

Article

Effects of 7-Day Ketone Ingestion and a Physiological Workload on Postural Stability, Cognitive, and Muscular Exertion Measures in Professional Firefighters

Harish Chander ^{1,*}, Matthew J. McAllister ², Angelia M. Holland ³, Hunter S. Waldman ⁴, Benjamin M. Krings ⁵, Jonathan C. Swain ⁶, Alana J. Turner ¹, Steven A. Basham ⁴, JohnEric W. Smith ⁴ and Adam C. Knight ¹

¹ Neuromechanics Laboratory, Department of Kinesiology, Mississippi State University, Mississippi State, MS 39762, USA; ajt188@msstate.edu (A.J.T.); aknight@colled.msstate.edu (A.C.K.)

² Metabolic and Applied Physiology Laboratory, Department of Health and Human Performance, Texas State University, San Marcos, TX 78666, USA; mjm445@txstate.edu

³ Nutrition, Exercise and Stress Lab, Department of Kinesiology, Augusta University, Augusta, GA 30912, USA; angholland@augusta.edu

⁴ Applied Physiology Laboratory, Department of Kinesiology, Mississippi State University, Mississippi State, MS 39762, USA; hsw78@msstate.edu (H.S.W.); sbasham2593@gmail.com (S.A.B.); jesmith@colled.msstate.edu (J.W.S.)

⁵ Department of Health and Human Performance, University of Wisconsin-Platteville, Platteville, WI 53818, USA; kringsb@uwplatt.edu

⁶ Department of Health, Physical Education, and Recreation, University of North Alabama, Florence, AL 35632, USA; jswain1@una.edu

* Correspondence: hchander@colled.msstate.edu; Tel.: +1(662)-202-7977

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Abstract: Background: Postural stability and cognitive performance are challenged in firefighters. The purpose of this investigation was to examine the impact of 7-day ketone supplementation on postural stability, cognitive performance, and muscular activation before and after a physiological workload. Methods: Nine professional firefighters completed two experimental sessions (pre- and post-workload) in a counterbalanced, double-blind design. Participants ingested either a ketone salt (KS) or placebo (PLA) daily for seven days, and had an eighth ingestion 30 min prior to testing. Each experimental testing consisted of maximal voluntary contractions (MVIC) for four muscles (knee flexors—BF, extensor—VM, ankle dorsiflexors—TA, and plantar flexors—MG) using electromyography and postural stability testing (eyes open (EO), eyes closed (EC), and eyes open-dual-task using a FitLight™ system (EOT)), before (pre-workload) and after (post-workload) a simulated physiological workload. The workload consisted of 35 min steady state exercise at 60% of peak oxygen consumption wearing firefighter personal protective equipment (PPE). Results: Significant differences were limited to time effects (pre-workload vs. post-workload), with no differences between groups (KS vs. PLA). Significantly lower muscle activity in VM, TA, and MG during MVIC, greater postural sway and muscle activity in BF during EC and EOT, and slower response time during EOT were evident post-workload. Conclusions: A 7-day ketone supplementation does not impact postural stability, muscle activity, and cognitive tasks, but a fatiguing workload causes significant performance reduction.

Keywords: firefighters; ketones; muscular exertion; postural stability; body balance; response times

1. Introduction

Due to the requirements of their profession, firefighters are routinely placed in high-risk situations where the probabilities for occupational injuries to be sustained are increased [1,2]. In 2016, 2.9 million non-fatal occupational injuries and illnesses cases were reported in firefighters by the United States Bureau of Labor Statistics, with 27% of all cases resulting from falls, slips, and trips, possibly due to reduced or compromised postural stability [3]. Firefighters must maintain postural stability while navigating hazardous environments in the performance of their duties. The loss of postural stability can lead to falls and fall-related injuries and put the wellbeing of a firefighter in extreme jeopardy [4–7]. The firefighter's physical and cognitive performance can be impacted by extrinsic (environmental) factors, such as the temperature, working conditions, and personal protective equipment (PPE), and by intrinsic (human) factors such as fatigue, stress, anxiety, and sleep deprivation. Specific to postural stability, the firefighter's PPE, even though it serves a protective function, has been reported to cause reductions in balance performance due to added physiological energy expenditure and muscular fatigue [4–9]. Specific PPE such as firefighter boots have also been shown to be influential in postural stability due to the design features of the boots, such as heavier mass, leading to a faster rate of fatigue, impacting postural stability negatively, or an elevated boot shaft design aiding postural stability [5–7]. Similar reductions in postural stability in firefighters have also been reported due to muscular fatigue resulting from simulated physical workloads that negatively affect the sensory and motor components of the postural control system [7–10]. Finally, stress due to strenuous firefighting events has been reported to cause a decline cognitive functions, specifically in identifying solutions to problems and making correct decisions in a timely manner [11]. Subsequently, the cognitive and physical task of firefighting is a dual-task paradigm, where one of the tasks may negatively impact the other and can lead to an increased likelihood of injuries [11]. The measurement of postural sway has been suggested as a potentially inexpensive and simple means for monitoring physical exhaustion and safety of PPE-wearing workers during task performance [4]. However, further investigation of neuromechanical factors, such as muscle activation and response times to cognitive tasks influencing postural stability in a dual-task paradigm, is very much warranted in this population.

