $df = 1680$), mouthguard ($p = .0177$, $F = 4.04$, $df = 1680$), and work ($p < 0.0001$, $F = 5428.16$, $df = 1680$) and a significant interaction for mask*work ($p = .0280$, $F = 4.84$, $df = 1680$). For RPE there was a significant effect for facemask type ($p = .0005$, $F = 12.28$, $df = 1657$) and for work ($p < 0.0001$, $F = 4040.53$, $df = 1657$). For RPE there were also significant interactions for mask*mouthguard ($p<.0001$, $F = 11.82$, $df = 1657$) and for mask*work ($p<.0001$, $F = 18.88$, $df = 1657$). There were significant interactions for fixed effects of VO_2 in mask x work and mask x mouthguard. There were significant interaction for fixed effects of RPE in mask x mouthguard x work, mask x work, and mask x mouthguard. There were significant interactions for fixed effects of V_E in mask x work and mask x mouthguard. Although we found statistically significant interactions for these fixed effects, we do not feel that these interactions are practically significant. We focused on the main effects due to the fact that our measurements were taken every 10 seconds during a 1-minute period. Theses values are highly correlated, and therefore are well explained by the growth curve analysis.

Discussion

Results indicate a number of statistically significant fixed effects for VO_2, V_E, and RPE. Although the main effects for mouthguard were of statistical significance, we speculate that the results may not have practical implication. Due to the number of subjects, independent and dependent variables in the study, and number of tests performed, statistical power was large, thereby decreasing the magnitude of differences that were significant. The least square means (LS) were used to evaluate the clinical significance of the differences in responses to wearing the two mouthguards. For example, a significant ($p = .0177$) effect of mouthguard was found for VO_2. However, in observing the LS means of VO_2 differences between mouthguards for both the open and closed facemasks, and for each workload level, it is our opinion that the differences ranging from 0.02 L/min to 0.08 L/min are not clinically significant (Table 1). This small difference is not sufficient to be considered a relevant ventilatory change that could effect performance in sports, in which mouthguards are worn. Similar results were found across all dependent variables that were measured in this study. However, we have chosen to report the results of VO_2, V_E, and RPE as the primary indicators of the effects of wearing mouthguards.

Despite the statistical significance in relatively infinitesimal differences reported in this study (Table 1) the results strongly suggest that there is no negative effect on ventilation when using a mouthguard. Our results (Table 1) do concur with the findings of Amis et al.[9,10] and Francis and Brasher.[1] A study by Amis et al.[9] evaluated two different custom-fitted mouthguards to determine if they elicited a change in respiration. The subjects were seated and were tested in both a fixed jaw position and a non-fixed jaw position. Amis et al.[9] reported a significant decrease in airflow dynamics when the subjects were tested in the fixed-jaw position. In the non-fixed jaw position, there was variation from subject to subject in airflow dynamics, and only one of the mouthguards showed statistical significance. Thus, based on the Amis et al. findings,[9] there is a change in airflow dynamics when wearing a mouthguard under non-active breathing conditions.

During exercise, breathing changes from a strictly nasal route to an oro-nasal route.[10] Amis et al.[10] reported that approximately 80% of the breathing at rest occurs via the nasal route. O'Kroy et al.[11] reported that 80% of the breathing during exercise occurs via the oro-nasal route. The effect of mouthguard use on ventilation during exercise is not very clear. Francis and Brasher[1] exercised subjects at moderate and high intensities on a cycle ergometer. Subjects exercised with and without a mouthguard for 5 minutes at each workload while wearing a Hans Rudolf rubberized facemask that covered both the nose and mouth. It was unclear as to whether the facemask was partitioned to allow only oral breathing. Our study used facemasks allowing oral-only and oro-nasal breathing. We used these two types in hopes that facemask 1 (oral-only breathing) would be more sensitive to ventilatory changes caused by the mouthguard. The participants in our study exercised at intensities equivalent to 60% and 80% of VO_2peak (Table 1) and therefore worked at intensities well above those used by Francis.[1] Francis[1] reported decreases in forced expiratory volume (FEV) and peak expiratory flow (PEF). Compared to not wearing a mouthguard, VO_2 was unchanged at moderate exercise intensity and lower at high intensity workload.[1] Francis et al. attributed this unexpected decrease in VO_2 to "pursed lip breathing" as occurs with cardiopulmonary obstructive disease (COPD) patients.[1] COPD patients will often use pursed lip breathing to increase the time of inspiration and expiration, thus maximizing oxygen uptake. Our data show no such decrease in VO_2 at moderate or high intensity work (Table 1).

