

EFFECTS OF CAFFEINE CAPSULES ON DYNAMIC AND STATIC BALANCE

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Abstract

Caffeine (CAF) is known for its central nervous system (CNS) stimulating function by acting as an adenosine receptor antagonist, but it also has some ergogenic effects. That is, CAF has implications in enhancing physical performance and endurance¹⁰. CAF has been shown to alter skeletal muscle contractions by opening of calcium ion channels¹⁹. There is also some evidence that suggests that CAF affects rate of relaxation of the skeletal muscles². To further understand how caffeine affects humans in our daily living activities, the effects of CAF on dynamic and static balance were investigated. With the consumption of CAF, it can be assumed that there will be improvement in balance and motor control due to increase in force and duration of skeletal muscle contraction in the muscles being used for balance.

Introduction

Caffeine

Caffeine (1,3,7-Trimethylxanthine) is a drug that is highly consumed by people every single day, making the industry for it an ever-growing one. According to a 2014 coffee survey, participants indicated they consumed 2.3 cups of coffee per day on average¹. It is mostly ingested in the form of coffee, tea, soft drinks, chocolate, ice cream, yogurt, capsules/tablets, and is a component in many medicines²⁹. Its primary function for habitual CAF consumers is as a central nervous system (CNS) stimulant. By acting as an antagonist to adenosine receptors⁹, CAF has been found to increase alertness, psychomotor and cognitive performance, and even improve

mood²². But on the other hand, adverse psychological effects are associated when habitual CAF consumers are experiencing withdrawals. Common withdrawal symptoms are decreased alertness and clearheadedness⁹.

However, in skeletal muscles data that suggests CAF may have beneficial effects to lead to ergogenic consequences. In other words, CAF is thought to have a positive impact on physical performance¹⁰. A 2009 meta-analysis of CAF's effect on endurance events showed CAF ingestion before exercise lead to a mean performance improvement of $2.3 \pm 3.2\%$. All studies studied in this meta-analysis administered CAF 60 minutes prior to exercise except for one study; MacIntosh and Wright administered CAF 150 minutes prior to exercise¹⁶. The events included in this meta-analysis were rowing (2000-meters³), running (8-kilometers⁸, 10-kilometers⁶, 18-kilometers²⁷, 1500-meters²⁸, time-to-exhaustion²⁵), bicycling (100-kilometers¹⁴), swimming (1500-meters¹⁶), and other unnamed endurance events¹⁵. Performance was even further improved ($4.3 \pm 5.3\%$) when CAF was ingested before and during the exercise¹⁰. The researchers also determined that abstaining from CAF for 2 and 4 days (versus 0 days) lead to an even greater performance improvement¹⁰. Essentially, these researchers have shown that when athletes abstained from CAF for 2 and 4 days before the ingestion of CAF on the day of testing, their performance was improved when compared to performances when CAF was not abstained prior to testing.

The absolute amount of CAF ingested is very loosely associated with performance improvement. According to Ganio et al, at least 3 mg/kg of body weight was needed to result in an improvement¹⁰. The maximal amount of improvement was seen when amount of ingested caffeine was 6 mg/kg. No improvement was detected with CAF amounts greater than 9 mg/kg¹⁰.

This implies that the body is not as sensitive to the effects of CAF when ingested at great amounts.

This apparent ergogenic effect may have to do with calcium (Ca^{2+}) ion channels of skeletal muscles. CAF showed a greater force and duration of muscle contraction in dissected gastrocnemius muscle of a frog¹⁹. Ca^{2+} ion channels stayed open longer, causing an increase in cytosolic Ca^{2+} concentrations from Ca^{2+} being released by the sarcoplasmic reticulum (SR)². The elevated concentration of Ca^{2+} allows for greater amounts of the calcium to bind with the troponin (TN). This then leads to greater cross-bridges to form by the actin and myosin²⁶. The formation is heavily dependent on Ca^{2+} , but also Adenosine Triphosphate (ATP) and ATPase located in very close proximity to the actin-binding site²⁰. The hydrolysis of ATP to ADP and inorganic phosphate (P_i) is required for the muscular contraction to occur. ATP is an essential high-energy compound for mechanical work, and CAF is said to improve carbohydrate (CHO) oxidation²⁰. With the oxidation of CHO, the body is able to produce the needed amount of ATP for the mechanical work being done.

