Spring 5-8-2020

Blood Glucose Levels of Esports Athletes During High Intensity Gaming

Gunner Rhoden

BLOOD GLUCOSE LEVELS OF ESPORTS ATHLETES DURING HIGH INTENSITY GAMING

by
Gunner Rhoden

A thesis submitted to the faculty of The University of Mississippi in partial fulfillment of the requirements of the Sally McDonnell Barksdale Honors College.

Oxford
May 2020

Approved by

_____
Advisor: Professor Thomas Andre

_____
Reader: Professor Martha Ann Bass

_____
Reader: Professor Xin Ye

ACKNOWLEDGEMENTS

I would like to thank my research advisor, Dr. Thomas Andre, for guiding me through the entirety of this research process. My time in the lab has been amazing, and I will miss everyone greatly. I honestly believe that I was part of the coolest research lab at Ole Miss.

I would also like to thank the Sally McDonnell Barksdale Honors College for their generous support in funding my research. My experience as a part of the SMBHC has been nothing short of incredible. Over my four years at Ole Miss, I have spent more time studying within the walls of the Honors College than I can count, but I do not regret a single one of them. The Honors College allowed me to forge friendships and gain knowledge that I am certain will be with me throughout my entire life.

Finally, I would like to thank my family for supporting me in everything that I do. They instilled the values and work ethic that make me into who I am and always made sure to tell me that I could accomplish anything that I put my mind to.

ABSTRACT

Gunner Rhoden: Blood Glucose Levels of Esports Athletes During High Intensity Gaming

Given the rise in popularity of Esports, it is important to better understand the relationship between Esports and the human body. The purpose of this study was to determine the relationship between blood glucose levels and performance in Esports. Ten undergraduate students (9 male, 1 female; age = 20.3±1.2 years; BMI = 28.8±7.6; Esports mean hours per week = 18.9±14.3) were recruited from the Esports club at the University of Mississippi. Blood glucose levels were measured using a HemoCue Glucose 201 Analyzer (Angelhome, Sweden) a total of 8 times (4 per session). After the completion of an initial familiarization session, participants arrived at the laboratory for two further sessions (fed & fasted) following an 8 hour fast. During these sessions an initial baseline measurement was recorded upon entry to the lab to ensure a fasted state, after which the participant either received a Cliff Bar (Emeryville, CA; 21g of sugar, 250kcals) or remained fasted. Participants then waited one hour before having their blood glucose and mental fatigue recorded. They then played the two Esports training programs Aim Hero and Osu in counterbalanced order for 30 minutes each. Two further glucose measurements were taken following completion of each 30 minute gaming interval, and mental fatigue and enjoyment level were recorded at the end of the session. Mean blood glucose was significantly higher at the pre (110.8±25.3mg/dL vs 90.9±9.4mg/dL, P = 0.045), 30 min (96.3±10.3mg/dL vs 84.9±89mg/dL, P = 0.002), and post (91.9±5.7mg/dL vs 83.7±7.0mg/dL, P = 0.011) recordings during the fed session in comparison to fasted. Mental fatigue was not significantly affected by session and/or time. There was no significant increase in performance (P > 0.05) for any of the measured statistics in either of the training programs;

however, mean values for most performance statistics did increase for the fed session of both programs. Given that some increase in performance was measured, further research should be conducted on the relationship between blood glucose levels and Esports performance.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ABBREVIATIONS

Esports	electronic sports
g	grams
kcals	kilocalories
FPS	first person shooter
mL	milliliter
ANOVA	analysis of variance
n	number
SD	standard deviation
cm	centimeters
kg	kilograms
BMI	body mass index
Avg.	average
%	percent
P	probability
s	seconds
ms	milliseconds
mg/dL	milligrams per deciliter
APM	actions per minute

Blood Glucose Levels of Esports Athletes During High Intensity Gaming

Esports (Electronic Sports) is a rapidly growing field of competitive video gaming that has become a dominant figure in the entertainment industry in recent years.[1] It is a blanket term that includes many different video games that are played competitively where either solo individuals or coordinated teams are pitted against one another. In 2019, Esports surpassed 1.7 billion viewers with a total revenue of 1.096 billion dollars.[2] Both the International Olympic Games Committee and the Asian Games have recognized Esports as an official sport, and it has also solidified a place in collegiate sports with multiple schools adding Esports to their athletic programs.[3] In these competitions, quick response time, team coordination, and mechanical prowess are all key requirements for victory. Despite the success of Esports and its acceptance as a variant of sports, there has been very little research conducted on these athletes. Due to this absence of published literature, it remains unclear the impact Esports has on these athletes including physiological responses, nutritional requirements, and cognitive demand and function.