Nutritional interventions have been utilized in many populations to determine the effects on performance exercise and health. Recent evidence suggests the potential role of increasing endogenous ketone levels on enhancing cognitive performance [11–14]. Typically, increasing endogenous ketone levels to a level of ketosis is achieved by consuming a ketogenic diet (<50 g carbohydrates/day) [12–14]. However, adherence to the ketogenic diet is often difficult; instead, elevated circulating ketone levels can be increased via exogenous ketone supplementation [12–14]. Ingestion of ketone salts (KS) (similar dosing protocol and form of treatment) has commonly been done in other studies and has been shown to be effective at increasing ketone levels and improving cognitive performance [12–15]. Ketones, specifically β -hydroxybutyrate (β HB), are a substrate utilized in the brain during times of starvation and carbohydrate restriction [12–15]. It is hypothesized that increased ketone levels can alter metabolism, cognition, and exercise performance. Although enhancements in cognitive performance are typically seen in those suffering from mild to severe neurological impairments [12,14,15], firefighters may benefit from increased endogenous ketone levels since they can be used as a fuel source by the muscles and central nervous system. Firefighters are constantly challenged both physically and mentally during work, and those challenges are exacerbated when wearing PPE. With limited research in human models, there is not enough literature to fully elucidate the effects of ketone supplementation in high-stress occupations. Due to the increased interest in exogenous ketone supplementation on cognitive function [16] and cognitive performance [17], further research is warranted. KS have been shown to increase blood ketone levels, inducing nutritional ketosis following acute ingestion (i.e., within 30–60 min after ingestion); however, the impact on physical performance is equivocal [18–20].

Therefore, the purpose of this study was to determine the impact of ingesting exogenous ketones as KS on markers of postural stability, muscle activity, and cognitive performance after performing a physical workload challenge in firefighters. It was hypothesized that the 7-day KS ingestion would

result in significant increases in maximal muscle activity during maximal exertion and improved postural stability performance with minimal muscle activity during both single tasks of postural stability and during the cognitive dual-task postural stability measures, including faster response times in cognitive task, especially after a physical workload in firefighters.

2. Materials and Methods

2.1. Participants

Ten professional firefighters (males), between the ages of 18 and 39 (mean age 30 ± 6 years) participated in this study. One participant failed to meet compliance guidelines and was excluded from analysis. Therefore, nine participants completed the protocol. Descriptive characteristics are shown in Table 1. Participants were required to (1) be an active duty firefighter, (2) be at low risk for cardiac diseases according to the American College of Sports Medicine (ACSM), (3) regularly participate in at least 150 min of moderate intensity aerobic activity or 60 min of vigorous intensity aerobic activity per week, (4) avoid consumption of dietary supplements that contain any antioxidants or ergogenic aids for at least two weeks prior to and throughout the duration of the study, and 5) avoid caffeine and alcohol consumption 24 h prior to the experimental testing sessions. Additionally, participants with any previous history of any neurological, cardiovascular, or metabolic diseases and with any current musculoskeletal injuries were excluded from the study. All participants read and signed the informed consent form that was approved by the University's Institutional Review Board for research on human participants (Approved protocol IRB 17-423).

Table 1. Participant descriptive characteristics ($n = 9$).

| Body Mass (kg) | Height (cm) | Body Mass Index (BMI) (kg/m ²) | Gear Mass (kg) | Total Mass with Gear (kg) | VO _{2peak} (L/min) | 60% VO _{2peak} (L/min) |
|-----------------|-----------------|--|----------------|---------------------------|-----------------------------|---------------------------------|
| 84.1 \pm 13.4 | 177.1 \pm 5.3 | 26.7 \pm 3.5 | 18.6 \pm 1.0 | 102.7 \pm 13.5 | 4.11 \pm 0.6 | 2.47 \pm 0.4 |

Data presented as means \pm standard deviation.

2.2. Experimental Design

This study utilized a randomized, counterbalanced, double-blind, placebo-controlled crossover design with repeated measures on each participant. Each participant was randomly assigned regarding the order of which they ingested either KS or the placebo (PLA) for 7 days prior to the testing session. The packets were unlabeled and coded "A" or "B" and contained either KS or PLA. The participants were asked to ingest two packets per day (one in the morning, one in the early evening) for the 7-day supplemental period. Additionally, on each testing day, participants were tested for biomechanical measures (explained in detail under experimental procedures) before (pre-workload) and after (post-workload) a simulated physiological workload. Before laboratory testing sessions, the supplement was ingested 30 min before the start of exercise. A 7-day washout period was incorporated before each participant was supplemented with the opposite treatment for another 7-day supplemental period. Four firefighters had to respond to a building fire on the morning of the eighth day of supplementation, therefore, these four firefighters ingested their supplement for eight days and completed session two on the morning of the ninth day.