Balance and Caffeine

Balance refers to postural stability according to Shumway-Cook and Wollacott (2011)²⁵. In simpler terms, balance is our capability to not fall while performing a given task. There are said to be at least two different types of balance¹⁷: static and dynamic. Static and dynamic balance both indicate the ability to maintain postural equilibrium, but specifically the capability of maintaining the postural stability while stationary and in motion, respectively. Dynamic and static balance are known to be different abilities. In fact, Rose et al showed that static balance and dynamic balance are different motor abilities; children suffering from Cerebral

Palsy showed trouble with dynamic balance, but not static balance²³. Some evidence in the literature suggests a large factor in the difference is due to repetitive training experience involving balance, as well as differences in the level of involvement of the vestibular system⁵. The vestibular system is a sensory system in place to provide self-sense of balance and spatial orientation for the purpose of coordination.

Balance is at the fundamental core of motor skills that are required for physical activity. Almost all physical activity requires a form of balance. From toddlerhood to late adulthood, the importance of maintaining balance is clear. As people get older they are more prone to balance disorders that lead to falls, leading to fall-related injuries⁴. For this reason, CAF ingestion in a moderate amount outlined by Ganio et al¹⁰ should improve both static and dynamic balance.

Sleep and Balance

Many coaches and athletes believe that adequate sleep is crucial for optimum performance. Mejri et al found that sleep deprivation led to hindered physical performance the next day compared to each subject's own baseline sleep night¹⁸. The performance measured in this study was called the shuttle run test. The method in which Mejri et al conducted this test was to make the purpose of the shuttle run test a time objective; the athletes had to complete the test before time runs out. Speed was increased at each stage of the shuttle run test. This is a test to measure overall agility, speed, and coordination. The researchers found that when the Taekwondo players were sleep deprived (less than 3 hours of sleep), their performance on the shuttle run test was significantly worse than their performance after a normal night's sleep. The cause for the worsened performance could be due to disruption of regular physiological activities due to insufficient sleep. This then in turn could lead to worsened balance capabilities.

Additionally, researchers¹² found that when subjects were sleep deprived 24-hours and 36-hours (compared to normal night of sleep), several near falls occurred with balance perturbations. These perturbations consisted of vibratory proprioceptive calf stimulation. Proprioceptors are sensory receptors found in muscles, tendons, joints, and inner ear to help us relay information about the position of the body and its movement in space¹². When subjects in the three conditions (normal sleep [8-hours], 24-hours sleep deprived, 36-hours sleep deprived) were faced with the same postural stability disruption, sleep deprived subjects struggled more to maintain postural equilibrium. The subjects' balance was tested utilizing a technique designed for assessing movement and posture (posturography).

Sleep's importance on balance has been seen both in older adults²¹ and children⁷. Robillard et al found that older subjects (mean age of 64 years) after sleep deprivation (for 26-hours) led to worsened performance on postural tasks on a force plates under three conditions: interference task (auditory task), control task, and no cognitive task. In the auditory task, the subjects (while maintaining balance), had to listen to words different words in each ear; they had to quickly and accurately report what word they heard in the right ear while ignoring the auditory stimulus from the left ear²¹. In the control task, the same words were played into both right and left ears congruently. Again, they had to report the words they were hearing. In the no cognitive task condition, subjects only maintained balance without any additional tasks. The researchers found older adults compared to younger adults (mean age of 24 years), were more sensitive to sleep deprivation; their performance on balance (measured in the velocity and force produced by postural instability on force plates) was worsened when compared to their own baseline measurements after normal night of sleeping based on their own self-selected sleep-wake schedule. Boto et al⁷ found that children admitted to hospitals for fall-related injuries had shorter

sleep durations compared to children admitted to hospitals for routine check ups. G1 refers to the group of kids admitted to the hospital with fall-related injuries, G2 refers to the group of kids admitted to the hospital for routine check ups. This descriptive study compared these two groups of children aged 1-14 years and studied their sleep pattern. Children in G1 had a higher percentage of children getting less than 8 hours of sleep per night and a lower percentage of kids getting more than 10 hours of sleep per night. The opposite was true for children in G2; more children in this group got more than 10 hours of sleep while fewer children getting less than 8 hours. This suggests that children who are not getting sufficient sleep (based on an 8-hour/night standard) were statistically more prone to fall-related injuries. Overall, insufficient sleep should lead to worsened balance; both static and dynamic balance.

