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Validity and Reliability of Temperature Sensing Devices During and Following Exercise in the Heat

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Chapter I: Introduction

Exertional heat stroke (EHS) is a danger for athletes that participate in outdoor and indoor sports. It can be fatal if it is not recognized and treated properly. Athletic trainers (ATs) must be able to recognize when an athlete is experiencing EHS and accurately measure an athlete’s core body temperature. The National Athletic Trainers’ Association recommends that ATs use rectal temperature as it is the most valid way to access core body temperature in an athlete that has been exercising. It has been found that oral temperature is not a valid way to access core body temperature in an athlete that has been exercising.

There is a mouthguard prototype that claims to change color when an athlete reaches a temperature of 39°C Celsius to warn ATs that the athlete is getting close to dangerous temperatures. The purpose of this study was to determine the reliability and validity of various temperature devices and this mouthguard to see if it was an accurate gauge of an athlete’s core body temperature. The objective of this study was to determine if this mouthguard has clinical viability to protect athletes from EHS. To test this mouthguard, a quasi-experiment was completed in a laboratory setting and was a single group pretest/posttest design. Each participant saw the same conditions and acted as their own control. There were thirteen healthy volunteers that participated in the study (26 ± 5.28 yrs; 171 ± 8.14 cm; 70.1 ± 11.58 kg; 17.0 ± 4.75% body fat). The trial took place inside an environmental chamber and the participants exercised on a treadmill or a stationary bike with the goal of each participant reaching a core body temperature of 39.5°C. Oral and ingestible temperature devices were used to keep track of the participant’s temperature at the same time intervals throughout the trial. This project was conducted because it can be a health risk to athletes if this mouthguard is relied on by ATs to see the athlete’s temperature, if it is not accurately measuring the body’s core temperature. An ATs ability to
recognize EHS is hindered if they are only relying on an invalid means to alert them when the athlete is reaching an elevated core temperature. This research will help to advise ATs on the safest way to take an athlete’s temperature during exercise. I hypothesized that, when an athlete worked out with the mouthguard in and reached a core temperature of 39°C, it would not change color, therefore, making it unreliable and invalid. The color changes of the mouthguard were compared to the data points from the oral and ingestible temperature devices. The independent variable was the exercise done in the environmental chamber by the participant. The dependent variable was the core body temperature of the participant. The dependent variable was tested by the temperature measuring devices and the color changing mouthguard. The controls were that the environment chamber was set to 26.7°C and 50% humidity and that the participants could not drink liquids while they were wearing the mouthguard.
Chapter II: Literature Review

*Importance of Recognizing Exertional Heat Stroke*

EHS is a risk for athletes when they are performing intense exercise in a hot environment, but it can also occur during many different environmental conditions. ATs use a variety of temperature devices to measure an athlete’s core temperature, despite the fact that rectal temperature is the recommended device by the National Athletic Trainer’s Association to obtain core body temperature (Casa, D. J. et al., 2015). There is a very large difference among temperature devices in their validity and reliability when measuring the temperature of an athlete in a hyperthermic state. Being able to take an accurate measurement of an athlete’s core temperature is very important as it can help prevent death and injury due to EHS. If EHS is not recognized and treated early enough, it can result in morbidity and mortality (Adams, Hosokawa, & Casa, 2015). Fatalities can be prevented if EHS is recognized by an accurate measurement of core temperature using a valid device and initiating efficient treatment. In order to do that, ATs must be following the correct protocol and using the recommended tools to assess and treat EHS (Mazerolle et al., 2011) It is important to understand what EHS is and its warning signs, the validity and reliability of different temperature devices, and how exercise affects temperature measurements.

*Defining Exertional Heat Stroke and its Risks*

The American College of Sports Medicine defines EHS as an elevated core temperature, usually above 40° C, with central nervous system dysfunction (Armstrong et al., 2007). EHS occurs from excessive heat production and or inhibited heat loss such as sweating (Casa et al., 2015). Contrary to popular belief, EHS does not always occur in an extreme heat environment. It
is possible for EHS to occur in normal conditions during intense physical activity (Casa et al., 2015). This is dangerous as it puts athletes at risk as they may be less likely to be diagnosed with EHS if they are not in an extreme heat environment. It is extremely important that ATs can diagnose and treat EHS as early and quickly as possible. When recognized early and treated correctly, EHS related deaths and injuries are completely preventable (Casa, Douglas J., Armstrong, Ganio, & Yeargin, 2005).