Each packet was mixed with 8 oz of water. The supplemental treatments, at 41 kcal each, included a KS mixture (Keto//OS[®] MAX[™], Melissa, TX, USA) which contained 7 g of β HB, erythritol, L-taurine, fermented L-leucine, citric acid, natural flavor, vegetable juice color, stevia, xanthan gum, beta carotene, and approximately 920 mg of sodium. The PLA contained the same ingredients except the β HB, L-taurine, and L-leucine which were replaced with an isocaloric amount of maltodextrin. Ketone salts were specifically chosen (as opposed to esters) because they are much more readily and commercially available. The dosing was chosen by preliminary data showing that the chosen dose is effective at

inducing nutritional ketosis [18–20]. All participants were asked to maintain consistent dietary habits as much as possible throughout the study. The nature of work for firefighters may lead to irregular sleep and dietary habits and, therefore, inconsistencies may be viewed as a limitation; however, the aim of the study was to involve firefighters to maximize practical occupational application. Blood ketone levels were measured via finger prick procedure using a 26 gauge Dynarex (1.8 mm, Orangeburg, NY, USA) self-withdrawing safety lancet and a ketone testing strip (Precision Xtra, Abbott, Alameda, CA, USA). Measurements were taken immediately upon arrival to the laboratory, as well as 20 min after KS ingestion.

2.3. Experimental Procedures

Three total experimental sessions were conducted during session one, where a peak oxygen consumption (VO_{2peak}) test was performed. Sessions two and three involved a simulated physiological workload that consisted of a steady state exercise at 60% of VO_{2peak} with maximal voluntary isometric contractions (MVIC) and postural stability without and with a cognitive task testing performed both prior to the workload (PRE) and after the workload (POST). Each session was separated by 14 days. VO_{2peak} was tested while the participants were wearing a heart rate monitor (FT1, Polar, Electro Inc., Lake Success, NY, USA) and comfortable clothes (PPE were not worn due to safety concerns). Expelled gasses were collected using a MOXUS Modular metabolic system (AEI Technologies, Bastrop, TX, USA). Exercise took place on a Woodway treadmill (Waukesha, WI, USA). Each stage was 3 min in duration. The initial speed was 4.0 km/h with a 4% grade. Stages two through five were fitted at 4% grade and the speed increased by 1.6 km/h at every stage until a speed of 10.4 km/h was reached. For each subsequent stage, the speed did not increase but the grade increased by 1%. Testing was terminated at volitional exhaustion. VO_{2peak} was recorded as the highest VO_2 values averaged over a one-min interval.

All participants arrived at the testing facility after at least an 8 h fast and electromyography (EMG) surface bipolar electrodes were placed on the muscle bellies of vastus medialis (VM), biceps femoris (BF), tibialis anterior (TA), and medial gastrocnemius (MG) of the dominant lower extremity with an interelectrode distance of 2 mm. A Noraxon™ DTS surface EMG system (Scottsdale, AZ, USA) was used to collect muscle activity data with a sampling frequency of 1500 Hz and filtered using a band-pass filter at 20–300 Hz. Following a 5 min warm-up that included jumping jacks, jogs, and high knees, participants completed a pre-workload (PRE) and post-workload (POST) measure of MVIC and postural stability without and with a cognitive task testing, separated by a standardized treadmill exercise protocol which consisted of 35 min of steady state exercise at a workload corresponding to 60% of their VO_{2peak} (L/min). During the workload, all participants wore their full firefighter gear/PPE. Data were collected while participants performed MVIC in a seated position with knees at 90° of flexion for three trials of 3 s each.

Postural stability was measured in (i) eyes open (EO), (ii) eyes closed (EC), and (iii) eyes open dual-task conditions (EOT) for three trials of 20 s using an AMTI™ force plate (AMTI, Watertown, MA, USA) with a sampling frequency of 1000 Hz. The FitLight™ (FL) system (FITLIGHT Sports Corp. Aurora, ON, Canada) was also used for EOT (four lights within comfortable reach distance) while the participants stood on a force plate (Figure 1). For the cognitive dual-task postural stability protocol, one light (same color) lit up every second for 20 s and the participants were allowed 1 s to respond (i.e., to turn the light off). Participants were instructed to touch the turned-on lights to turn them off. This was performed while postural stability was assessed in a dual-task paradigm. Postural stability data were collected while participants completed the cognitive task, as well as without the cognitive task during the EO and EC conditions. Additionally, EMG muscle activity from the VM, BF, TA, and MG muscles were all collected during the postural stability tasks. The postural stability and EMG/MVIC protocols were performed before and after the 35 min steady state exercise at participant's 60% VO_{2peak} (L/min) wearing firefighter PPE.

