HOW DOES CAFFEINE SUPPLEMENTATION AFFECT MUSCULAR PERFORMANCE IN ADOLESCENT MALES?

Jamaal Stewart
Grade 11, White Oaks Secondary School, Halton District School Board (Oakville, Ontario), Mentor: Amanda MacFarlane (Health Canada)

ABSTRACT
Caffeine consumption has become increasingly popular among children, adolescents, and young adults around the world. Many consumers indicate that they ingest caffeinated beverages to increase their energy and compensate for insufficient sleep. The most common forms of supplementation include coffee, soda and energy drinks such as “Monster Energy” and “Red Bull”. Increased caffeinated beverage consumption, especially among youth, is controversial due to concerns surrounding the safety and effectiveness of caffeine supplementation. Caffeinated products are often marketed as enhancing physical performance; This review investigates the efficacy of caffeine supplementation on muscular performance, specifically in terms of muscle strength and endurance. The results demonstrate a variable response to caffeine, with multiple studies demonstrating an increase in muscular strength or endurance, while others showed no effect. Overall, studies lacked consistent evidence to support the hypothesis that caffeine supplementation has beneficial effects on muscular performance, regardless of the dose administered.

INTRODUCTION
Caffeine stimulates the central nervous system and restores alertness. Following ingestion, caffeine restricts adenosine receptors located throughout the body, which are responsible for inhibiting the release of various neurotransmitters. The caffeine does not slow down the cell’s activity like adenosine does, allowing the nerve cells to speed up. This leads to heightened blood pressure, and greater excretion of sodium and water, as well as acid and pepsin. Furthermore, caffeine increases reaction time while also preventing lapses in attention and improving one’s ability to stay awake. Caffeine is most commonly ingested in the form of coffee, soda, and energy drinks. In recent years, energy drinks have achieved widespread popularity with products like “Red Bull” and “Monster Energy” being promoted as being able to enhance mental and physical performance due to their high caffeine content (accompanied by various other vitamins, stimulants). An energy drink is a beverage used by consumers to provide an extra boost in energy, containing caffeine and sugar among other stimulants. A recent study concluded that within the United States, as much as 31% of individuals between the ages of 12 and 17 regularly consume energy drinks, demonstrating that these drinks are especially marketable towards adolescents.

Human anatomy contains two main classes of muscle fibres, known as slow twitch and fast twitch muscle fibres. These muscle fibres are controlled by motor
neurons, which are classified as either large or small according to their cell body size and axon diameter\textsuperscript{14}. The larger motor neurons possess a high threshold for synaptic stimulation and conduct action potentials at a higher velocity, allowing them to control the fast twitch muscle fibres\textsuperscript{14}. The smaller motor neurons have a lower threshold and react more slowly, so they control the slow twitch muscle fibres. Fast twitch muscle fibres contract quickly, and provide strength and power when it is required. Because of this, they are the fibres used when completing exercises involving muscular strength, due to the need for an intense burst of power over a short duration. On the contrary, as their name suggests, slow twitch muscle fibres contract slowly to allow for low intensity repetitive contractions. Because of this unique quality, slow twitch muscle fibres are essential for exercises requiring muscular endurance.

This review will investigate the effect caffeine supplementation has on muscular performance in adolescent males, in terms of muscular endurance and strength. More specifically, the review will examine articles related to muscular enhancement through the use of caffeine in different vehicles, such as caffeinated energy drinks or pre-workout supplements. In addition, the controversial aspects of caffeine supplementation will be discussed. The similarities and differences between the methods used in the studies, composition of the supplements, and the results have also been examined.