Exertional Heat Stroke Incidence Rates in Sports

Athletes are put at risk when ATs are not properly trained on the recognition and protocol of EHS. Even if an athlete does not die from EHS, they could face long-term neurologic deficits (Casa et al., 2015). According to the National Center for Catastrophic Sport Injury Research (NCCSIR) All Sport Report for 2016-2017, there were four reported heat stroke related catastrophic injuries (NCCSIR, 2017). The NCCSIR defines a catastrophic injury “as any severe injury incurred during participation in a school/college sponsored sport”. Heat related injuries are classified as indirect injuries which means they are caused by systemic failure from exertion during a sport, not directly from participation in the sport itself (NCCSIR, 2017). Heat stroke related catastrophic injuries accounted for 6.1% of all indirect events for that year. A total of three out of the four athletes died as a result of heat related injuries and EHS (NCCSIR, 2017). This is an improvement from just one year before, as heat related injuries and fatalities accounted for 17.5% of the indirect events that occurred (NCCSIR, 2017). Most of the heat stroke injuries and fatalities have occurred during the sport of football (NCCSIR, 2017). It should be noted that heat stroke related catastrophic injuries may include both classic and exertional heat stroke. The NCCSIR dedicates a separate survey every year to document the injuries and fatalities that have
occurred entirely as a result of football called the NCCSIR Annual Football Survey. The NCCSIR Annual Football Survey 2018 reported that there have been 148 football player heat stroke fatalities since 1960 (NCCSIR, 2018). Similar to the All Sport Report, the Annual Football Survey showed that there has been a decline in the heat stroke fatalities over time. While both of these reports show a decline, they also show that EHS is dangerous and can still result in fatality.

Validity and Reliability of Oral Temperature During Exercise

If EHS symptoms occur, it is important that ATs use the correct device to diagnose athletes with EHS and avoid misdiagnosing them with conditions that have similar symptoms (Mazerolle et al., 2011). If EHS is not primarily prevented, death or injury from EHS can be secondarily prevented if the correct protocol is followed and valid equipment is used to assess core body temperature. While they may seem the same to many people, different temperature devices have different levels of validity and reliability in individuals that are exercising. One of the commonly used devices used by ATs and healthcare providers is the oral thermometer. It is minimally invasive, relatively quick, and easy to use. These are all useful benefits of the device, especially if it is being used in a school setting with younger athletes. Oral temperature devices should not be used on exercising athletes because oral temperature can be affected by several external factors as it is administered through the mouth (Casa, Douglas J., Becker, Ganio, Brown, Yeargin, Roti, Siegler, Blowers, Glaviano, Huggins, Armstrong, & Maresh, 2007a). These can include liquids that the athlete is drinking and the speed that they are breathing. The fact that the results of this device can be altered by several external factors means that it cannot be relied on to give the user an accurate measurement of their core body temperature. In a study done on the validity and reliability of temperature devices during indoor exercise, it was found that oral temperature is an invalid measurement of core temperature as it was influenced by
environmental factors (Ganio et al., 2009). Ganio found that during and after indoor exercise, oral temperatures measured with an expensive device and an inexpensive device were both lower than rectal temperature at every point of measurement. When compared to rectal temperature, the expensive oral device had a difference of -1.25°C ± 0.72°C. When compared to rectal temperature, the inexpensive oral device had a difference of -1.53°C ± 0.45°C (Ganio et al., 2009). Using oral thermometers to get a measurement of core body temperature can pose as a risk to the athletes themselves. In a 2011 study on oral temperature, Stephanie Mazzerolle found that using oral temperature could have catastrophic outcomes due to difference in oral temperature and core body temperature measurements. Mazzerolle did an analysis on 16 different studies and analyzed their data on oral temperature versus the criterion standard. It was found that the difference in oral temperature and core body temperature increased with increased hyperthermia (Mazerolle, Ganio, Casa, Vingren, & Klau, 2011). During non-steady state body temperatures, there was a -0.58°C ± 0.75°C difference between the oral temperature and core body temperature measurements (Mazerolle et al., 2011).