Since the subjects who were a part of this study were college students, insufficient sleep would be defined by less than 8 hours/night¹³. And it is assumed that college students who depend on CAF for mental wakefulness, there should be a negative correlation between CAF and sleep duration.

Methods

Subjects

Volunteers were recruited through flyers (IRB approved on November 9th, 2015) on bulletin boards and word-of-mouth advertisement. A total of 25 volunteer subjects (12 women and 13 men) were included in this study. Ages of the males (22.3 ± 3.5 years) and females (21.6 ± 3.4 years) were similar. Mean age for all subjects was 21.9 ± 3.4 years. Average weight for males and females were 75 ± 7.28 -kg and 57.46 ± 6.35 -kg, respectively. Average weight for

males and females in the CAF condition groups was 70.76 ± 5.63 -kg and 58.18 ± 8.04 -kg, respectively. All subjects met all required inclusion criteria: habitual CAF consumption without any adverse reactions, between the ages of 18-35 years, self-reported good health without any known medical conditions, no drug use, is not or not planning to become pregnant, and is able to understand the consent form (IRB approved November 9th, 2015). The study was described to the subjects as a research study investigating the effects of CAF on motor control, and were also told it had been approved by the Institutional Review Board (IRB). After completing the habitual sleep logs and three balance tests, they were paid \$25. All funds for compensating the subjects were provided by the Undergraduate Research Opportunity Program (UROP).

Habitual sleep logs

For 7 days preceding the start of the study and the morning of the study, the subjects self-reported their sleep and wake times. The subjects' sleep logs were then utilized to calculate sleep duration to assess whether sleep duration plays a role in the effect of CAF on static and dynamic balance.

Randomized assignment to conditions

The subjects were randomly assigned to one of two groups via GraphPad Software, either the control group or the experimental (CAF) group. They were not told what condition they had been assigned to until after the completion of the entire study, making this a single-blind study. Regardless of his/her assigned group, each subject was studied in the morning and was asked not to consume any CAF on the day of the experimental testing to avoid as many confounding

variables as possible. The subjects were given their treatment; placebo capsule for the control group and a 200 milligram CAF capsule for the experimental group. Water was the only mode of delivery for all subjects. 20 minutes after ingestion of the treatment, the subjects underwent three balance tests to quantify their balance performance.

Balance tests

The investigator conducted three novel balance tests instead of complex motor control tests to avoid skills that some subjects may have had deliberate practice in as compared to other subjects. Although quantifying the ability to balance is not transferrable to more complex movements we produce, the basic balance measurements may allow the effect of CAF on motor control to be detected in a more practical manner. By studying simple balance tests instead of complex ones, it will assure that there are no other factors (i.e. intentional practice by some subjects on complicated tasks) to skew the results. The balance measurements consisted of the stick test, stork stand, and the book-balancing test. None of the tests had a time objective, but the goal is to maximize the time in balance for the static tests, and minimize the duration of the book-balancing test. A stopwatch was utilized to measure time in balance in all three tests:

The Stick Test (STI) measures static balance by measuring the length of time the subject can remain in balance on one foot on a narrow stick (1 in. x 1 in. x 12 in. long). Subjects begin by placing the ball of one foot of choosing crosswise on the stick. Once the investigator begins timing, the subject will raise the other foot off the floor. Any loss of balance stops timing.

The Stork Stand (STO) also measures static balance by measuring how well the subject can maintain balance in a highly specific body position. The subject begins with hands on his/her hips. Once the investigator gives the command to begin, the subject will raise and place the non-

preferred leg on the inside of the knee of the preferred leg on which he/she will balance on. The heel of the preferred leg will then be raised. Once it is raised, the timing will begin and any loss of balance stops the timing trial.

The Book-Balance Test (BB) measures dynamic balance. The subject walks along a marked line on the floor that is 10 feet long while balancing a medium-sized book on his/her head. The subject walks heel-to-toe to one end of the line and back to original starting point. If he/she drops the book, he/she must stop, balance the book before continuing to walk from the point at which the book was dropped. The time it takes to walk down and back was recorded. The subjects were told that walking along the line and completing it at the fastest time possible were equally important in this test.