One of the purposes of our study was to determine whether or not complaints of difficulty breathing had a physiological basis. Participants reported RPE values at each intensity during the six submaximal exercise tests. We speculated that complaints of difficulty breathing or increased perceptions of physiologic exertion would be reflected by higher RPE values. Mean RPE mean values at 60% and 80% VO_2peak when wearing each facemask and mouthguard are shown in Table 1. Although the differences were statistically significant (p = .0021) for the mask*mouthguard*work interaction, they are not clinically relevant since the differences were less than one (one is the smallest unit of measurement on the Borg scale).

Based on the literature, athletes complain of discomfort, inability to communicate, and difficulty breathing when wearing a mouthguard.[2-6] The use of mouthguards may also be a psychological disadvantage.[1,7,8] In 1963, the National Federation of State High School Athletics Association mandated mouthguard use for all football players in organized games. In 1974, the National Collegiate Athletic Association implemented the same regulation[1,12] and dental injuries decreased dramatically.[1] Parents lacking the proper education concerning the use of mouthguards are often unaware of the protective benefit of wearing mouthguards.[3,4] Coaches are also frequently uninformed or unwilling to advise their athletes about proper mouthguard use.[3] These factors could greatly influence the decision to use, or not use, a mouthguard from a very early age. Studies have shown that if mouthguard use during practices and games begins at an early age, it is more likely that the common complaints of discomfort, difficulty breathing, and difficulty communicating are greatly reduced.[2,6,8]

Our experience has been similar to others who have compliance issues with mouthguards. The subjects in our study were members of a collegiate-level lacrosse team. All subjects were accustomed to wearing mouthguards during practices and games, and were therefore comfortable using the mouthguard during the submaximal exercise tests. However, a few subjects stated that if given a choice, they would choose to not use a mouthguard. We believed that the volume of the mouthguard may have caused this preference. However, the mouthguard volumes were essentially the same. The boil and bite mouthguard had a volume of 12 mL. The custom fit mouthguard had an average volume of 10 mL.

In addition to complaints of difficulty breathing and communicating, some athletes suggest that wearing a mouthguard doesn’t look good or that there is a psychological disadvantage to wearing a mouthguard. The fact that the participants in our study were well trained and accustomed to wearing mouthguards may have been a limitation. Whether or not highly trained subjects, who are accustomed to wearing a mouthguard, exhibit different ventilatory responses than subjects who are less trained or unaccustomed to wearing a mouthguard is unknown and may warrant further research. In addition, future research could look at a 100% effort during a sprint to determine if any changes in airflow occur at this intensity.

Conclusions

We found no difference between the boil and bite mouthguard and the custom-fit mouthguard in regards to ventilation. We feel that with regard to ventilation, there is no difference between the OTC boil and bite and the custom-fit mouthguard. We conclude that wearing a mouthguard does not change ventilation. Wearing a mouthguard does not inhibit or impede normal breathing during moderate to high intensity activity with well conditioned athletes. Based on our findings we support the use of mouthguards in conjunction with other mandatory protective equipment to diminish the likelihood of injury. Complaints of difficulty breathing appear to be psychological as suggested by previous research.

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Table 1 Least Squares Means

	Facemask 1 (closed)		Facemask 2 (open)	
	60%	80%	60%	80%
RPE				
mouthguard A	13.38	16.32	12.66	16.55
mouthguard B	13.09	16.20	13.06	16.53
no mouthguard	13.38	16.60	12.88	16.17
VO_2 (L/min)				
mouthguard A	2.51	3.42	2.45	3.30
mouthguard B	2.51	3.45	2.48	3.37
no mouthguard	2.49	3.38	2.48	3.32
V_E (L/min)				
mouthguard A	46.72	74.54	45.59	70.67
mouthguard B	47.52	76.36	47.69	74.53
no mouthguard	46.13	74.08	47.21	72.75

Appendix A

Prospectus

Chapter 1

Introduction

Inherent risk accompanies participation in sports. Contact sports present an increase in the probability that a serious injury could occur. The use of protective equipment in sports, especially in contact sports, has dramatically increased over the last 30 years.[1] Rule changes, which require the use of adequate protection, have reinforced attempts to make athletics safer for the participant. One piece of equipment designed to protect athletes is the mouthguard. Mouthguard use has become increasingly popular in a wide range of sporting events. Historically, mouthguards were first used in boxing. Boxers in England began developing techniques for protecting their mouths in the early 1900s.[2] During the 1960s, football became the focus for much of the research done in this area. Today, it is not uncommon to see protective mouthguards used in soccer, baseball, softball, basketball, and many other sports where there is a possibility of injury to the mouth, teeth, or head.