**Validity and Reliability of Aural Temperature During Exercise**

Aural temperature is measured with a tympanic ear thermometer. This device is easy to use and noninvasive. Contrary to its name, this device is not a valid measurement of tympanic membrane temperature as most devices do not come into contact with the tympanic membrane (Casa, Douglas J., Becker, Ganio, Brown, Yeargin, Roti, Siegler, Blowers, Glaviano, Huggins, Armstrong, & Maresh, 2007b). In a study done on the validity and reliability of temperature devices during outdoor exercise, it was found that aural temperature was already lower than rectal temperature prior to exercise. During this study, they found that aural temperature was lower than rectal temperature during and after exercise, likely due to several factors such as
changes in blood flow to the skin in the ear canal, the evaporative cooling of the ear from air or sweat, and sweat in the ear. The aural temperature followed a similar trend to rectal temperature as they both increased at the same points, but aural temperature was always lower and increased at a lower magnitude. At the 60-minute mark of exercise, the mean aural temperature for the 8 highest responders was 1.86°C less than the mean rectal temperature at that same time point. This mean rectal temperature value registered these individuals hyperthermic as it was 39.77°C, but the mean aural temperature value was only 37.91°C; therefore, showing the individuals at a safe temperature (Casa et al., 2007). This same laboratory did a study on the validity and reliability of temperature devices during indoor exercise in the heat. This study supported the idea that aural temperature is not an accurate representation of core body temperature as it was lower than rectal temperature at every time point prior, during, and after exercise (Ganio et al., 2009). A meta-analysis was completed over nine articles with data on aural and rectal temperature in hyperthermic participants during exercise (Huggins, Glaviano, Negishi, Casa, & Hertel, 2012). Their study has similar findings to the ones above and stresses the danger of the use of a tympanic ear thermometer on a hyperthermic individual. This is due to the fact that as an individual approached hyperthermia, the difference between rectal temperature and aural temperature increased (Huggins et al., 2012). There are great risks to the individual that may be experiencing EHS as their aural temperature can read 1.7°C less than their core body temperature (Huggins et al., 2012)

**Validity and Reliability of Temporal Artery Temperature During Exercise**

Temporal artery temperature is another popular method to assess temperature, and like the devices discussed above, it is easy to use and noninvasive. These devices perform an infrared measurement of the skin temperature above the superficial temporal artery (Kistemaker, Den
Hartog, & Daanen, 2006). This has proved to be invalid for exercising individuals that show signs of EHS (Ronneberg, Roberts, McBean, & Center, 2008). In Casa’s study over temperature devices during outdoor exercise, it was found that temporal artery temperature was not only lower than rectal temperature, but that it decreased as rectal temperature increased and vice versa (Casa et al., 2007). The same findings were also found in a different study done by Kistemaker that compared temporal artery temperature to rectal and oesophageal temperatures. Kistemaker concluded that measurement of the temporal artery on the forehead can be affected by several factors such as sweat, vasodilation of blood vessels in the forehead, and changes in environmental conditions (Kistemaker et al., 2006). Ganio’s indoor comparison of temperature devices during exercise study found that their temporal artery device was reliable, but it was not a valid measurement of rectal temperature (Ganio et al., 2009). In 2005, the Boston Marathon released that a temporal artery thermometer was their thermometer of choice for collapsed runners. This prompted a study to be done on 60 collapsed marathon runners in which both rectal temperature and temporal artery temperature were used to evaluate the athletes for EHS (Ronneberg et al., 2008). The results showed poor correlation between rectal and temporal artery temperature, especially as rectal temperature increased. Additionally, only 2 of the 17 runners that were hyperthermic with a rectal temperature $\geq 39.4^\circ C$ were identified with a temporal artery thermometer. This supports the idea that temporal artery temperature is not safe for use in hyperthermic individuals as it is not valid or reliable when compared to rectal temperature (Ronneberg et al., 2008).