Each subject had three trials for each balance test. Since we are investigating the effect of CAF on a motor ability (i.e. balance) and not the effects of intentional practice on balance nor a learning curve, only three trials were conducted for each subject. He/she was given verbal directions prior to the start of testing. For all subjects, a total of six variables were considered for the data collected for each of the three balance tests: an overall average and an average of the best recorded times (a single time point from each subject for each balance test). The six variables for each subject were Average Stick Test (AVG STI), Best Stick Test (Best STI), Average Stork Stand (AVG STO), Best Stork Stand (Best STO), Average Book Balance (AVG BB), and Best Book Balance (Best BB).

Data Analysis

An Analysis of Variance (ANOVA) was performed to analyze the differences among the group means (CAF versus control) for the six variables. A Pearson correlation was performed to

measure the relationships between the six balance test variables, sleep duration, and sleep regularity between all subjects and among each group (CAF and control). Correlations between all variables was conducted to identify any relationships among them.

Results

Between-group differences in self-reported sleep duration were not statistically significant ($F(1, 24)=0.003$, $p=0.957$). The mean sleep durations (\pm standard deviations) were 7.74 ± 0.81 and 7.72 ± 0.86 hours/night for the CAF and control groups, respectively.

As portrayed in Figure 1, there were statistically significant differences between the two groups for the average of book-balancing (AVG BB) and the average of the best recorded times for book-balancing (Best BB). According to the ANOVA results, the control group (18.25 seconds) completed the task significantly faster than the CAF group (23.59 seconds), $F(1, 24)=5.512$, $p=0.028$ when comparing Best BB. The AVG BB for the caffeine group was 25.40 seconds versus 21.71 seconds for the control group, $F(1, 24)=4.687$, $p=0.041$. Since one of the objectives of the BB tests is to complete the task as quickly as possible, it can be said that the CAF group performed *worse* than the control group. There were also some between-group insignificant differences on the balance tests; AVG STI ($F(1, 24)=2.493$, $p=0.128$), Best STI ($F(1, 24)=0.541$, $p=0.469$), AVG STO ($F(1, 24)=2.397$, $p=0.135$), Best STO ($F(1, 24)=1.063$, $p=0.313$).

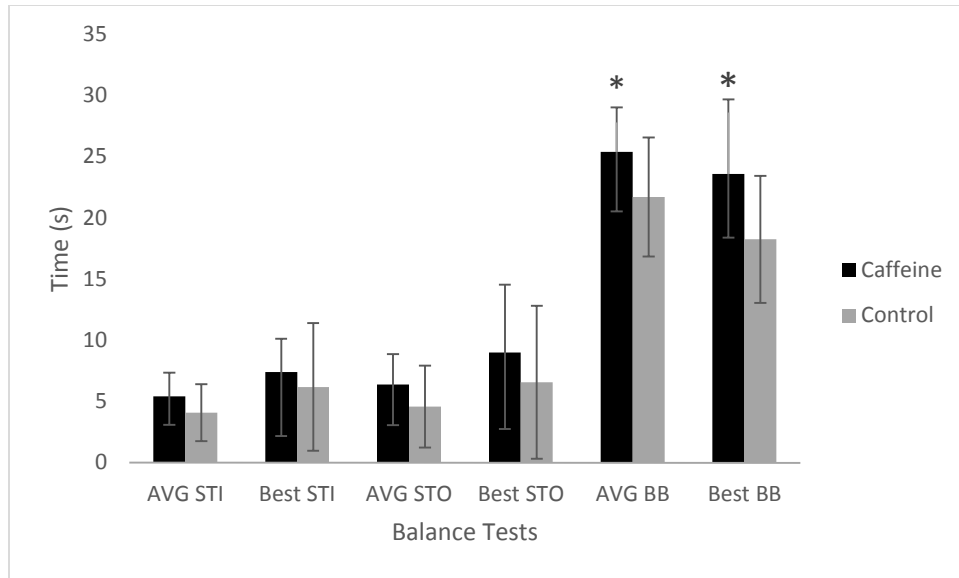


Figure 1. Comparison of caffeine (n= 13) and control (n=12) groups' performances in three balance tests: Stick Tests (STI), Stork Stand (STO), and Book-Balancing (BB). Time was measured in all three tests utilizing a standard stopwatch. * Represents statistically significant difference between groups at an alpha value of 0.05. Standard deviation error bars are shown.