There have been a significant number of studies conducted on the effects of varying blood glucose levels on cognitive function.[4] The brain has greater metabolic activity than any other organ within the human body. By mass it makes up only 2% of the body, but it

[1] Hamari and Sjöblom, "What Is ESports and Why Do People Watch It?"
[2] Wu, "The Possibility Analysis of Esports Becoming an Olympic Sport."
[3] Hallmann and Giel, "ESports – Competitive Sports or Recreational Activity?"; Jenny et al., "Virtual(Ly) Athletes: Where ESports Fit Within the Definition of 'Sport'"; Wu, "The Possibility Analysis of Esports Becoming an Olympic Sport."
[4] Owens, Parker, and Benton, "Blood Glucose and Subjective Energy Following Cognitive Demand"; Scholey, Harper, and Kennedy, "Cognitive Demand and Blood Glucose"; Donohoe and Benton, "Cognitive Functioning Is Susceptible to the Level of Blood Glucose"; Benton and Parker, "Breakfast, Blood Glucose, and Cognition"; Feldman and Barshi, "The Effects of Blood Glucose Levels on Cognitive Performance: A Review of the Literature."

has an energy requirement of nearly 20% of total energy expenditure at rest.[5] Although it requires a constant supply of fuel, it does not contain substantial stores of glycogen for energy production. This means that the brain relies on glucose that is being carried by the blood to meet its energy needs. This circulating glucose is transported through the blood-brain barrier into the extracellular fluid at a rate directly proportional to local capillary surface area.[6] Research has shown that specific compartments of the brain contain varying levels of glucose in their extracellular fluid in a ratio directly linked to neural activity in those areas. This increased use of glucose within the brain for cognitively demanding tasks is correlated to a measurable decrease in circulating blood glucose, which means that blood glucose measurements can be used as a marker for increased uptake and use in the brain.[7] Researchers typically observe elevated blood glucose concentrations following subsequent consumption of glucose rich substance with an associated increase in performance in cognitively demanding tests.[8] However, less demanding cognitive tests observe smaller improvements or no significant increase at all.[9] Previous research conducted on this topic has utilized a wide range of tests to determine the effect of glucose on cognitive function including serial subtraction, the Stroop paradigm, rapid information processing, driver

[5] Kennedy and Scholey, "Glucose Administration, Heart Rate and Cognitive Performance: Effects of Increasing Mental Effort"; Donohoe and Benton, "Cognitive Functioning Is Susceptible to the Level of Blood Glucose."

[6] Donohoe and Benton, "Cognitive Functioning Is Susceptible to the Level of Blood Glucose."

[7] McNay, McCarty, and Gold, "Fluctuations in Brain Glucose Concentration during Behavioral Testing."

[8] Kennedy and Scholey, "Glucose Administration, Heart Rate and Cognitive Performance: Effects of Increasing Mental Effort"; Scholey, Harper, and Kennedy, "Cognitive Demand and Blood Glucose"; Donohoe and Benton, "Cognitive Functioning Is Susceptible to the Level of Blood Glucose"; Benton and Parker, "Breakfast, Blood Glucose, and Cognition."

[9] Kennedy and Scholey, "Glucose Administration, Heart Rate and Cognitive Performance: Effects of Increasing Mental Effort"; Donohoe and Benton, "Cognitive Functioning Is Susceptible to the Level of Blood Glucose."

simulations, word retrieval, and the Porteus maze test.[10] An increase in performance was observed across all modalities post consumption of a glucose-rich beverage (25-50g at 20-45 minutes prior) with the most pronounced increases occurring on tasks considered most cognitively demanding.[11] Further, connections between fluctuations in glucose levels with increased performance have been noted, with greater decreases in blood glucose corresponding to increased utilization of glucose within the body during particularly taxing tests.[12]

Interestingly, this paradigm has yet to be examined within Esports even though several studies have previously demonstrated this field's high cognitive demand.[13] Given the cognitive demand of Esports, the nutritional status (fed vs. fasted) could impact an individual's blood glucose levels and subsequently their performance. Therefore, the purpose of this study was to determine the impact of Esports on blood glucose levels and performance.

[10] Kennedy and Scholey, "Glucose Administration, Heart Rate and Cognitive Performance: Effects of Increasing Mental Effort"; Scholey, Harper, and Kennedy, "Cognitive Demand and Blood Glucose"; Donohoe and Benton, "Cognitive Functioning Is Susceptible to the Level of Blood Glucose."

[11] Scholey, Harper, and Kennedy, "Cognitive Demand and Blood Glucose"; Donohoe and Benton, "Cognitive Functioning Is Susceptible to the Level of Blood Glucose"; Kennedy and Scholey, "Glucose Administration, Heart Rate and Cognitive Performance: Effects of Increasing Mental Effort."

[12] Kennedy and Scholey, "Glucose Administration, Heart Rate and Cognitive Performance: Effects of Increasing Mental Effort."

[13] Bejjanki et al., "Action Video Game Play Facilitates the Development of Better Perceptual Templates"; "Video Games Affect the Brain—for Better and Worse"; Talan and Matvey, "AN IMPACT OF ESPORTS ON COGNITIVE ABILITIES."

Materials and Methods

Participants

Ten undergraduate students (9 male, 1 female, mean age 20 years, range 19-22 years) were recruited from the Esports club at the University of Mississippi. These individuals had to play at least 6 hours of Esports per week and could not have type I or II diabetes mellitus or a peanut allergy. Each participant completed the University of Mississippi approved informed consent and a medical history inventory.