Most injuries to the head and/or face occur by one of two mechanisms[2]: (1) a direct anterior impact (as in a straight punch), which can cause fractured, avulsed, damaged, or loose teeth, as well as lacerations to the lip and the gum surfaces; (2) impact to the mandible from below (as in an uppercut or kick), that can cause the teeth to be forced together, which could also damage teeth, fracture the mandible, or cause a concussion. Both mechanisms can cause injury to the brain through impact forces. Concussion, cerebral bleeding, or even death could result from impact depending on the force generated and the transmission of that force to the head.[2] Wearing a protective mouthguard will decrease the forces transmitted to the teeth and surrounding tissue, as well as decrease the transmission of force to the brain. [3-6]

Mouthguards, however, do present certain complications. There are often complaints of discomfort, inability to communicate, and difficulty breathing. [2-6] Some say mouthguards are a psychological disadvantage.[1,7,8] In 1963, the National Federation of State High School Athletics Association mandated mouthguard use for all football players in organized games. In 1974, the National Collegiate Athletic Association followed by implementing the same regulation[1,9] and dental injuries decreased dramatically.[1]

An important factor in this study will be resistance to airflow provided by the mouthguard that will be placed in the route of oral airflow. Amis[10] looked at oral and nasal airflow resistance to measure the amount of inspired and expired gas. He states, "While airflow resistance of the nasal airway (RN) is restricted to a relatively narrow range of values, oral resistance (RO) has the potential to vary from infinity (mouth closed) to something approaching zero (mouth widely open)." [10] The degree that the oral route is obstructed may be a factor in ventilatory changes during exercise.

Officials have the option to penalize a team if even one player on the football field is not wearing a mouthguard, but this rule is almost never enforced. Parents lacking the proper education concerning protective mouthguards are often unaware of the benefit that wearing a mouthguard could be to their child. [3,4] Coaches, also, are frequently uninformed or unwilling to advise their athletes about proper mouthguard use.[3] These factors could greatly influence the decision to use, or not use, a mouthguard from a very early age. Studies have shown that if mouthguard use during practices and games begins at an early age, it is more likely that the common complaints of discomfort, difficulty breathing, and difficulty communicating are greatly reduced. [2,6,8]

While at rest, breathing is primarily accomplished through the nose. However, when a person begins to exercise, the breathing pattern changes and breathing occurs through both the nose and the mouth.[11] The majority of inspired air enters the lungs via the oral route during exercise.[11] Unfortunately, there has been relatively little research looking at respiration and airflow dynamics while wearing a mouthguard during exercise. A mouthguard could present increased resistance to airflow during respiration.

A study by Amis[11] looked at two different custom-fitted mouthguards to determine if they elicited a change in respiration. The subjects were seated and were tested in both a fixed jaw position and a non-fixed jaw position. Amis reported a significant decrease in airflow dynamics when the subjects were tested in the jaw controlled position. In the non-fixed jaw position, there was variation from subject to subject in airflow dynamics, and only one of the mouthguards showed statistical significance.

Thus, based on the Amis' findings,[11] there is some change in airflow dynamics when wearing a mouthguard. However, the effect of mouthguard use during activity on airflow and respiratory physiological response is not understood.

Research Question

Does wearing a mouthguard during moderate intensity aerobic exercise influence normal respiratory functions, which could lead to decreased performance and decreased physiological response?

Null Hypotheses

The following null hypotheses will be tested:

1) There will be no difference in breathing frequency (B_f) at 50% or 80% of age predicted max heart rate (HRmax) between mouthguards A, B, and the control.

2) There will be no difference in VO_2 at 50% or 80% of age predicted HRmax between mouthguards A, B, and the control.

3) There will be no difference in VCO_2 at 50% or 80% of age predicted HRmax between mouthguards A, B, and the control.

4) There will be no difference in rate of perceived exertion (RPE) at 50% or 80% of age predicted HRmax between mouthguards A, B, and the control.

5) There will be no difference in heart rate at 50% or 80% of age predicted HRmax between mouthguards A, B, and the control.

6) There will be no difference in tidal volume (V_t) at 50% or 80% of age predicted HRmax between mouthguards A, B, and the control.

7) There will be no difference in respiratory exchange ration (RER) at 50% or 80% of age predicted HRmax between mouthguards A, B, and the control.

Definitions

Moderate exercise - will be defined as exercise performed at a percentage of the subjects' age predicted maximum heart rate. Previous studies have defined moderate as 60-75%.[1] This study will test at 50% and 80% of the subjects age predicted HR max.

Breathing frequency - the number of breaths a person takes in a one minute interval.

Physiological response - in this study will be defined as measures of the following: VO_2, VCO_2, RPE, heart rate, RER, V_T (tidal volume)

Rate of perceived exertion (RPE) - the rate of perceived exertion that the subject will determine from a standard RPE scale.

VO_2 - the volume of oxygen consumed.