The correlation of the variables considered for the balance tests, sleep duration, and deviation in sleep duration (sleep irregularity) is shown in Figure 2. Average STO and average of the best STO recordings both indicated a significant positive correlation ($r=0.699$, $p=0.008$; $r=0.792$, $p=0.001$) with sleep regularity within the CAF group; the more irregular sleep subjects in the CAF condition reported, better performance on the STO was measured. Similar results were indicative for the Best BB ($r=-0.576$, $p=0.039$). As sleep irregularity increased for subjects in the CAF group, the average of the best times recorded for BB had a negative slope. Recall the objective of the BB test was to complete the task in the fastest time possible while keeping dynamic balance of the body in motion and the book. No significant correlation was detected

between sleep regularity (i.e. standard deviation in sleep duration) and balance test variables for control subjects.

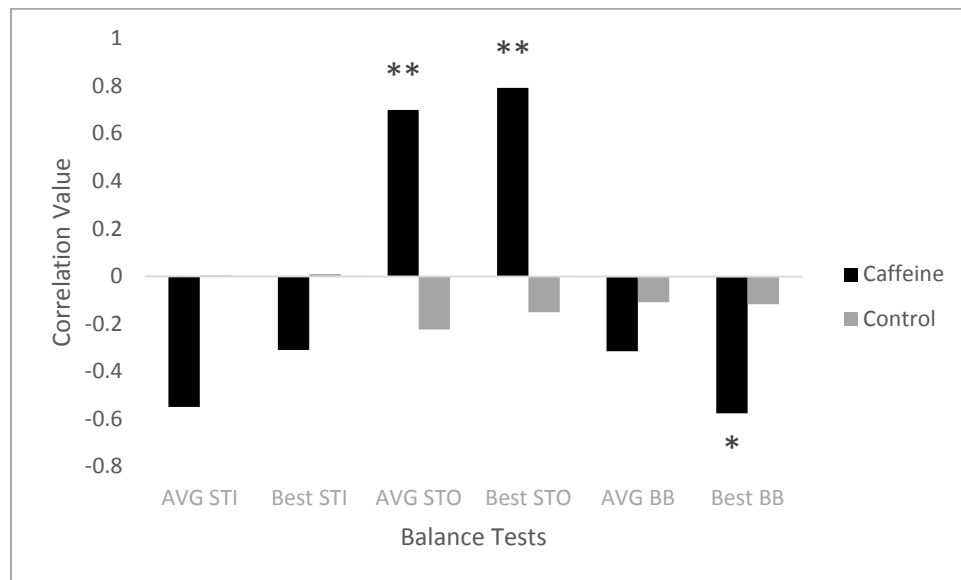


Figure 2. Average Pearson correlations of the balance tests (Stick Tests [STI], Stork Stand [STO], and Book-Balancing [BB]) among all subjects (N=25) with deviation in sleep duration. * Represents statistical significance at an alpha value of 0.05. ** Represents statistical significance at an alpha value of 0.01.

However, there were significant positive correlations with sleep duration with the balance test variables among all subjects (N=25). With greater sleep duration, time kept in balance on the STI test was also lengthened. The average STI ($r=0.417$, $p=0.038$) and best STI ($r=0.432$, $p=0.031$) times had significant positive correlations with sleep duration. Among the separate conditions, only average STI ($r=0.586$, $p=0.045$) for the control condition had a significant

correlation with sleep duration. No other balance testing variables had significant correlations with sleep duration in either condition.