Procedure

Participants interested in taking part in the study were scheduled for an initial baseline session. Upon arrival to the lab, the participants were given consent forms and were screened for any exclusionary criteria including mean Esports hours per week, peanut allergy (due to its presence in the Cliff bar used in the fed trial), and/or type I or II diabetes mellitus. Participants self-reported age and Esports hours per week. The participants also completed a health, exercise, and diet form, and their height and weight were recorded using a Dectecto scale (Webb City, MO) within the laboratory. The participants were familiarized with the training programs Aim Hero and Osu for approximately one hour and their mouse/game sensitivities were calibrated. At the conclusion of the initial session, participants were scheduled for session 2 and were instructed to fast for at least 8 hours prior to the session. They were also instructed to avoid deviating greatly from their normal sleeping habits and were informed to duplicate the same sleeping schedule for the third session. Participants were randomly assigned to complete a fasted gaming session or fed gaming session first in a counterbalanced crossover order. Subsequent sessions occurred

after a minimum of 24 hours and all sessions were completed within 2 weeks of the initial baseline session.

For both the fed and fasted sessions, participants arrived in the lab during the morning without having eaten any form of breakfast (no caffeine or juice additionally). Once the participants entered the laboratory their blood glucose levels were measured to ensure that they have completed an overnight fast and provide a baseline measure. Following this measurement, for the fed trial participants received a Cliff bar (Emeryville, CA; 21 g of sugar, 250 kcals) to consume and then waited one-hour before their next blood glucose measurement. After the one-hour period, participants' mental fatigue level was recorded, and participants once again had their blood glucose measured and began their time on the Esports training programs Aim Hero and Osu (counterbalanced). Directly following 30 minutes within the first program, participant blood glucose levels were once again measured, and they were then instructed to begin playing the second training program (Osu or Aim Hero). Once they had completed 30 minutes on the second training program, their blood glucose, mental fatigue, and enjoyment levels were recorded. All procedures were identical between the fed and fasted sessions with the exception being the absence of Cliff bar consumption during the fasted session to ensure a fasted state throughout the entirety of the session. A total of 4 finger sticks occurred for each of the trials for a total of 8 for entirety of the study.

Esports Training Programs

Osu

Osu (Herbert 2007) is a rhythm-based computer game in which circular targets and "sliders" appear around the computer screen for the player to click and/or drag using the mouse cursor. While this game has its own active Esports community, it is also used by professional athletes of other games in order to practice or warm-up.[14] The targets appear on the screen following the rhythm of a song which it refers to as a beatmap. These beatmaps are rated based on difficulty (i.e. the number of targets and speed in which they appear), and each map has many different difficulty options. Three beatmaps were selected from a database based on both song length and number of separate difficulties. Player performance is based on both accuracy and precision with regards to clicking the targets/sliders on the screen. The number of misses and largest combo (the greatest number of consecutive target hits without missing) also play a role in the player's performance. Participants were familiarized with Osu during their first session in the laboratory during which their beatmap difficulties were calibrated to ensure a challenging experience.

Aim Hero

Aim Hero (ProGames Studio 2016) is an aim-training program for the computer which offers multiple game variants targeted at improving specific aspects of aiming that are necessary in other FPS (first-person shooter) games. The game variants utilized in this study include: classic, reflex, simple, and time trial. In classic, targets continually appear

[14] Carpenter, "Gamers with Godlike Reflexes Are Racing to Break World Records in This Rhythm Game"; Webb, "Professional Gamers like Ninja Use This Music Game to Practice Their Aim and Improve Their Mouse Skills — Here's How You Can Play for Free."

around the screen at a speed that increases with time, and the player is required to shoot each target to destroy it. The targets disappear after approximately six seconds, and if the player allows five targets to disappear during a level, then the game ends. In the reflex game variant, a single target briefly appears in a random location on a two-dimensional surface in front of the player. This happens once every second for three minutes. In simple, a single, moving target appears somewhere in a three-dimensional firing range and remains until the player has destroyed it. Once it has been destroyed another target appears at a random location, and this sequence continues for three minutes. In time trial the participant in positioned within a large three-dimensional arena with targets surrounding them at varying distances. The play is required to shoot fifty targets before this game variant ends.

Blood Glucose Testing

Blood glucose levels were measured using a HemoCue Glucose 201 Analyzer (Angelhome, Sweden) a total of 8 times (4 per session). Blood samples were obtained using standard procedures and sterile techniques. Participants were seated in the lab and had their finger cleaned using sterile alcohol pads. Light pressure was applied to the participant's fingertip on their left hand (non-computer mouse hand) which was then punctured using a lancet (drawn samples of less than ½ mL). Blood was then collected in a capillary cuvette and analyzed. Glucose measurements occurred at baseline, pre, 30 minutes, and immediately post.

Enjoyment Level

Participants self-reported their enjoyment level upon completion of the one-hour gaming session. They did this by creating a mark on a 10 cm. line which ranged from not enjoyable (left most point) to highly enjoyable (right most point). A ruler was then used to measure the distance of the mark from the left side of the line with this distance in cm corresponding to the enjoyment level on a 1-10 scale.

Mental Fatigue Scale

Participants self-reported their mental fatigue level directly prior to and following the one-hour gaming portion of each session. Their response was based on a scale ranging from 1 (fully alert) to 7 (completely exhausted).