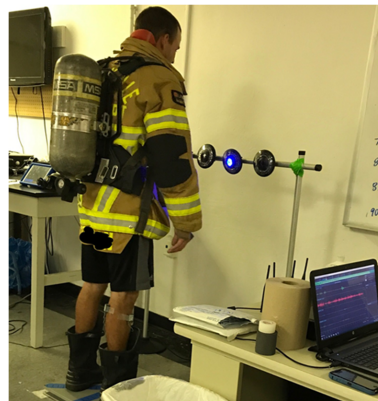


Figure 1. Professional firefighter performing the eyes open dual-task (EOT) cognitive task standing on a force plate measuring postural stability and with electromyography measuring muscle activation of lower extremity muscles.

2.4. Data Analyses

EMG muscle activities from four lower extremity muscles were used to quantify muscle activation levels. EMG variables included mean, root mean square (RMS), and percentage of MVIC (%MVIC) during postural stability trials, and mean and peak during MVIC trials. Postural stability performance was quantified by center of pressure (COP) excursions. Postural stability center of pressure variables included COP sway displacement in the M/L and A/P directions (DISP-ML and DISP-AP), 95% ellipsoid sway area (EA), average sway velocity (SV), and sway length (LEN). The number of correct–incorrect responses and response times (slowest and fastest) were used as an outcome measure to quantify the cognitive task. The number of correct–incorrect responses were determined as the number of correct hits and misses within a second. The response times were determined as the time taken between the light turning on to the light being turned off by the participant in seconds. The fastest and slowest response times were defined as the fastest and slowest time to turn off the lights respectively. Data from all three trials of MVIC, postural stability and cognitive tasks were averaged to be used for statistical analyses.

2.5. Statistical Analysis

A 2×2 (Group (PLA vs. KS) \times Time (Pre-test vs. Post-test)) repeated measures analysis of variance was performed for all dependent EMG (mean and peak during MVIC, mean, RMS, and %MVIC during postural stability trials), postural stability (DISP-ML, DISP-AP, EA, SV, and LEN) and cognitive task variables (correct–incorrect responses, fastest and slowest response times). Alpha level was set at $p < 0.05$ and all statistical analyses was performed using SPSS 24 (IBM SPSS Statistics V24, Armonk, NY, USA).

3. Results

Significant differences in the biomechanical measures were limited to the time main effect (pre-workload vs. post-workload), with no significant differences identified between the group intervention (PLA vs. KS) (Table 2). In addition to the biomechanical measures reported in this paper, it was also found that ingestion of KS resulted in elevated ketone levels compared to placebo ($0.55 \text{ mmol/L} \pm 0.133$ vs. $0.08 \text{ mmol/L} \pm 0.03$) at $p < 0.0001$ using a paired sample t -test.

Table 2. Descriptive statistics for significant results.

| Postural Stability COP Variables | PLA | | KS | |
|--------------------------------------|---------------|-----------------|----------------|----------------|
| | PRE | POST | PRE | POST |
| EC Condition | | | | |
| DISP-ML (cm) | 0.218 ± 0.08 | 0.228 ± 0.08 * | 0.209 ± 0.09 | 0.247 ± 0.09 * |
| DISP-AP (cm) | 0.508 ± 0.12 | 0.500 ± 0.17 | 0.443 ± 0.09 | 0.540 ± 0.18 # |
| EA (cm ²) | 3.42 ± 2.11 | 3.43 ± 2.04 * | 3.22 ± 1.52 | 4.39 ± 2.34 * |
| EOT Condition | | | | |
| EA (cm ²) | 30.4 ± 9.66 | 39.10 ± 19.87 * | 33.47 ± 15.26 | 37.19 ± 16 * |
| EMG during MVIC | | | | |
| Mean TA (mV) | 396.27 ± 145 | 293.4 ± 123 * | 385.72 ± 149 * | 279.10 ± 113 * |
| Mean MG (mV) | 326.79 ± 114 | 264.42 ± 99 * | 292.64 ± 94 | 245.7 ± 121 * |
| Mean VM (mV) | 360.6 ± 212 | 283.22 ± 159 * | 418.8 ± 156 | 333.10 ± 129 * |
| Peak TA (mV) | 2492.3 ± 887 | 1707.9 ± 673 * | 2165.7 ± 762 | 1651.9 ± 651 * |
| Peak MG (mV) | 2229.3 ± 688 | 1796.3 ± 718 * | 2018.9 ± 611 | 1683.1 ± 837 * |
| Peak VM (mV) | 2123 ± 1033 | 1621 ± 697 * | 2316.7 ± 816 | 1802.4 ± 594 * |
| EMG during Postural Stability | | | | |
| EC Condition | | | | |
| %MVIC BF | 6.18 ± 4.5 | 3.35 ± 2.5 * | 7.30 ± 6.1 | 5.84 ± 5.5 * |
| EOT Condition | | | | |
| %MVIC BF | 17.345 ± 8.0 | 13.17 ± 6.0 * | 21.67 ± 12.2 | 17.51 ± 16.6 * |
| Cognitive Performance | | | | |
| Slowest Response Times (s) | 0.72 ± 0.12 * | 0.67 ± 0.12 * | 0.67 ± 0.08 | 0.65 ± 0.11 |

Descriptive statistics for significant postural stability, Electromyography (EMG), and cognitive performance variables reported as mean ± SD. * denotes significantly different from PRE and # denotes KS different from PLA but only for POST. All significance values are at $p < 0.05$. PLA: placebo intervention; KS: ketone salts intervention; PRE: pre-workload; POST: post-workload; EC: eyes closed; EOT: eyes open cognitive task; DISP-ML: postural sway in medial-lateral direction; DISP-AP: postural sway; EA: postural sway area; MVIC: maximal voluntary isometric contraction; TA: tibialis anterior; MG: medial gastrocnemius; VM: vastus medialis; BF: biceps femoris.