VCO_2 - the volume of CO2 produced

RER - the respiratory exchange ratio calculated as VCO_2/VO_2

Age predicted maximal heart rate (HRmax) – predicted maximal HR based on age. Calculated as 220-age.

Mouthguard A - a pre-fabricated boil-and-bite mouthguard that can be purchased at most sporting goods stores.

Mouthguard B - a custom fit vacuum formed single laminate (EVA) mouthguard made from an impression of the subjects upper teeth.

Control - for this study will be a test in which no mouthguard is worn during the testing protocol.

Facemask 1 – a facemask with a closed nasal passage that allows for only oral breathing.

Facemask 2 – a facemask with an open nasal passage that allows for both oral and nasal breathing.

Assumptions

This study will be based on the following assumptions:

1. Age predicted HR max will be sufficient to determine the exercise level during the testing protocol;
2. Moderate intensity exercise is sufficient to elicit changes in respiration and physiological response;
3. Changes will not be the result of familiarization to the testing procedure; and
4. Results of this study can be generalized to other populations who wear mouthguards.

Delimitations

This study will be delimited to:

1. Sub-maximal VO_2 testing on all subjects;
2. A college-age population comprised of males;

3. The custom fitted mouthguards will be fit and fabricated by the same person;
4. All subjects will be tested by the same person, with the same parameters of age predicted HR max, and the same exercise parameters; and
5. Subjects will be taken from a population that is accustomed to wearing mouthguards regularly, the men’s LaCrosse team at BYU.

Significance of this study

Mouthguards have been proven effective in reducing the number of orofacial injuries as well as the frequency and severity of concussions. However, if they are not being used due to changes in ventilation experienced by the athlete, they are not effective as a protective device. In our experience, athletes commonly complain of difficulty breathing when wearing a mouthguard. This study will shed new light on the issue of respiratory influence of the mouthguard during activity. This study may show that there is no change in respiration or in physiological response during activity, when wearing a mouthguard. If there is no change in respiratory response, this information will be vital to athletes. They can be assured that wearing a mouthguard will not be detrimental to their performance. If there is a change in respiratory function due only to the mouthguard, it could lead to more research in the area of mouthguard fabrication and design.

Chapter 2

Literature Review

Literature Searched

Databases, years, and keywords searched are summarized below:

Database	Years Searched	Keyword(s) in Search
PubMed	1975-Present	Mouthguards
PubMed	1940-Present	Athletic Mouthguards
PubMed	1975-Present	Protective Mouthguards
Medline	1975-Present	EVA, materials
Medline	1960-Present	Respiration, exercise
Medline	1975-Present	Ventilation, exercise
Medline	1975-Present	Face mask, mouthpiece
EBSCO	1975-Present	VO_2, exercise, facemask
Ref. Chasing	-----------------	----------------------------------

Mouthguards

The development of effective mouthguards has advanced due to research and the availability of better materials. There has been a dramatic decrease in the number of orofacial injuries, [1] as well as reported reduction in the number of concussions due to mouthguard use.[8,12] Francis[1] states that, "when football players wear mouth protectors, the incidence of dental trauma can be reduced to 0.6 per 100 players."

Despite the fact that wearing a mouthguard could decrease the likelihood of injury, many athletes do not wear them. In our experience, even in football, at both the high school and college levels, where rules are in place to ensure their use [1,9] mouthguards often are overlooked. The official rule states[9]:

> Article 4: All players shall wear the following mandatory equipment which shall be professionally manufactured and not altered to decrease protection:
>
> d. An intraoral mouthpiece of any readily visible color (not white or transparent) with FDA approved base materials (FDCS) that covers all upper teeth. It is recommended that the mouthpiece be properly fitted.
>
> Note: If a player is not wearing the mandatory equipment in compliance in all respects with Rule 1-4-4 the team shall be charged a timeout and the player shall not be permitted to play until he complies. Each of the first 3 infractions for failure to wear mandatory equipment requires a charged timeout. The fourth infraction in a half requires a 5-yard penalty.[9]

Mouthguards vary primarily in shape, size, and density of materials. There are currently three classifications for available mouthguards.[12] A "stock" or "ready made" mouthguard can be found in many sporting good stores. It fits directly over the teeth, but does not conform to the teeth in any way. It is held in place by the force of the top and bottom teeth as the mouth is closed tightly. A "mouth-formed" mouthguard does conform to the shape of the teeth. The "boil and bite" mouthguard is an example of this type. The material is heated and then pressed over the upper teeth and held in place until the material has cooled. This type is also very common, cost effective, and can be purchased in most sporting-goods stores. A “custom-fitted” mouthguard, is vacuum formed over an impression taken of the upper teeth. It is generally a much tighter fit, and is reportedly more comfortable to wear.[7,8,12]