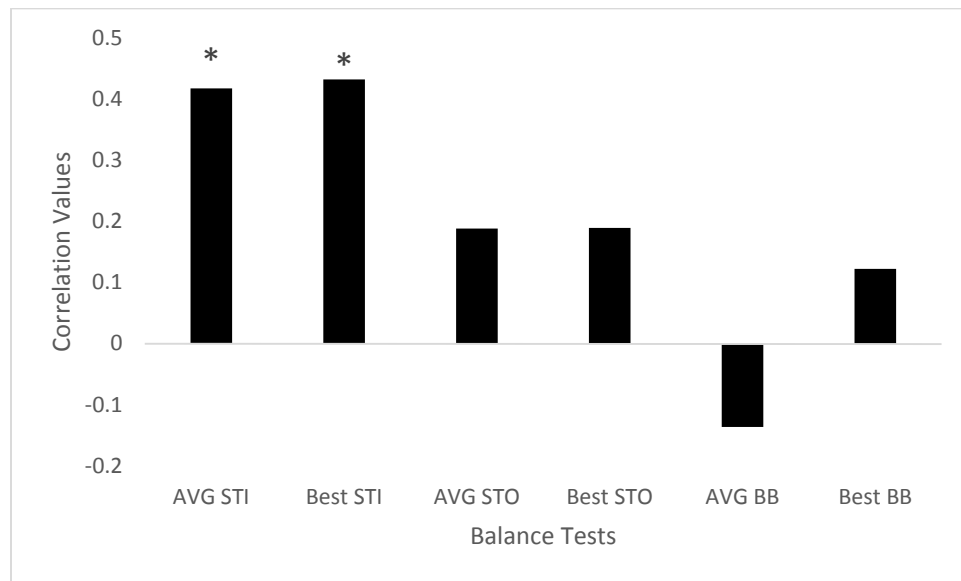


Figure 3. Average Pearson correlations of the balance tests (Stick Tests [STI], Stork Stand [STO], and Book-Balancing [BB]) among all subjects (N=25) with sleep duration. * Represents statistical significance at an alpha value of 0.05.

Discussion

The initial hypothesis was that ingestion of CAF (versus no CAF) would improve balance. With currently collected data, it can be said CAF *hindered* dynamic balance as compared to no CAF; both the AVG BB and Best BB were significantly faster for the control group. It is not completely clear as to why only dynamic balance was affected by CAF but not static balance, but it could be due to a combination of CAF withdrawal and insufficient sleep.

When observing the amount of sleep each subject got the night before the balance measurements, CAF subjects got 6.33 ± 1.12 hours and control subjects got 7.77 ± 1.31 hours the night before the balance testing. The insufficient sleep received by CAF subjects may have had negative implications. As mentioned by Mejri et al, insufficient sleep led to hindered physical performance the next day compared to each subject's own baseline sleep night¹⁸.

The worsened performance with CAF could be due to a synergistic, or additive, effect of CAF withdrawal and insufficient CAF amount ingested along with insufficient sleep duration the night before the balance measurements. Withdrawal from CAF may have been possible since the subjects were asked to abstain from CAF the day of the balance testing. Although both conditions were subjected to potential CAF withdrawals, the CAF subjects were also subjected to insufficient sleep. Previous research²¹ has shown that CAF withdrawal is involved in decreased steadiness in the extremities (i.e. hands and feet) and fatigue. Assuming the effects of CAF withdrawal had an influence on performance, CAF may have been a limiting factor for individuals going through CAF withdrawals and sleep deprivation in the study. Ingestion of CAF at amounts between 3 mg/kg and 6 mg/kg was noted to show improvement with 6 mg/kg showing the maximum performance improvement⁹. CAF amounts normalized to the subjects' weights were not administered in this study; 200-mg CAF capsules were given to all subjects in the CAF condition. The average weights for males (n=13) and females (n=12) were 75 ± 7.28 -kg and 57.76 ± 6.35 -kg, respectively, but only the body weight of subjects in the CAF condition is more important when investigating whether the CAF amount was sufficient enough to see detectable results. Average weights for males (n= 6) and females (n=7) in the CAF condition were 70.76 ± 5.63 -kg and 58.18 ± 8.04 -kg, respectively. For CAF condition male subjects, when normalized to average body weight, the amount of CAF administered is 2.83 ± 0.22 mg/kg (and

3.44 ± 0.49 mg/kg for the CAF female subjects). Therefore, it can be said that the male subjects did not get enough CAF to result in an improvement like the subjects in previous studies⁹.