3.1. Electromyography MVIC

Significantly lower mean and peak muscle activity were identified for TA, MG, and VM for MVIC during the post-workload measures at $p < 0.05$ level with the exception of BF (Figure 2). No significant difference was seen in MH.

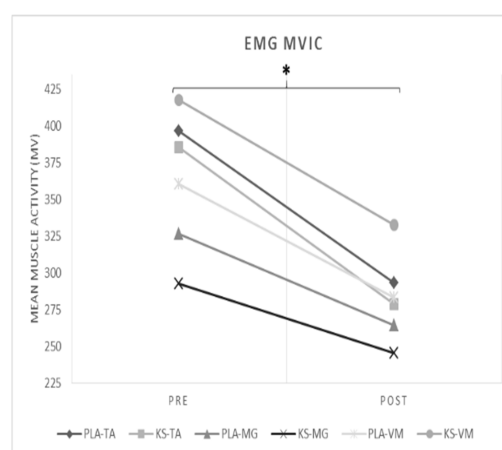


Figure 2. Mean EMG muscle activity during maximal voluntary isometric contractions (MVIC) before (PRE) and after (POST) the treadmill workload in firefighters. Groups: Placebo (PLA) and Ketone (KS). Muscles: Tibialis anterior (TA), medial gastrocnemius (MG) and vastus medialis (VM). * represents significant difference for all muscles and for both groups between PRE and POST at $p < 0.05$.

3.2. Postural Stability

Significantly greater DISP-ML ($p = 0.014$), significantly greater EA ($p = 0.004$) and a significant interaction ($p = 0.027$) with greater DISP-AP in KET were identified during the post-workload measures for EC condition. Significantly greater EA ($p = 0.039$) was evident in the post-workload during the EOT condition (Figure 3). No other significant differences were found for the rest of the variables.

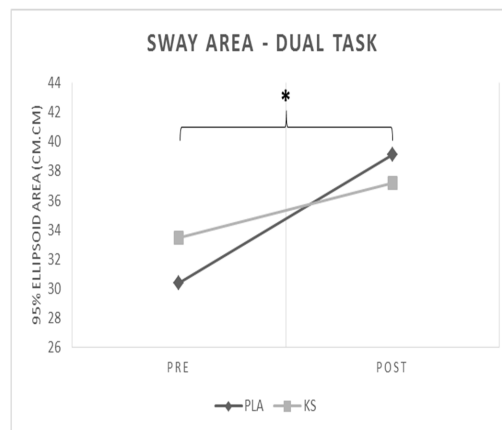


Figure 3. Mean center of pressure sway area during eyes open dual-task postural stability test, before (PRE) and after (POST) the treadmill workload in firefighters. Groups: Placebo (PLA) and Ketone (KS). * represents significant difference between PRE and POST at $p < 0.05$.

3.3. Electromyography during Postural Stability

During postural stability tasks, significantly lower %MVIC for BF during EC ($p = 0.002$) (Figure 4a) and EOT ($p = 0.049$) (Figure 4b) conditions were identified for the post-workload measures. No other significant differences were found for the rest of the dependent EMG variables.

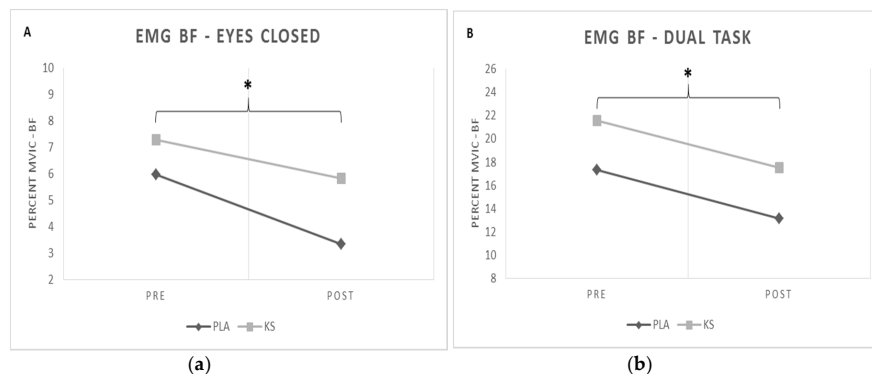


Figure 4. Mean EMG percent maximal voluntary isometric contraction (%MVIC) during eyes closed (a) and eyes open dual-task; (b) postural stability tests, before (PRE) and after (POST) the treadmill workload in firefighters. Groups: Placebo (PLA) and Ketone (KS) for biceps femoris (BF). * represents significant difference for biceps femoris in both groups between PRE and POST at $p < 0.05$.