There are a number of materials used to fabricate custom-fitted mouthguards. They are generally made from natural or synthetic polymers that can be classified as thermoplastic or thermosetting.[12] One of the most commonly used material is the ethyl-vinyl acetate (EVA) copolymer.[12] Other common polymers include poly (ethyl-vinyl acetate) copolymer (EVA), poly vinyl chloride (PVC), natural rubber, and polyurethane.[12] It is imperative that mouthguards be properly tested to ensure optimal performance for the user. Normal testing procedures for the materials used include measurements of compressive stress resistance, tensile strength, tear strength, elongation tests, and elasticity. Also, hardness of material, rebound, penetration, and dynamic resistance are all related to the amount of protection provided by the mouthguard.[12] The most important properties in the material used to fabricate a mouthguard are those which provide the greatest degree of protection and durability during normal use.[12]

There have been numerous studies looking at other properties of mouthguards. They have been tested for appropriate and optimal thickness of material,[4,13] strength of material during impact,[4,5,12,14] force studies on teeth with and without mouthguards[8] and reducing concussions with mouthguard use.[7,8] This research is vital to improving mouthguards and protection in athletic participation.

There are a number of ways to test mouthguards for impact resistance. Based on the numerous studies that have been performed to measure impact forces, the pendulum impact machine seems to be the most widely used.[4,5,13-16] When this type of testing is employed, the mouthguard is generally impacted with a pendulum of known mass and acceleration. From a simple equation, f = ma, the force transmitted to the mouthguard can be equated. In some studies, teeth are placed in a resin to simulate impact as it would happen under normal circumstances.[4] The model teeth are attached to a strain gauge and a voltmeter is then used to amplify the signal of the impact forces.

Materials

The material from which a protective mouthguard is fabricated is vital to its performance. The optimal mouthguard would be one that resists dimensional deformation, absorbs and disperses forces in impact, and is comfortable to wear for the athlete. Some research has been done to improve the materials and to make mouthguards better protective devices.

In a study performed by the UCLA School of Dentistry,[12] a comparison was made between three materials used in the fabrication of protective mouthguards. "The mouthguards were constructed from the following materials: (1) poly (ethyl-vinyl acetate) copolymer clear thermoplastic (EVA); (2) polyurethane; and (3) laminated thermoplastic."[12] The mouthguards were fitted to 40 members of the UCLA football team (1978) and eleven measurements were taken from each to show dimensional changes that occurred with normal use. The athletes were given one mouthguard to use for the first half of the season, and a different mouthguard to use during the second half of the season. Measurements were taken to see if there were significant dimensional changes, focusing specifically on the material in direct contact with the incisors, canines, and first molars.[12] When the two mouthguards were compared, there were no significant differences between the different types. However, it was found that the laminate material had the least deformation and was found to be significantly better than the polyurethane material.

Although there were no force measurements taken directly on the incisors, canines, or first molars, [12] it can be reasoned that because of the small amount of deformation in the material and the absorption capacity of the material, the forces would have been transmitted to the material, relieving stress on the teeth. In addition, the space between the mandibular condyles and the mandibular fossa could be better maintained. When the space between the mandibular condyles and the mandibular fossa is increased, as it is when wearing a mouthguard, impact force is transmitted toward the articulation and not transferred to the brain or the deep craniofacial structures.[12]

Material is probably the most crucial element affecting the shock absorption capabilities of the mouthguard. The EVA mouthguard is the most widely used in sports. [2,3,6-8] It has been proven effective in reducing injury to the orofacial complex. [2,6,8] There have been several studies investigating optimal thickness of the material, [3,4,16] the effect of an insert in the EVA material to decrease the force on teeth,[5] and modifications to the polymer itself to increase effectiveness.[13,15]

The thickness of the material in the prefabrication state, as well as in the finished product, is important. When making a custom-fitted mouthguard, it is possible to vary the thickness from mouthguard to mouthguard using the same thickness starting sheet. Normal EVA sheets are between 3 mm and 5 mm prior to any heating or deformation over the stone teeth model.[16] However, the thickness of the starting material and the thickness of the finished product will not be the same. In one study Westerman et al.[16] compared mouthguard thickness from 1 mm to 6 mm. They measured maximum transmitted forces in relation to a fixed impact force at each of these thicknesses. They impacted the mouthguards using a pendulum impact machine with the same force (4.4 J and a velocity of 3 m/s).[16] The striker plate on the pendulum was fitted with an accelerometer and had a diameter of 20 mm. The force of the impact was determined using the equation f = ma, where (f)= force, (m) = mass, and (a) = acceleration.[15] The accelerometer was mounted on the reverse side of the pendulum head, and was aligned in the direction of impact. In this study, the acceleration of the pendulum was constant, and therefore, the force of impact was directly related to the acceleration.[15] Each mouthguard was impacted 8 times and a mean score was recorded.[16] For some reason, the impact force from the 1 mm thickness was not measured. The 2mm thickness had the highest mean maximum impact force. The 6 mm thickness had the lowest mean maximum impact force. When the different thicknesses were compared to each other, they found significant differences were reported at the 4 mm thickness, but not between 4 mm, 5 mm, and 6 mm.[16] This suggests that a 4mm thickness provides adequate protection to the teeth and orofacial structures.