Although females received CAF amounts greater than the minimum amount needed to see significant improvements, this amount is just over the threshold of what is required to see some results. If all subjects in the CAF condition received amounts closer to the 6 mg/kg, there could have been potential to see greater influence of CAF on static and dynamic balance tested in this study.

There were also positive correlations for a few tested variables: average sleep duration with AVG STI (control group), sleep irregularity with AVG STO and Best STO (CAF group). There was a negative correlation with sleep irregularity with Best BB in the CAF group as well. As mentioned earlier, sufficient sleep is crucial for maintaining proper postural stability in both (older) adults and children. Increased sleep duration should have a positive correlation with static balance, and a negative correlation with dynamic balance. We did not get positive correlations with sleep duration and static balance for both conditions; only the control (no CAF) group had a correlation with a single variable among the balance measures. The reason as to why the other static balance variables (Best STI, AVG STO, Best STO) did not show a positive relationship with sleep duration in either condition could be due to the limitations mentioned above. Sleep regularity has not been shown to have any clear relationships with balance based on literature research. This suggests that this may be a topic of research that can be furthered with future studies.

Habitual sleep logs

With self-recorded data, there will almost always be associated errors. One of the main fallacies of analyzing self-recorded values is the possibility to utilizing incorrect information. The causes for these concerns may be due to memory lapses, wishful thinking, fear of how research investigators may react to results, and potentially even intentional deception. Despite having to consider a variety of possible disadvantages, the primary researcher was able to make the assumption that average sleep duration was not a factor in altering the results for better or worse; average sleep duration between the two groups were not significantly different from one another. This supports the assumption that average sleep duration was not a confounding factor for the purpose of this study. Based on conclusions made by Mejri et al¹⁸, the lack of difference in average sleep duration between conditions (CAF and control) implies that sleep was not a deciding factor for the results of this study. But the difference in sleep duration the night before the testing measurements may show that insufficient sleep in CAF subjects may have to do with the worsened results.

Subjects

As mentioned earlier, all studied subjects met the required inclusion criteria. However, there may have been variables associated with the subjects that may have impacted their performance on the balance tests. These include the subjects' motivation, prior experience or practice in balance-related tasks, variability in neuromotor development¹¹ among subjects, and differing results based on their own preconceptions about the effects of CAF, resulting in a confirmation bias.

Caffeine withdrawal

The symptoms of caffeine withdrawal vary from person to person. Headaches and decreased clearheadedness and alertness are the most commonly detected impairments from abstinence of CAF. But there are a couple of non-cognitive effects of abstaining from CAF relating to motor performance. Fatigue and performance changes (positive or negative depending on the length of abstinence) are related to CAF withdrawals. According to Ganio et al, physical performance was improved with CAF ingestion after CAF abstinence for 2 and 4 days (compared to 0 days) prior to ingestion of CAF the day of the balance measurements.

The subjects in our study only were asked to not ingest CAF the day of the balance testing. Instead of the potential ergogenic effects of CAF seen in the study by Ganio et al¹⁰, the subjects' performance in our may have been hindered due to the short-term withdrawal symptoms of CAF. The results of our study may have been consistent with the results of a previous study looking at the ergogenic effects of CAF if CAF abstinence was required for a longer period of time while sleep duration was a controlled factor among all subjects.

Future studies

Our data suggests that CAF has a negative effect on dynamic balance. To further understand the effects of CAF on essential activities of daily living (including balance), more studies need to be performed to get more accurate results. The ways in which this study could be furthered is to increase the sample size (for better representation of the population), collect accurate recording of sleep duration with modern sleep study technology (e.g. Actiwatch monitoring), administer variable amounts of CAF concentrations, control sleep duration, and

view of muscle activity tracings via myographies to better view the effects of CAF on muscles related to balance. Future studies will hopefully provide any missing information.