3.4. Cognitive Task

During the EOT cognitive task for the slowest-response time variable, a significant group \times time interaction ($p = 0.015$) was observed with post hoc comparisons revealing quicker response times during the post-workload measure for PLA (Figure 5). No other significant differences were found for the rest of the cognitive task variables.

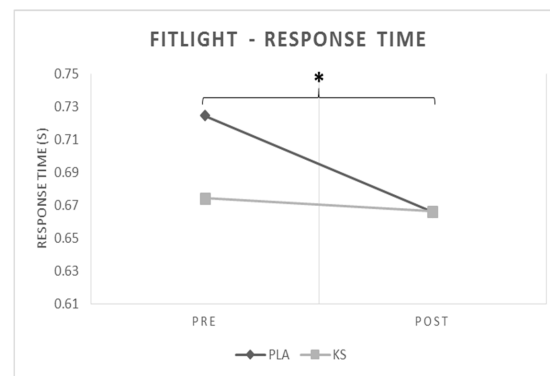


Figure 5. Mean slowest response time during eyes open dual-task postural stability test, before (PRE) and after (POST) the treadmill workload in firefighters. Groups: Placebo (PLA) and Ketone (KS).

* represents significant difference for PLA from KS during POST at $p < 0.05$.

4. Discussion

The purpose of the study was to determine the impact of ingesting KS on postural stability in single and dual-task conditions and muscle activity before and after a physical workload. The main findings of this study suggest that the ingestion of KS did not impact postural stability, muscle activity, and response times of the cognitive task, as significant differences between PLA and KS were not evident. However, significant differences in postural stability, muscular exertion, and cognitive performance were negatively impacted following the physical workload while wearing full firefighter PPE.

Short-term ingestion of exogenous KS did not affect muscular activation, dual-task postural stability, or cognitive performance in the firefighters. Previous research investigating cognitive performance with ketones has seen potential benefits in individuals with mild cognitive impairments [12] and in individuals with Alzheimer's disease [14], thus aiding in the hypothesis that a 7-day ketone supplementation can potentially impact cognitive performance specific to postural control without and with cognitive tasks. It has been suggested that elevated circulating ketones bodies may provide neuroprotective benefits, such as decreasing reactive oxygen species production [21,22]. However, many investigations utilize calorie restriction and a ketogenic diet to induce elevations in endogenous ketone levels. It is also hypothesized that ketone supplementation can alter metabolism and exercise performance [12,14]. The current literature with exogenous ketone supplementation is limited, and the exact mechanisms or benefits are unknown [22]. The lack of differences in postural stability between KS and PLA could be attributed to the already healthy physiological and neurological state of the current sample of firefighters. Additionally, the supplements were only consumed for 1 week, which may be too short of a period to observe differences in the nervous system. With the lack of literature in this area of ketone supplementation, specific to postural stability, cognitive performance, and muscular exertion in active duty firefighters, the findings from the study help fill the gaps in the literature. It should be noted that 7 out of the 9 participants reported mild gastrointestinal discomfort while taking the KS. However, this was not formally measured and is therefore not quantifiable.

The exertional physical workload of the treadmill task with full PPE gear resulted in reduced postural stability and increased muscular fatigue as demonstrated by increased postural sway and decreased muscle activity of lower extremity muscles during maximal voluntary isometric contractions. With regards to postural stability, significantly greater medial lateral postural sway (DISP-ML) and postural sway area (EA) indicate decreased postural stability in the EC condition, especially when one of the sensory systems (visual system) is not available. Similarly, significantly decreased balance performance has been reported during postural stability assessments that challenge the sensory postural control systems in firefighters with full PPE following a stair-climb workload [7]. The only interaction in the study included a significantly greater anterior posterior postural sway (DISP-AP)

for the KS group in EC condition, but was only observed in the post-workload testing, indicating poor performance in postural stability. However, this was the only variable that was significant, and results should be interpreted with caution. The degradation of the sensory postural control systems, specifically the proprioceptive/ somatosensory system, due to muscular fatigue has been reported as a reason for the decrements in postural stability [7–10]. Additionally, the effects of firefighter PPE which included rubber boots on balance abilities have been assessed in firefighters, and the PPE was found to impair balance performance especially in eyes closed conditions [7]. These impacts are more pronounced when other sensory systems are challenged, such as firefighting scenes that compromise vision and have the dual task of performing firefighting rescue activities, which can be analogous to the EC and EOT postural stability testing conditions in the current study.