Availability of more comfortable and less bulky mouthguards could increase the use of mouthguards throughout practice and game activity. Westerman et al. performed two separate studies[13,15] that investigated the effects of altering the EVA material was in a 4mm thickness mouthguard. In the first study,[13] closed cell foam was added to the EVA material to a matrix of “gas cells in an indiscriminate manner within the polymer.”[13] The addition of the closed cell foam decreased the weight of the material as well as the bulk of material. Thus, decreasing cost and improving performance of the mouthguard. After impact testing was completed, the mouthguards were sectioned and inspected under an electron microscope to examine the deformation in the closed cell foam to determine the change in the material.

When compared to regular EVA material, the closed cell foam EVA did not appear to absorb the force more effectively. This is most likely due to the manner in which the foam itself is structured. “The cells are ‘indiscriminate’ or random throughout the material. The cells are not homogenous in nature, and it would appear that this decreases the ability of the material to absorb and decrease the force to the teeth and surrounding structures.”[13] If the material consisted of a more consistent set of cells, the ability of the material to decrease force on the teeth would more than likely be improved.[17] Westerman et al. proved this to be true in their second study.[15]

In Westerman’s second study,[15] the EVA material was altered to have air inclusions in the mouthguard material. The author compared this to bubble wrap that is commonly used in packing fragile items that need to be protected during shipping.[15] The air inclusions were of equal size and shape. The material had, “air cells with dimensions of 2 x 2 x 2 mm with 1 mm thick separating walls.” A second sample was tested with the same air inclusion layout, but dimensions of 2 x 2 x 2 mm with 2 mm thick separating walls. A third sample, with dimensions 3 x 3 x 2 mm and 2 mm thick separating walls, was also tested.

The mouthguards were fabricated using this modified EVA material and then impact tested to determine the forces that would be transmitted to the teeth. Measurements of impact force, time to peak force, and rebound force were taken. Sample group 3 responded most favorably to the impact testing. The time to peak force was increased, the overall impact force transmitted to the teeth was decreased, and there was no reported rebound force as the material regained its original shape. The impact was effectively absorbed by the air inclusions and dispersed to the material rather than to the teeth and other tissues in the mouth. The author makes the following statement, "The impact characteristics of ethyl-vinyl acetate EVA mouthguard material, commonly used in sporting mouthguards, can be improved by the inclusion of air cells. Regulated air inclusions with relatively large volumes and controlled cell wall thickness improve the performance of 4 mm thick material and reduce the transmitted forces by 32%."[15] By improving the ability of the mouthguard material to absorb force, the effectiveness of the mouthguard is greatly improved. Innovations in mouthguard materials have made mouthguards more comfortable to wear and have made them better able to protect the orofacial structures and to prevent head injury, specifically concussions.

Respiratory Response to Exercise

Brooks defined breathing as the movement of air into and out of the pulmonary system. Breathing and ventilation can be used synonymously to describe the manner that O_2 and CO_2 are exchanged in the lungs.[18] During the eighteenth century Lavoisier and others of his time believed that “biological oxidation occurred in the lungs.”[18] At this time, ventilation and breathing became known as respiration. Brooks states,[18] “Today, by convention in the study of physiology, the three terms ventilation, breathing, and respiration are used synonymously. Properly speaking, however, ventilation is the breathing of air into and out of the pulmonary system (nose, mouth, trachea, lungs), whereas respiration is the cellular utilization of O_2.”

Ventilation at rest occurs primarily via the nasal route.[10,19] As a person begins to exercise, greater demands for oxygen are placed on the body, and breathing changes from a strictly nasal route to an oro-nasal route.[10] Most studies measure this change using minute ventilation, or pulmonary minute ventilation (V). Studies[10,12,19,20] have shown that the change from nasal to oro-nasal breathing occurs between 30-40 L/min. Amis[10] states that approximately 80% of the breathing at rest occurs via the nasal route. O’Kroy[20] states that 80% of the breathing during exercise occurs via the oro-nasal route.