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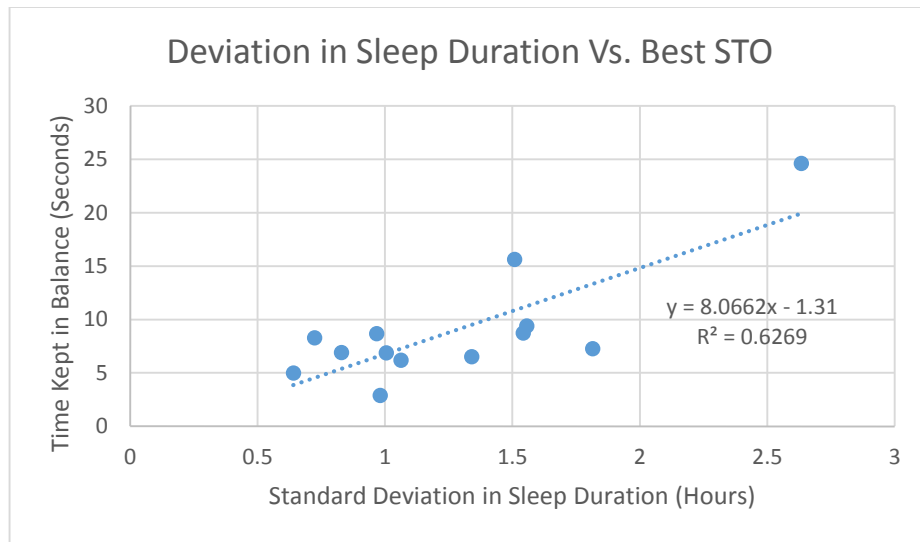
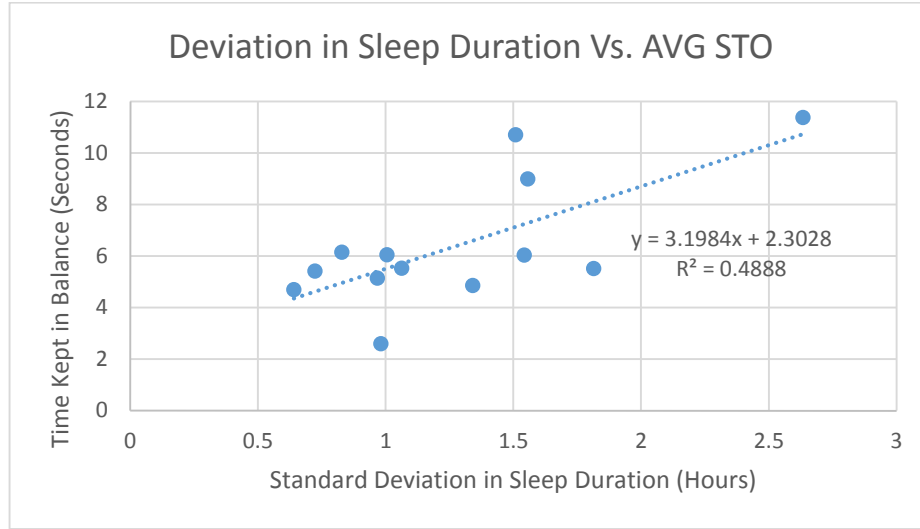
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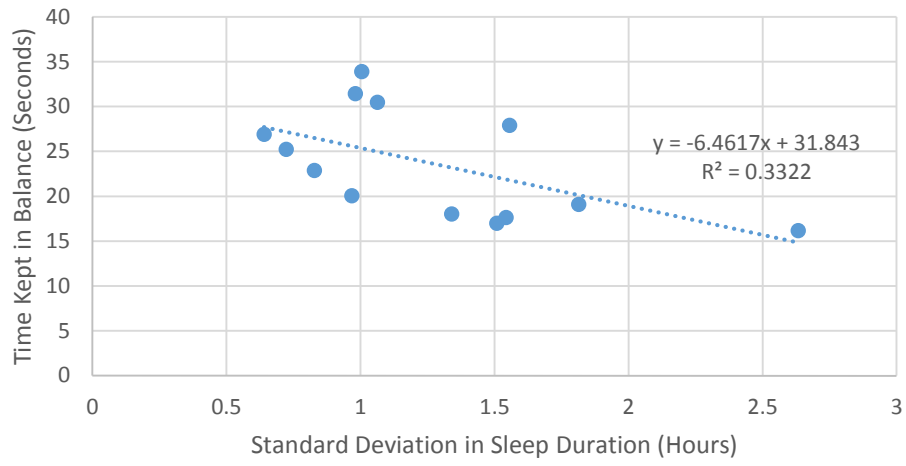
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Appendix



Deviation in Sleep Duration Vs. Best BB



Average Sleep Duration Vs. AVG STI