Validity and Reliability of Ingestible Thermistors During Exercise

While the previously discussed devices were not accurate or valid measurements of core body temperature, ingestible thermistors have gained credibility as a good representation of core
body temperature. An ingestible thermistor is a sensor that is ingested prior to exercise and transmits the gastrointestinal temperature to a receiver with instant feedback (Byrne & Lim, 2007). In a study of 12 different publications comparing intestinal temperature with esophageal temperature and/or rectal temperature, it was found that the ingestible thermistor gives a valid measurement of core body temperature (Byrne & Lim, 2007). In a study comparing different temperature devices to rectal temperature during indoor exercise, it was also found that intestinal temperature is a valid measurement of core body temperature (Ganio et al., 2009). In order to get an accurate measurement of core body temperature, the ingestible thermistors must be used correctly in order to prevent errors. Proper calibration prior to use and ingestion of the thermistor six hours before data collection is necessary for successful use (Byrne & Lim, 2007). While the ingestible thermistor is noninvasive and gives accurate, valid, and instant measurements of core body temperature, it is not practical for everyday use for athletes in the field. Its applications are limited due to the fact that it must be ingested six hours before use. It is also not practical due to the fact that each CorTemp ingestible thermistor device costs over $40.00. ATs must be able to obtain the rectal temperature in the case that the ingestible thermistor has malfunctioned, passed, or not been ingested (Ganio et al., 2009). For ATs trying to diagnose EHS in an athlete, it is not helpful as they need instant measurements and it is unlikely that the device was ingested prior to exercise in the average athlete (Huggins et al., 2012).

Validity and Reliability of Rectal Temperature During Exercise

Rectal temperature has been named the “gold standard” of temperature measuring devices during exercise (Ganio et al., 2009). It has earned this name because it provides valid and accurate measurements of core body temperature, while also having the ability to be performed in most settings (Ganio et al., 2009). The National Athletic Trainers’ Association states that
rectal temperature should be the only way that ATs are measuring the core body temperature of athletes during exercise in the heat (Casa et al., 2015). Despite this recommendation, ATs and healthcare providers are reluctant to use it due to its invasive nature and would prefer to use other devices that make it easier to obtain a temperature. A majority of ATs acknowledge that rectal temperature is the more accurate tool, but only a small minority actually use it in practice (Huggins et al., 2012). As seen in the earlier discussions of the use of other temperature devices, it is important to use the correct device because they do not all accurately measure core body temperature. It is important to get an accurate reading of the core temperature, because it rises differently than skin and axillary temperatures during exercise (Mazerolle et al., 2011). One drawback to rectal temperature is that it lags compared to the core body temperature and is not able to adjust as well to rapid changes when compared to esophageal temperatures (Roberts, 1994). Despite this lag, it can still accurately measure the temperature of an athlete with EHS symptoms (Roberts, 1994).
Chapter III: Methods

Research Design

A single trial quasi-experiment with a within-subjects design was used. Specifically, it was a single group pre-test/posttest.

Participants

Thirteen healthy volunteers participated in the trial (26 ± 5.28 yrs; 171 ± 8.14 cm; 70.1 ± 11.58 kg; 17.0 ± 4.75% body fat). The participants were recruited through the Arkansas Newswire, the exercise science research website, and visiting classes on campus. The participants were screened beforehand and could not meet any of the following exclusionary criteria: live a sedentary lifestyle, have a contradiction to ingestible thermistor, have a contraindication to exercise in the heat, or take medications that compromise thermoregulation or sweating.

Procedure

The total time commitment to the study for each participant was about 2.5 hours. There was a 30-minute screening process and then a 2-hour trial in the exercise science research center. Participants were screened by filling out their medical history and a physical activity questionnaire. This was reviewed to make sure that the participants did not meet any of the exclusionary criteria. If none of the exclusionary criteria was met, the participants read through and signed the informed consent form. Then, they were scheduled a trial time and given an ingestible thermistor with instructions to take the pill five to six hours prior to their trial time.