Data Analysis

Statistical analyses were performed by utilizing a 2 x 4 [Session (fed, fasted) x Time (baseline, pre, 30 min, post)] factorial ANOVA with repeated measures for blood glucose levels. A 2 (session) x 2 (time) repeated measures ANOVA was utilized to examine perceived mental fatigue. Paired samples T-test for mean game variant performance and enjoyment scales. Significant within-session and within-time differences were determined using Fisher's Least Significant Difference post-hoc test. If within-group assumption of sphericity was violated using Mauchly's Test of Sphericity, the Greenhouse-Geisser correction factor was used to evaluate observed within-group F-ratios to protect against Type I error. Interaction effects were investigated using separate repeated-measures ANOVA for each session and time point. Statistical procedures were performed using SPSS 26.0 software (Chicago, IL) and a probability level of ≤ 0.05 was adopted throughout.

Results

Table 1: Subject Characteristics (n=10)

Variable	Mean ± SD
Age (years)	20.3 ± 1.2
Height (cm)	179.3 ± 4.5
Bodyweight (kg)	92.5 ± 23.7
BMI	28.8 ± 7.6
Avg. Daily Caffeine (mg)	103.0 ± 102.7
Esports Hours Per Week	18.9 ± 14.3

Table 1. Subject characteristics. Means ± standard deviations.

Blood Glucose Levels

There was no significant session x time interaction for blood glucose levels [$F_{(3,77)}$ = 2.162, p = 0.100]. The main effect for session (fed/fasted) revealed a statistically significant difference for glucose levels [$F_{(1,79)}$ = 11.396, p = 0.001]. The main effect of time (baseline, pre, 30 min, post) demonstrated a statistically significant difference for participant blood glucose levels between time points [$F_{(3,77)}$ = 3.792, p = 0.014]. Post-hoc analysis revealed no significant difference for the baseline (p = 0.424) but did demonstrate significant changes in glucose levels for pre (p = 0.045), 30 min (p = 0.002), and post (p = 0.011). There was also a significant decrease in blood glucose levels between the pre and post measurements for both the fed (p = 0.030) and fasted (p = 0.045) sessions.

Figure 1: Fed vs. Fasted Blood Glucose Measurements

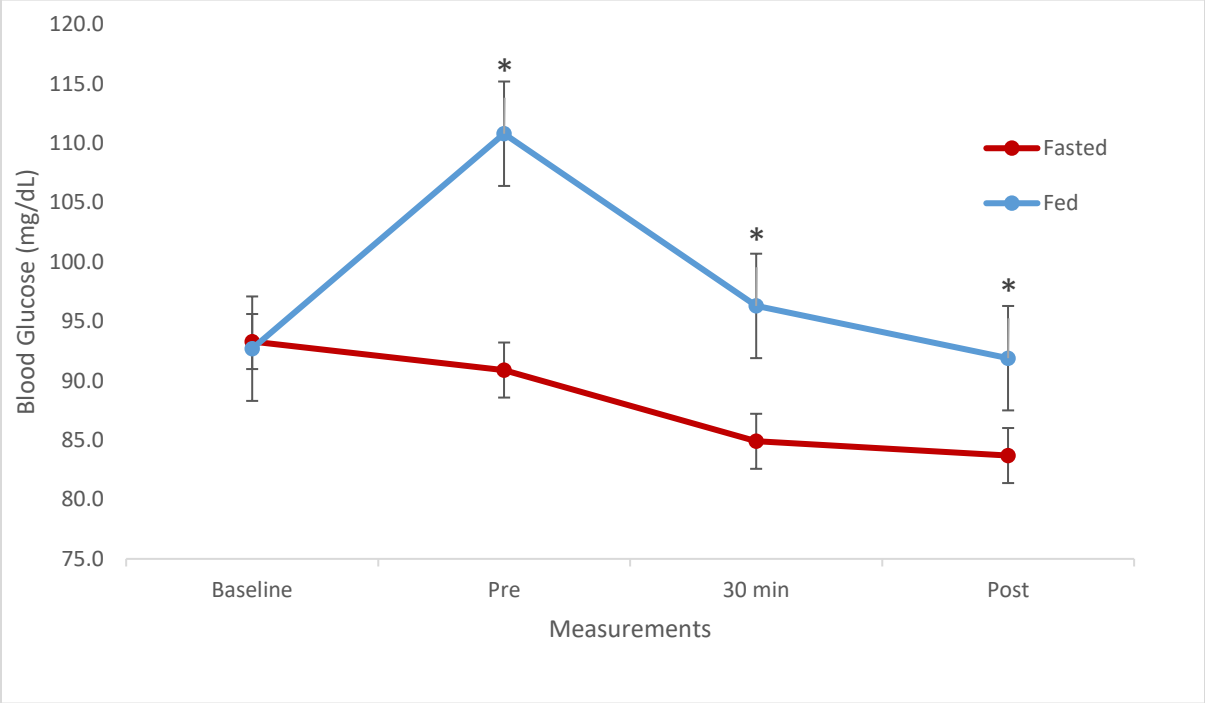

Figure 1. Blood glucose measurements in fed and fasted sessions. Each point represents the mean ± standard error. The baseline measurements for both fed and fasted sessions were taken upon entry to the laboratory in a fasted (overnight) state. The (*) denotes statistical significance ($p < 0.05$) for the Pre, 30 min, and Post time points when comparing fed versus fasted levels. The order in which Osu or Aim Hero were performed was counterbalanced across the participants.