Brooks states that, “Submaximal exercise tests attempt to predict functional capacity from the heart rate response during a submaximal bout of exercise.”[18] In this study, we will not specifically look at VO2max. Francis[1] used a similar method in his study. Subjects were exercised for a continuous 20 minute period at two exercise intensities (10 minutes each) based on a percentage of minute ventilation. Intensities of 60% and 80% of 30-40 L/min were used for the moderate and high intensities respectively.[1] Subjects were exercised using a cycle ergometer, and moderate and high intensity were represented by 80 and 100 Watts for the women and 100 and 120 Watts for the men. Subjects were exercised with, and without a mouthguard for 5 minutes each.

Measurements were taken during the last minute of exercise in each of the conditions.[1] The test was performed wearing a Hans Rudolf rubberized facemask that covered both the nose and mouth. It was unclear as to whether the nose was partitioned to allow only oral ventilation.

Francis[1] reported decreases in forced expiratory volume (FEV) and peak expiratory flow (PEF). VO_2 was reported to decrease at the moderate exercise intensity. These findings are in accordance with what should logically occur given the increased resistance to oral air flow. [1] However, at the high exercise intensity, VO_2 actually increased when wearing the mouthguard. Francis et al. attributed this to “pursed lip breathing” as occurs with cardiopulmonary obstructive disease (COPD) patients.[1] COPD patients will often use pursed lip breathing to increase the time of inspiration and expiration thus maximizing oxygen uptake. Francis et al. explained this unconventional increase in VO_2 to a pursed lip breathing phenomenon.

Normally, during exercise testing, a mouthpiece and nose-clip apparatus are used to determine expired gas volumes. It is standard convention to use this type of set-up for most exercise tests. The mouthpiece is held in place with a “bite-block” [21] similar to the end of a snorkel. A nose-clip is place over the nostrils to insure that only the oral airway is used during ventilation. During the test, the subject must keep a tight lip seal on the mouthpiece. In most instances, despite some difficulty swallowing and communicating[21] this procedure is accepted and widely used.

In certain cases, it is necessary to use a facemask rather than the standard mouthpiece and nose-clip. Baran performed a validation study[21] of one such facemask using congestive heart failure (CHF) patients. Due to the nature of their cardiac condition, these subjects are often hesitant to use the standard mouthpiece/nose-clip combination.[21] Patients often complained of feelings of breathlessness, and fatigue due to exertion which lead to further discomfort during the test.[21] Subjects are less likely to give a true maximal effort if they are uncomfortable during the test. Hans Rudolf designed a series of “half-facemasks” that can be used to collect gas exchange measurements. In his study, Baran[21] compared VO_2peak tests using the conventional mouthpiece/nose-clip combination and a Hans Rudolf half-facemask. He reported no significant differences between the two devices.

Other studies have compared the facemask and the mouthpiece, using a population that had no previous incidence of cardiac disease, to validate the facemask for use. Baran[21] sites Johnson, Dooley, and Jette that performed these tests on healthy populations and found similar results. The facemask showed no significant differences in VO_2 values when compared with the standard mouthpiece/nose-clip combination. In this study, we will use two facemasks during the testing protocol. Facemask 1 will have a closed nasal partition to allow only oral ventilation. Facemask 2 will not be closed and will allow for both oral and nasal breathing.

Chapter 3

Methods

Research Design

Subjects

Twenty-four college age males between the ages of 18-24 from the Brigham Young University Men's LaCrosse team will participate in this study. This is a population of convenience and subjects have been chosen due to the fact that they are accustomed to wearing mouthguards during activity. Those who meet the criteria will then be informed of the risks associated with participation in this study. Approval from the Institutional Review Board will be obtained prior to the collection of any data for this study. The subjects will be asked to sign an informed consent prior to participation. They will also be required to complete a questionnaire which includes the Par-Q in order to assess their risk level in participating. Any subjects that do not meet the Par-Q requirements will be excluded from the study.

Subjects will be required to meet the following criteria in addition to the Par-Q: (1) no respiratory or cardiac conditions, (2) no current complaints of pain in the ankle knee or hip, (3) resting HR< 85 bpm.

Subjects will be tested in the Health and Human Performance Lab at Brigham Young University. All gas volume and VO_2 measurements will be taken using a TrueMax 2400 (Consentious Technologies, Sandy, UT). The subjects will be tested on a Lode Excalibur Cycle Ergometer (Netherlands). All subjects will be tested by the same examiner who will perform the necessary calibration and set up procedures in the same way. The same testing protocol will be used during each test to ensure that the subjects in each group follow the same procedures.