When the participant arrived, a urine sample was collected to ensure hydration. If they were not hydrated, they were provided with fluids to drink until they reached hydration which was verified with a second urine test. Then, their height, nude body mass, and bioelectrical
impedance were measured. The bioelectrical impedance resulted in the participant’s body fat percentage and BMI. Next it was verified that the ingestible thermistor was reading correctly. If it was not, the participant inserted a rectal thermometer 15 cm past the anal sphincter. Then, the participant was fitted for the mouthguard (figure 1) following the procedures provided by the company. First, the mouthguard was heated in a microwave for 1 minute and 25 seconds. Once the mouthguard was a safe temperature, the participant put it in their mouth and sucked in to fit. In some trials, additional heating was required if the mouth guard was not pliable enough to fit to the mouth. After fitting, the participant could cut the mouthguard, so that it fit comfortably in their mouth. The participant dressed for exercise in the heat.

**Figure 1.** On the left is a photo of the mouth guard at room temperature. On the right is a photo of the mouth guard after being heated in boiling water to 39°C.

They entered the environmental chamber that was set to 26.7°C Celsius with 50% humidity. Researchers monitored the chamber’s conditions throughout the trial to ensure that it did not change. Participants began the trial by sitting inside the chamber for 10 minutes of equilibration. Following the 10 minutes, their temperature was recorded, mouthguard color was observed, and a photo was taken of the mouthguard. The following devices were used to take their temperature; a CorTemp ingestible thermistor or a rectal thermistor and the Welch Allyn SureTemp® Plus 690 oral thermometer. After their temperature was measured, the participant began their exercise of
choice on a bike or a treadmill at a moderate to intense level. The length of the exercise was up to the participant with the goal of reaching 39.5°C. They could stop at any time and if their body temperature reached 40°C or above or were showing signs of EHS, researchers ceased exercise and moved them to recovery. The participants could not drink any fluids during exercise in order to avoid compromising the mouthguard temperature assessment. Once the participant reached a temperature of 39°C, they were allowed to cease exercise. If they felt okay and were showing no symptoms of EHS, they were allowed to continue exercise in order to measure more data points over 39°C. They had the option to take a cool down by walking at a speed of 3 miles per hour for 2 minutes on the treadmill. Next, they sat in the chamber for 5 minutes. Then, they sat outside of the chamber at room temperature for 5 minutes. Finally, they sat in a cold-water bath (4.5-10°C) for 5 minutes. Refer to figure 2 for a diagram of the trial protocol. During both exercise and recovery, researchers recorded the participants’ body temperature data and took photos of the mouthguards every 5 minutes. The participants were offered to take a shower and change. Participants were provided with fluids for rehydration.

![Trial Protocol](image)

**Figure 2.**

Water baths were used to confirm that the mouth guards changed color at their reported threshold temperature.
Data

The validity of the various temperature devices was determined by how each device compared to the ingestible thermistor or the rectal thermistor as those two measurements are the most accurate measurement of core temperature during exercise. In order to ensure reliability, researchers recorded temperature measurements every 5 minutes during exercise and completed multiple trials with different participants to maximize the number of data points.
Chapter IV: Results

During the water bath tests, all of the mouth guards changed color at their reported threshold temperatures. The thirteen participants exercised for a mean of 47 ± 14 minutes. The participants reached a mean intestinal temperature of 39.08 ± 0.18°C, which was significantly greater than the maximal oral temperature of 37.33 ± 0.39°C; p<.001. The oral temperatures and intestinal temperatures of the participants throughout the trial are compared in Figure 3. Even though the participants’ mean core body temperature was above 39°C, none of the mouth guards changed color during any of the trials.

![Average Temperature with Oral and Intestinal Devices vs Time](image)

*Figure 3.* At the peak of average intestinal temperature (IG Temp 1: 38.9°C; IG Temp 2: 38.9°C), average oral temperature experienced a decrease (Oral Temp 1: 37.1°C, Oral Temp 2: 36.7°C).
Chapter V: Discussion

The purpose of this study was to determine the reliability and validity of various temperature devices and this mouthguard to see if it was an accurate gauge of an athlete’s core body temperature. The previous research has found that rectal temperature is the “gold standard” for measuring temperature during exercise (Ganio et al., 2009). While oral temperature is a popular choice of many ATs due to the noninvasive nature, previous research has found it to be an invalid measurement of core body temperature during indoor exercise (Ganio et al., 2009). Our hypothesis was supported in that the mouth guard never changed color during or after exercise, despite the fact that the participants’ mean core body temperature was above 39°C.