Mental Fatigue

The 2 x 2 factorial ANOVA showed no significant relationship between mental fatigue and session (fed/fasted) [$F_{(1,39)} = 1.791$, $p = 0.189$] or between mental fatigue and time (pre/post) [$F_{(1,39)} = 2.676$, $p = 0.111$]. There was also no significant correlation with session x time [$F_{(1,39)} = .199$, $p = 0.658$].

Table 2: Change in Mental Fatigue

Session	Mental Fatigue Pre (mean ± sd)	Mental Fatigue Post (mean ± sd)
Fed	2.7 ± 1.0	3.7 ± 1.1
Fasted	3.3 ± 0.9	3.4 ± 1.0

Table 2. Mental fatigue in fed and fasted sessions. Measurements were taken direction prior to beginning gameplay (pre) and directly following (post). Changes between session and/or time were not significant ($p > 0.05$). Values represent mean ± standard deviation.

Effects of Glucose on Aim Hero Performance

Paired sample T-tests were conducted on performance statistics across each separate game variant (classic, reflex, simple, and time trial) comparing them between sessions (fed/fasted). All four modes measured total shots fired, targets hit, accuracy, time per hit, and score. Classic and time trial also measured total time within the game variant. The T-tests showed no statistically significant change ($p > 0.05$) across any data point within Aim Hero between sessions.

Table 3: Aim Hero Classic Performance Statistics

Variable	Fed Mean ± SD	Fasted Mean ± SD
Total Shots	166.3 ± 41.1	156.9 ± 42.5
Targets	147.0 ± 35.7	139.0 ± 39.3
Accuracy (%)	93.3 ± 14.4	87.8 ± 4.0
Time Per Hit	0.536 ± 0.078	0.542 ± 0.077
Score	108,200 ± 26,300	99,300 ± 34,400
Time (s)	86.3 ± 10.1	82.1 ± 12.2

Table 3: Performance statistics for the Classic game variant within Aim Hero. Paired samples T-tests were used to determine statistical significance with a probability level of ≤ 0.05. No measurement demonstrated a P-value less than .05. Values represent mean ± standard deviation.

Figure 2: Accuracies Across Game Variants within Aim Hero

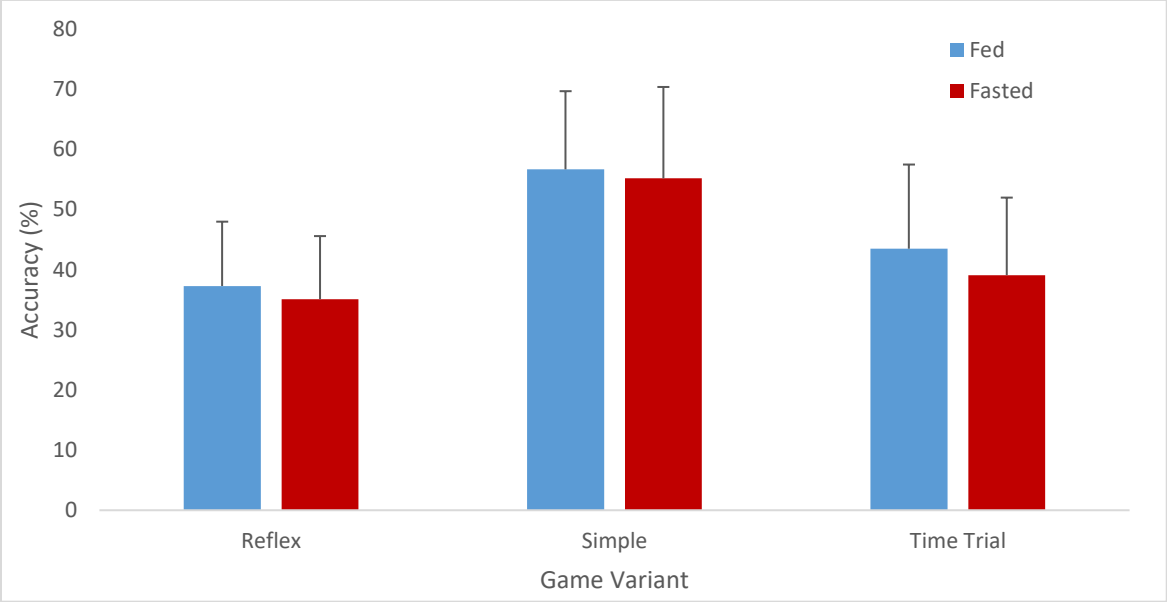

Figure 2: Mean accuracy (percentage of shots that landed on target) ± standard deviation in each game variant (excluding classic) within the training program Aim Hero. No variant demonstrated a statistically significant ($p > 0.05$) change in performance across sessions (fed/fasted).