Additionally, muscle activity during both the MVIC and during the more challenging postural stability tests of EC and EOT (dual-task) conditions, demonstrated significantly reduced muscle activity which could be attributed to the inefficient activation of the lower extremity muscles due to the exertion from physical workload and muscular fatigue [23,24]. Finally, results from the cognitive task, when viewed as a single-task, were contrary to the hypothesis, as the slowest response time was significantly lowered, indicating better cognitive performance after the physical workload for PLA. However, during EOT (dual-task), postural stability was significantly lowered. A reduction in the performance and ability to perform concomitant physical and mental tasks—when there is an increased need of mental effort in the execution of the mental task—was found to be altered by the magnitude of the simultaneous physical task performed [25]. Hence, during dual-task conditions of performing a cognitive task and maintaining optimal postural stability, the motor control system might have favored the cognitive task over the postural stability task, specifically under muscular exertion and fatigue as a result of the physical simulated workload with PPE. However, the limitation of a possible learning effect on the cognitive task may be a reason for the observed results. The KS supplementation was for a 7-day period in the current study, however, previous studies have also been done using a much shorter duration, such as on the same day [14], and as well as using a much longer intervention time, such as 6 weeks [12]. Hence, the results from the current study needs to be interpreted as 7-day supplementation-based findings. An additional limitation to this study was the small sample size. While a larger sample size would have been preferable, it is difficult to gain access to active duty professional firefighter population, and the study procedures did require a large time commitment on the behalf of the participants. The study was conducted at a University in a small college town, so the potential pool of participants was small. Other studies examining similar variables among firefighters or during firefighting simulations have used a comparable sample size such as twelve professional firefighters with a mean age of 33.42 ± 6.83 years [7], and with simulated firefighting workloads on 10 healthy individuals with a mean age of 21.6 ± 1.8 years [26,27]. Moreover, while the sample size was lower, our sample consisted of active duty professional firefighters who are indicative of the observed results in a real-world application.

5. Conclusions

The current findings add to the literature of firefighter research that aims to minimize occupational injuries and promote safety. The findings report on the impact of ketone supplementation and physiological workload on postural stability, muscular exertion, and cognitive measures, which can provide real-world applications in firefighter safety. Based on the results observed in the current study, 7-day ketone salts supplementation did not impact postural stability, muscle activity, and response times of the cognitive task, as significant group differences were not evident among the current sample of active duty firefighters. However, significant differences in postural stability, muscular exertion, and cognitive performance were negatively impacted following the physical workload while wearing full firefighter PPE. Additionally, the current study also suggests that the physical workload with full PPE has a greater impact on postural control and muscular exertion. Thus, future research should focus on modifications to firefighter PPE and the workload experienced by them to promote fire safety.

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References

1. Cloutier, E.; Champoux, D. Injury risk profile and aging among Quebec firefighters. *Int. J. Ind. Ergon.* **2000**, *25*, 513–523. [CrossRef]
2. Kong, P.W.; Suyama, J.; Cham, R.; Hostler, D. The relationship between physical activity and thermal protective clothing on functional balance in firefighters. *Res. Q. Exerc. Sport* **2012**, *83*, 546–552. [CrossRef] [PubMed]
3. Bureau of Labors Statistics. Fatal and Non-Fatal Occupational Injuries by Industry, Event, or Exposure. US Department of Labor, 2017. Available online: <https://www.bls.gov/iif/oshcdnew2017.htm> (accessed on 28 January 2019).
4. Kincl, L.D.; Bhattacharya, A.; Succop, P.A.; Clark, C.S. Postural sway measurements: A potential safety monitoring technique for workers wearing personal protective equipment. *Appl. Occup. Environ. Hyg.* **2002**, *17*, 256–266. [CrossRef] [PubMed]
5. Punakallio, A. Balance abilities of workers in physically demanding jobs: With special reference to firefighters of different ages. *J. Sports Sci. Med.* **2005**, *4*, 1–47.
6. Punakallio, A.; Lusa, S.; Luukkonen, R. Protective equipment affects balance abilities differently in younger and older firefighters. *Aviat. Space Environ. Med.* **2003**, *74*, 1151–1156.
7. Garner, J.C.; Wade, C.; Garten, R.; Chander, H.; Acevedo, E. The influence of firefighter boot type on balance. *Int. J. Ind. Ergon.* **2013**, *43*, 77–81. [CrossRef]
8. Chander, H.; Garner, J.C.; Wade, C. Impact on balance while walking in occupational footwear. *Footwear Sci.* **2014**, *6*, 59–66. [CrossRef]
9. Chander, H.; Morris, C.E.; Wilson, S.J.; Garner, J.C.; Wade, C. Impact of alternative footwear on human balance. *Footwear Sci.* **2016**, *8*, 165–174. [CrossRef]
10. DeBusk, H.; Hill, C.M.; Chander, H.; Knight, A.C.; Babski-Reeves, K. Influence of military workload and footwear on static and dynamic balance performance. *Int. J. Ind. Ergon.* **2018**, *64*, 51–58. [CrossRef]
11. Perroni, F.; Guidetti, L.; Cignitti, L.; Baldari, C. Psychophysiological responses of firefighters to emergencies: A review. *Open Sports Sci. J.* **2014**, *7* (Suppl. 1), 8–15. [CrossRef]
12. Krikorian, R.; Shidler, M.D.; Dangelo, K.; Couch, S.C.; Benoit, S.C.; Clegg, D.J. Dietary ketosis enhances memory in mild cognitive impairment. *Neurobiol. Aging* **2012**, *33*, 425.e19–425.e27. [CrossRef] [PubMed]
13. Murray, A.J.; Knight, N.S.; Cole, M.A.; Cochlin, L.E.; Carter, E.; Tchabanenko, K.; Pichulik, T.; Gulston, M.K.; Atherton, H.J.; Schroeder, M.A.; et al. Novel ketone diet enhances physical and cognitive performance. *FASEB J.* **2016**, *30*, 4021–4032. [CrossRef] [PubMed]
14. Reger, M.A.; Henderson, S.T.; Hale, C.; Cholerton, B.; Baker, L.D.; Watson, G.S.; Hyde, K.; Chapman, D.; Craft, S. Effects of β -hydroxybutyrate on cognition in memory-impaired adults. *Neurobiol. Aging* **2004**, *25*, 311–314. [CrossRef]
15. Henderson, S.T.; Vogel, J.L.; Barr, L.J.; Garvin, F.; Jones, J.J.; Costantini, L.C. Study of the ketogenic agent AC-1202 in mild to moderate Alzheimer’s disease: A randomized, double-blind, placebo-controlled, multicenter trial. *Nutr. Metab.* **2009**, *6*, 31. [CrossRef] [PubMed]
16. Meeusen, R.; Decroix, L. Nutritional Supplements and the Brain. *Int. J. Sport Nutr. Exerc. Metab.* **2018**, *28*, 200–211. [CrossRef] [PubMed]
17. Waldman, H.S.; Basham, S.A.; Price, F.G.; Smith, J.W.; Chander, H.; Knight, A.C.; Krings, B.M.; McAllister, M.J. Exogenous ketone salts do not improve cognitive responses after a high-intensity exercise protocol in healthy college-aged males. *Appl. Physiol. Nutr. Metab.* **2018**, *43*, 711–717. [CrossRef] [PubMed]