The National Athletic Trainers’ Association states that rectal temperature should be the only way that ATs are measuring the core body temperature of athletes during exercise in the heat (Casa et al., 2015). While it is not a practical option for ATs in a field setting, intestinal temperature has been found to be a valid and reliable measurement of core body temperature when compared to rectal temperature (Byrne & Lim, 2007). In a study on the validity and reliability of temperature measurements during indoor exercise, it was found that intestinal temperature was a valid and reliable assessment of hyperthermia (Ganio et al., 2009). Ingestible thermistors were used in our study due to their less invasive nature and quicker responsiveness to temperature changes when compared to rectal thermistors. The intestinal temperature was used to assess the validity and reliability of the oral temperature and mouth guard during exercise. We did not experience difficulties with the ingestible thermistors.

Our findings that oral temperature is an invalid and unreliable measurement of core body temperature during exercise is in agreement with the current research available. At every point prior, during, and after exercise, the participants’ mean oral temperature was lower than the
mean intestinal temperature. Mazzerolle found that the difference in oral temperature and core body temperature increased with increased hyperthermia (Mazerolle et al., 2011). Our study yielded similar findings. At the peak of mean intestinal temperature (39.08 ± 0.18°C), the largest mean difference between intestinal temperature and oral temperature was recorded (-2.18 ± 0.18°C). This finding is in line with a previous study that compared oral temperature to rectal temperature during indoor exercise (Ganio et al., 2009). They also found that at peak rectal temperature (38.80 ± 0.72°C), the largest mean difference between intestinal temperature and oral temperature was recorded. This is consistent with a study that compared oral and rectal temperatures during outdoor exercise (Casa et al., 2007). It is important for ATs to be aware of the dangers of using oral thermometers to assess an athlete that is exhibiting symptoms of EHS. There is potential for misdiagnosis of EHS if an oral thermometer is used and it reports a temperature that is significantly lower than the actual core body temperature. While it is a quick and non-invasive option, ATs should refrain from using oral temperature as a form of temperature measurement on exercising athletes.

The mouth guard was supposed to change color when the participants reached 39°C, but no color changes were reported throughout any of the trials. While the initial idea behind the mouth guards seems ideal for an athletic setting, it is not viable to create a mouth guard that accurately measures core body temperature. This is due to the fact that the mouth guard is changing color based on oral temperature, rather than core body temperature. The mouth guard could also potentially be affected by external factors such as the temperature of ingested liquids and the temperature of the air in the athletic setting. Even if the mouth guard had the ability to accurately measure core body temperature and change color at 39°C, color is a subjective measure and varies from person to person. It was also unclear on how much of the mouth guard
would have to change color in order to indicate that the athlete was at 39°C. If the mouth guard changes color gradually, it could be difficult to measure when the athlete is at 39°C. Our study found that the mouth guard is not a valid or reliable measurement of core body temperature during exercise. This would not be a recommended tool for ATs to use in the field on exercising athletes.
Chapter VI: Conclusion

The purpose of this study was to determine the reliability and validity of various temperature devices and this mouthguard to see if it was an accurate gauge of an athlete’s core body temperature. None of the mouth guards changed color throughout any of the trials, further supporting the evidence that oral temperature is not a valid or reliable measurement of one’s core body temperature. This mouth guard relies on oral temperature in order to change color. Due to the fact that our findings showed that oral temperature was consistently lower than intestinal temperature, the mouth guard would not be a valid measurement of core body temperature.

It would be unsafe to use this mouth guard to assess an athlete’s core temperature in a clinical setting. It could give ATs and athletes a sense of false security when in reality, it is not accurately measuring core body temperature. Early recognition of EHS is crucial in order to prevent EHS related injuries and fatalities and it is important that ATs are using the correct protocol and tools to assess and treat EHS. While oral temperature is a convenient and non-invasive technique, it is not recommended to assess the temperature of exercising athletes. Our findings and previous studies support that the most valid and reliable ways to measure an athlete’s core body temperature are rectal and intestinal temperatures.


Casa, D. J., Becker, S. M., Ganio, M. S., Brown, C. M., Yeargin, S. W., Roti, M. W., . . .


Ganio, M. S., Brown, C. M., Casa, D. J., Becker, S. M., Yeargin, S. W., McDermott, B. P., . . .


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