Effect of Glucose on Osu performance

As with Aim Hero, paired sample T-tests were conducted on each performance statistic from the three separate beatmaps (Megalovania, Blue Zenith, Everything Will Freeze) used within Osu. While each of these beatmaps contained a different sequence of targets and music track, they all offered the same performance statistic categories (score, targets missed, largest combo, accuracy, error pre, error post, unstable rate). The error pre and error post values represent the mean amount of time in which the participant either clicked the target too early (error pre) or too late (error post). The unstable rate is the standard deviation of hit errors multiplied by ten which represents the consistency of a

participants timing for hits. No performance statistics within Osu showed significant change ($p > 0.05$) between the two sessions.

Table 4: Osu Megalovania Performance Statistics

Variable	Fed Mean ± SD	Fasted Mean ± SD
Score	260,700 ± 256,700	181,200 ± 92,800
Misses	9.7 ± 11.3	11.8 ± 11.1
Combo	119.3 ± 68.5	102.7 ± 53.1
Accuracy (%)	82.3 ± 7.7	80.1 ± 8.7
Error Pre (ms)	-46.4 ± 13.7	-49.6 ± 13.3
Error Post (ms)	46.5 ± 6.7	44.1 ± 10.7
Unstable Rate	534.8 ± 93.9	558.2 ± 109.7

Table 4: Performance statistics for the Megalovania beatmap within Osu. Paired samples T-tests were used to determine statistical significance with a probability level of ≤ 0.05. No measurement demonstrated a P-value less than .05. Values represent mean ± standard deviation.

Effects of Glucose on Enjoyment Level

Paired sample T-tests showed no significant change ($p > 0.05$) in enjoyment level at the end of the two sessions (fed/fasted).

Table 5: Enjoyment Level of Each Session

Session	Enjoyment Level (mean ± sd)
Fed	7.7 ± 1.3
Fasted	7.3 ± 1.1

Table 2: Enjoyment in fed and fasted sessions. Measurements were taken directly following completion of second training program. Values represent mean ± standard deviation. No significant change ($p > 0.05$) was found.

Discussion

The aim of this study was to determine if blood glucose levels affected performance in Esports. The results of this study demonstrate that the consumption of glucose (21g) 60 minutes prior to playing the two Esports training programs Aim Hero or Osu failed to improve performance across the recorded variables. This lack of improvement occurred despite increases in blood glucose levels for the fed session and a decrease in circulating blood glucose between the pre and post measurements of both the fed and fasted trials (Fig. 1).

Increased levels of circulating blood glucose at the initiation of a task allows the brain to devote more energy to high cognitive demand tasks and subsequently increases performance.[15] Within these paradigms, researchers have shown that significant decreases in glucose over the duration of the test is correlated to its cognitive load as well as the performance increase derived from heightened glucose reserves.[16] Performance increases with glucose administration (20-50g at 0-120 minutes prior) occur in wide variety of both memory-based tasks as well as non-mnemonic tasks including reaction time, word list recall, the Brown-Petterson test, special memory tasks, rapid visual information processing, the Stroop Paradigm, Porteus Mazes, driving simulations, face recognition, serial sevens, water jars tests, as well as several others.[17]

[15] Scholey, Harper, and Kennedy, "Cognitive Demand and Blood Glucose"; Donohoe and Benton, "Cognitive Functioning Is Susceptible to the Level of Blood Glucose"; Smith et al., "Effects of Breakfast and Caffeine on Cognitive Performance, Mood and Cardiovascular Functioning"; Kennedy and Scholey, "Glucose Administration, Heart Rate and Cognitive Performance."

[16] Scholey, Harper, and Kennedy, "Cognitive Demand and Blood Glucose"; Donohoe and Benton, "Cognitive Functioning Is Susceptible to the Level of Blood Glucose."

[17] Benton and Parker, "Breakfast, Blood Glucose, and Cognition"; Scholey, Harper, and Kennedy, "Cognitive Demand and Blood Glucose"; Donohoe and Benton, "Cognitive Functioning Is Susceptible to the Level of Blood Glucose"; Smith et al., "Effects of Breakfast and Caffeine on Cognitive Performance, Mood and

Given that the blood glucose levels in this study followed a similar pattern of significance (Fig. 1) in regards to changes between and within the fed and fasted sessions in comparison to other documented high cognitive demand tasks,[18] the training programs Aim Hero and Osu likely caused a high cognitive load to the participant. This is demonstrated by the mean participant glucose levels which decreased significantly by ~18.9 mg/dL (fed) and ~7.2 mg/dL (fasted) between the pre and post measurements of each respective session (Fig. 1). One future approach to further observe this change might be to begin gaming at alternative time intervals rather than at a single one hour time point. Plausibly providing insight as to meal timing to optimize performance while also minimizing the effect of mental fatigue on the Esport participant which is particularly relevant due to the periods of time that participants reported gaming each week. Given that the mean hours gaming spent each week was equal to 18.9±14.3 hours (Table 1), it is clear that most participants spend longer than one hour per gaming session. Due to the likelihood of high cognitive demand for both tasks within this study, the resulting lack of improved mean performance was unexpected, but there are several other factors to potentially explain this occurrence.