18. Rodger, S.; Plews, D.; Laursen, P.; Driller, M. The effects of an oral β -hydroxybutyrate supplement on exercise metabolism and cycling performance. *J. Sci. Cycl.* **2017**, *6*, 26–31.
19. O'Malley, T.; Myette-Cote, E.; Durrer, C.; Little, J.P. Nutritional ketone salts increase fat oxidation but impair high-intensity exercise performance in healthy adult males. *Appl. Physiol. Nutr. Metab.* **2017**, *42*, 1031–1035. [[CrossRef](#)]
20. Stubbs, B.J.; Cox, P.J.; Evans, R.D.; Santer, P.; Miller, J.J.; Faull, O.K.; Magor-Elliott, S.; Hiyama, S.; Stirling, M.; Clarke, K. On the metabolism of exogenous ketones in humans. *Front. Physiol.* **2017**, *8*, 848. [[CrossRef](#)]
21. Maalouf, M.; Sullivan, P.G.; Davis, L.; Kim, D.Y.; Rho, J.M. Ketones inhibit mitochondrial production of reactive oxygen species production following glutamate excitotoxicity by increasing NADH oxidation. *Neuroscience* **2007**, *145*, 256–264. [[CrossRef](#)]
22. Maalouf, M.; Rho, J.M.; Mattson, M.P. The neuroprotective properties of calorie restriction, the ketogenic diet, and ketone bodies. *Brain Res. Rev.* **2009**, *59*, 293–315. [[CrossRef](#)] [[PubMed](#)]
23. Turner, A.J.; Swain, J.C.; McWhirter, K.L.; Knight, A.C.; Carruth, D.W.; Chander, H. Impact of occupational footwear and workload on lower extremity muscular exertion. *Int. J. Exerc. Sci.* **2018**, *11*, 331–341.
24. Hill, C.M.; DeBusk, H.; Knight, A.C.; Chander, H. Influence of military-type workload and footwear on muscle exertion during static standing. *Footwear Sci.* **2017**, *9*, 169–180. [[CrossRef](#)]
25. DiDomenico, A.; Nussbaum, M.A. Effects of different physical workload parameters on mental workload and performance. *Int. J. Ind. Ergon.* **2011**, *41*, 255–260. [[CrossRef](#)]
26. Morris, C.E.; Winchester, L.J.; Jackson, A.J.; Tomes, A.S.; Neal, W.A.; Wilcoxon, D.M.; Chander, H.; Arnett, S.W. Effect of a simulated tactical occupation task on physiological strain index, stress and inflammation. *Int. J. Occup. Saf. Ergon.* **2018**. [[CrossRef](#)] [[PubMed](#)]
27. Morris, C.E.; Winchester, L.J.; Jackson, A.J.; Tomes, A.S.; Neal, W.A.; Wilcoxon, D.M.; Chander, H.; Arnett, S.W. Effect of a simulated tactical occupation stressor and task complexity on mental focus and related physiological parameters. *Int. J. Ind. Ergon.* **2018**, *66*, 200–205. [[CrossRef](#)]



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