Mouthguards

There will be 2 different mouthguards tested in this study. Mouthguard A will be a “boil and bite” or stock mouthguard (Mueller Strapguard SG-50, Mueller Sports Medicine, Inc., One Quench Drive, Prairie du Sac, WI) that can be purchased at almost any sporting-goods store. The directions that accompany the mouthguard will be followed in order to ensure a proper fit. In addition, subjects’ will heat the mouthguard and form it in their mouth, in the lab, to minimize problems with fit. The strap will be trimmed off the anterior portion of the mouthguard to facilitate wearing the facemask that will be used during testing. Mouthguard B will be a custom fit single laminant EVA mouthguard (Proform, Dental Resources, Delano, MN) fabricated using a stone model made from an impression of the subjects upper teeth.   The models of the teeth will be poured from an impression taken using dental alginate (Patterson, Algitec, St. Paul, MN) common in any dental laboratory. The EVA material, prior to deformation, is 4 mm thick, which is standard for most custom fitted mouthguards. The material will be heated until it begins to “sag”. It will then be vacuum formed over the stone model of the subjects’ upper teeth. Once formed, the mouthguard will be separated and trimmed to the appropriate size. The mouthguard will be placed in the subjects’ mouth to assure a comfortable and correct fit, and any rough edges will be buffed to maximize comfort for the subjects’. Mouthguards will be stored on the stone model to reduce any deformation between test days.

Testing protocol

The subjects will be fitted with their mouthguards prior to the first day of testing. The subjects' treatment order will be randomized using a 6X6 Balanced Latin Square.

Tx order	1	2	n	3	n-1	4
Day	1	2	3	4	5	6
Subjects						
1-4	1	2	6	3	5	4
5-8	2	3	1	4	6	5
9-12	3	4	2	5	1	6
13-16	4	5	3	6	2	1
17-20	5	6	4	1	3	2
21-24	6	1	5	2	4	3

6x6 Balanced Latin Square 1

The Latin Square is a method of randomizing treatments. It will allow us to be able to group the subjects by number and assign a subject number that will group them into a corresponding treatment order. The treatment conditions will be as follows:

(1) Mouthguard C/Facemask 1

(2) Mouthguard A/Facemask 1

(3) Mouthguard B/Facemask 1

(4) Mouthguard C/Facemask 2

(5) Mouthguard A/Facemask 2

(6) Mouthguard B/Facemask 2

Subjects will arrive in the lab dressed in gym clothes. Subjects will complete a questionnaire which includes the ACSM Par-Q in order to be included in the study. If included, subjects will read an informed consent form and sign. The subjects information (age, height, weight) will be recorded. Subjects will draw a number from a hat in order to determine their subject number that corresponds to the 6 x 6 Balanced Latin Square. This will determine the testing protocol that they will follow over the 2 week testing period.

Subjects will be tested at a moderate intensity (100W) and a high intensity (175 W). Based on our pilot work (n=4), these intensities were sufficient to elicit V_E of < 30 L/min and > 40 L/min. The total testing time will be 20-25 minutes with a 5 minute warm-up period and a 2-5 minute cool-down period.

Subjects will be fitted with a HR monitor that straps around the chest. All subjects will warm up for 5 minutes at an intensity of 40 watts on the Lode cycle ergometer. After the 5 minute warm up, subjects will begin testing. The mouthguard will be placed in their mouth and the facemask that will be used for that day will be placed over their mouth and nose.

Subjects will be instructed to begin pedaling. The subjects' will begin pedaling at 100W. In our pilot study (n = 4) this resistance was sufficient to elicit minute ventilation (V_E) values that were approximately 30 L/min. This V_E value has been determined in the literature and by ACSM to be consistent with a moderate exercise level. Steady state values will be averaged during the fifth minute of the exercise period at 100W. This value is also consistent with the ACMS definition of moderate as 40-60% of HRmax. A fifth minute average will be used in statistical analysis to compare the mouthguards and the facemasks. Values of VO_2, VCO_2, RPE, RER, V_T, breathing frequency, V_E, and heart rate will be recorded during the 1 minute measurement periods.

Subjects will be instructed to slow to 40 Watts again for 2 minutes. After this 2 minute period, subjects will begin a second 5 minute exercise period at 100W. The subjects will be increased in 25W increments every minute up to 175W. This intensity should elicit a V_E greater than 40 L/min or 80% of HRmax. Subjects will pedal for 4 minutes at 175W to achieve steady state. RPE values will again be taken every minute during the first 4 minutes of the exercise period. Steady state averages will be calculated and used in statistical analysis. After the second 1 minute measurement period, the facemask and mouthguard will be removed. The intensity will be set at 40W and subjects' will be instructed to continue pedaling for 3-5 minutes in order to cool down. Subjects will be reminded of their next testing day. The testing will be concluded for that day.

Statistical Analysis

A 2x2x3 MANOVA will be run for 8 dependent variables as measured on the metabolic cart during testing (VO_2, VCO_2, RPE, RER, V_T, breathing frequency, V_E, and heart rate(HR)). Post Hoc tests as needed will be run to test for significance.

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