In conjunction with mental fatigue, the participants' enjoyment level was recorded at the end of each session. The mean enjoyment level of participants was higher for the fed session but not by a significant amount (Table 5) which follows previous research by Owens et al. which saw a significant increase in mental fatigue following completion of

Cardiovascular Functioning"; Kennedy and Scholey, "Glucose Administration, Heart Rate and Cognitive Performance"; Owens and Benton, "The Impact of Raising Blood Glucose on Reaction Times."

[18] Fairclough and Houston, "A Metabolic Measure of Mental Effort"; Kennedy and Scholey, "Glucose Administration, Heart Rate and Cognitive Performance"; Scholey, Harper, and Kennedy, "Cognitive Demand and Blood Glucose."

assigned computer game task in fed (50g glucose) and fasted trials but saw no increase in irritability or other negative factors of mood upon test completion in either session. Owens' study recorded mood/mental fatigue 15 minutes after consumption (immediately prior to beginning computer task) and 20 minutes later upon completion of computer game.[19] Additionally, the nature of the tests within this study lends itself to higher enjoyment levels given that both training programs were also designed to be enjoyable for the user.

Although there are a large number of cognitive testing modalities that show improvement during increased glucose levels, alternative cognitive tests that researchers have administered produced contrasting results. These tests include logical reasoning, embedded figures, verbal fluency, and simple reaction time.[20] Despite the importance of reaction time in both Esports training programs utilized in the current paradigm, caution should be used to equate the results of this study to Owen's reaction time test given the nature of the Esports programs are much more complex comparatively to the previously mentioned literature. Owens and Benton tested the speed in which an individual could discern which of two strings were longer and upon completion of that observation pressed a key corresponding to the longer line.[21] Therefore, the added mechanical requirements of aiming at each target as well as their locations being randomized in the case of Aim Hero and in place to a rhythm in Osu makes these actions fall into a complex reaction category.

An additional distinction that must be made is the difference between the Esports training programs used within this study and actual Esports video games. While both Osu

[19]Owens, Parker, and Benton, "Blood Glucose and Subjective Energy Following Cognitive Demand."
[20] Donohoe and Benton, "Cognitive Functioning Is Susceptible to the Level of Blood Glucose"; Owens and Benton, "The Impact of Raising Blood Glucose on Reaction Times."
[21] Owens and Benton, "The Impact of Raising Blood Glucose on Reaction Times."

and Aim hero offer a large number of performance statistics granting a greater insight into specific controllable elements of performance (Tables 3 & 4), the player versus player element that is present within all major Esports is absent, which greatly subtracts from the intensity of the experience. Furthermore, the number of mechanical actions required in each of these programs is lower than the average of many Esports games. The actions per minute (APM) varies based on the specific type of game, but the most mechanically demanding Esports titles such as StarCraft II have players averaging 300+ APM.[22] The highest average number of shots fired within Aim Hero was ~120 per minute within the classic game variant with a similar amount (~121) of actions in the fastest OSU song Everything Will Freeze at the average selected difficulty. Due to the song difficulties within OSU being calibrated to each specific participant, the most advanced participants played at ~200 APM which is more representative of the mechanical input in professional Esports. However, only 2 of the 10 participants were skilled enough to perform at this level.

Another potential explanation that these values do not demonstrate statistical significance is the nature of the measurements themselves. For example, while the mean accuracy difference of ~5.5% for the classic game variant of Aim Hero (Table 3) does not reach the set statistical significance of $p < 0.05$, it does however show a very sizable increase when framed from an Esports perspective. One example of this is the differences in average accuracy for professional players of the game CS:GO at a tournament where researchers from the Russian State University of Physical Education compared player performance statistics. These researchers found that the average accuracy of the first place winner of the tournament to be 79.00%, while the compiled averages for the 4-8 places

[22]LeJacq, "How Fast Is Fast?"

were 77.39%.[23] While this example is somewhat exaggerated due to it comparing top players in the world instead of collegiate athletes, it does demonstrate that some of these changes are greater than one might infer through only examining P-values. Additionally, the number of participants for this study (n = 10) was relatively small and the observed trends towards significance might have reach significance with more individuals.

Conclusion

There are many potential future directions with regards to the effects of blood glucose levels on performance in Esports athletes given that this study was the first to observe this particular relationship. One interaction that would be beneficial to observe in future research, as previously noted, would be the time intervals in which participants begin gaming following glucose consumption. Additionally, the duration of the gaming portion could be altered to determine if glucose has more or less of an effect over times greater than 1 hour. This increased duration might also help mimic tournament settings to a higher degree. The testing programs themselves could also be replaced with actual Esports video games to add the competitive element that was absent from this study; however, this will add an additional level of uncertainty to the experiment given the unpredictable nature of online games. Ideally, a study using only elite Esports players within a live Esports setting would give the greatest accuracy as to the effects of glucose on performance.

[23]Talan and Matvey, "AN IMPACT OF ESPORTS ON COGNITIVE ABILITIES."

Bibliography

Bejjanki, Vikranth R., Ruyuan Zhang, Renjie Li, Alexandre Pouget, C. Shawn Green, Zhong-Lin Lu, and Daphne Bavelier. "Action Video Game Play Facilitates the Development of Better Perceptual Templates." *Proceedings of the National Academy of Sciences* 111, no. 47 (November 25, 2014): 16961–66. https://doi.org/10.1073/pnas.1417056111.

Benton, D., and P. Y. Parker. "Breakfast, Blood Glucose, and Cognition." *The American Journal of Clinical Nutrition* 67, no. 4 (April 1, 1998): 772S-778S. https://doi.org/10.1093/ajcn/67.4.772S.

Carpenter, Nicole. "Gamers with Godlike Reflexes Are Racing to Break World Records in This Rhythm Game." *PC Gamer* (blog), July 16, 2019. https://www.pcgamer.com/two-teens-are-on-a-crazy-world-record-race-in-extremely-challenging-rhythm-game-osu/.

Donohoe, R. T., and David Benton. "Cognitive Functioning Is Susceptible to the Level of Blood Glucose." *Psychopharmacology* 145, no. 4 (August 1, 1999): 378–85. https://doi.org/10.1007/s002130051071.

Fairclough, Stephen H, and Kim Houston. "A Metabolic Measure of Mental Effort." *Biological Psychology* 66, no. 2 (April 1, 2004): 177–90. https://doi.org/10.1016/j.biopsycho.2003.10.001.

Feldman, Jolene, and Immanuel Barshi. "The Effects of Blood Glucose Levels on Cognitive Performance: A Review of the Literature," 2007, 142.

Hallmann, Kirstin, and Thomas Giel. "ESports – Competitive Sports or Recreational Activity?" *Sport Management Review* 21, no. 1 (February 1, 2018): 14–20. https://doi.org/10.1016/j.smr.2017.07.011.

Hamari, Juho, and Max Sjöblom. "What Is ESports and Why Do People Watch It?" *Internet Research* 27, no. 2 (January 1, 2017): 211–32. https://doi.org/10.1108/IntR-04-2016-0085.

Jenny, Seth E., R. Douglas Manning, Margaret C. Keiper, and Tracy W. Olrich. "Virtual(Ly) Athletes: Where ESports Fit Within the Definition of 'Sport.'" *Quest* 69, no. 1 (January 2, 2017): 1–18. https://doi.org/10.1080/00336297.2016.1144517.

Kennedy, D. O., and A. B. Scholey. "Glucose Administration, Heart Rate and Cognitive Performance: Effects of Increasing Mental Effort." *Psychopharmacology* 149, no. 1 (March 1, 2000): 63–71. https://doi.org/10.1007/s002139900335.

LeJacq, Yannick. "How Fast Is Fast? Some pro Gamers Make 10 Moves per Second." NBC News, October 24, 2013. http://www.nbcnews.com/tech/video-games/how-fast-fast-some-pro-gamers-make-10-moves-second-f8C11422946.

McNay, Ewan C., Richard C. McCarty, and Paul E. Gold. "Fluctuations in Brain Glucose Concentration during Behavioral Testing: Dissociations between Brain Areas and between Brain and Blood." *Neurobiology of Learning and Memory* 75, no. 3 (May 1, 2001): 325–37. https://doi.org/10.1006/nlme.2000.3976.

Owens, D. S., and D. Benton. "The Impact of Raising Blood Glucose on Reaction Times." *Neuropsychobiology* 30, no. 2–3 (1994): 106–13. https://doi.org/10.1159/000119146.

Owens, Deborah S, Pearl Y Parker, and David Benton. “Blood Glucose and Subjective Energy Following Cognitive Demand.” *Physiology & Behavior* 62, no. 3 (September 1, 1997): 471–78. https://doi.org/10.1016/S0031-9384(97)00156-X.

Scholey, Andrew B, Susan Harper, and David O Kennedy. “Cognitive Demand and Blood Glucose.” *Physiology & Behavior* 73, no. 4 (July 1, 2001): 585–92. https://doi.org/10.1016/S0031-9384(01)00476-0.

Smith, Andrew, Anna Kendrick, Andrea Maben, and Jenny Salmon. “Effects of Breakfast and Caffeine on Cognitive Performance, Mood and Cardiovascular Functioning.” *Appetite* 22, no. 1 (February 1, 1994): 39–55. https://doi.org/10.1006/appe.1994.1004.

Talan, Alexey, and Talan Matvey. “AN IMPACT OF ESPORTS ON COGNITIVE ABILITIES,” 2019.

Dana Foundation. “Video Games Affect the Brain—for Better and Worse.” Accessed March 28, 2020. https://www.dana.org/article/video-games-affect-the-brain-for-better-and-worse/.

Webb, Kevin. “Professional Gamers like Ninja Use This Music Game to Practice Their Aim and Improve Their Mouse Skills — Here’s How You Can Play for Free.” Business Insider. Accessed March 6, 2020. https://www.businessinsider.com/osu-game-pro-gamers-practice-aim-improve-mouse-skills-esports-2019-8.

Wu, Yucong. “The Possibility Analysis of Esports Becoming an Olympic Sport.” Fi=AMK-opinnäytetyö|sv=YH-examensarbete|en=Bachelor’s thesis|, 2019. http://www.theseus.fi/handle/10024/267651.