**Muscular Endurance**

Muscular endurance refers to the ability to move one’s body or an object repeatedly, without feeling fatigued. This is a crucial aspect of muscular performance, and five separate studies attempted to determine whether caffeine supplementation has a significant effect on this attribute (Table 1). The first study, conducted by Kendall KL et al. was a double blind study that utilized 17 physically active male participants (mean age 21 ± 4 years). The participants in the supplement group were instructed to take 46 g of a pre workout supplement containing 3.5 mg of caffeine per kilogram of body mass, 6 g of branch chain amino acids (BCAA’s)\textsuperscript{11}, 5 g of creatine, 4 g of β-alanine, and 1.5 g of citrulline malate per serving\textsuperscript{9}. One hour after ingesting the supplement, the participants performed repetitions until failure (no more repetitions can be completed) for both the leg and bench press, at 75% of their predetermined maximum weight. This procedure was repeated daily for 28 days. The results showed no significant increase in repetitions until failure for either exercise, when compared to the placebo group. The second study by Gallo-Salazar C et al. was also double blind. The participants of this study were sixteen male and female junior elite tennis players (mean age 16 ± 1 years), tested on handgrip-strength, maximal-velocity serving, and sprinting performance. The participants selected for the supplement group were given 3 mg of caffeine per kilogram of body mass, 60 minutes prior to performing the various tests. This process was completed twice, and the sessions were separated by a week’s time.

Upon completion of the trials, the results showed that the supplement group was able to complete a significantly higher amount of sprints, in comparison to the placebo group. In a study by Michael J. Duncan et al., the thirteen subjects were shown how to properly perform the resistance exercises before participating in the double blind study (mean age 22.7 ± 6 years). Participants consumed 2.2 mg of caffeine per kilogram of body mass 60 minutes prior to exercising. This was repeated twice and the sessions were separated by 48-72 hours. The participants were required to complete repetitions until failure for bench press, deadlift, prone row, and back squat, at 60% of their one repetition maximum weight. The supplement group produced significantly better results in terms of repetitions to failure on the bench press, deadlift, prone row, and back squat. These results suggest that caffeine can have a significant effect on muscular performance, more specifically in terms of muscular endurance. In a double blind study involving seventeen subjects by Woolf K et al., the participants (mean age 20 ± 2 years) in the supplement group ingested 5 mg of caffeine per kilogram of body mass prior (the exact time is unspecified) to completing a chest press, leg press, and Wingate test. A Wingate test is an anaerobic test that measures peak anaerobic power and capacity\textsuperscript{17}. The results showed no significant difference between the groups in regards to muscular performance. Finally, a double blind study by Astorino T. et al. consisted of twenty-two male participants (mean age 23.4 ± 3.6 years) who ingested 6 mg of caffeine per kilogram of body mass...
60 minutes prior to completing the trials of repetitions until failure for leg and bench press. This process was completed twice, and the trials were separated by a week. This study also showed no significant difference between the supplement and placebo groups in regards to muscular endurance. Overall, the results of these studies vary and do not demonstrate that caffeine has any effect on muscular endurance.

**Muscular Strength**

Muscular strength refers to the maximum amount of force that a group of muscles can produce in order to perform a task. This is the second aspect of muscular performance to be examined and five studies set out to determine if caffeine supplementation would have any effect on an individual's strength (Table 2). In the study carried out by Kendall KL et al. the participants also completed one repetition maximum for both bench and leg press in order to determine the effects of the pre workout supplement on muscular strength. There was a notable increase in one repetition maximum weight for the leg press in the supplement group when contrasted to the placebo group, indicating an increase in muscular strength as a direct result of the caffeine supplementation. In the study conducted by Gallo-Salazar C et al. participants were tested on their hand grip strength, maximal velocity serve, and instantaneous running speeds. Hand grip strength was increased 4.2% ± 7.2% in comparison to the placebo group and maximal running velocity alongside high intensity running pace were also increased. The study by Glaister M et al. included only male participants who performed 7 maximal 10 second sprints on an electromagnetically braked cycle ergometer. In an attempt to determine dose response effects, participants were given either 2, 4, 6, 8, or 10 mg of caffeine per kilogram of body mass 60 minutes before completing the sessions. The results showed no significant differences between any of the doses for any of the tests and the placebo group in terms of peak power, mean power, or time required to reach peak power. Subjects participating in the study conducted by Wooff K et al. completed a chest press, leg press, and Wingate test. Greater peak power was achieved during the Wingate test, and more chest press weight was lifted in the supplement group than the placebo group in this trial. In the study by Astorino T et al. participants completed one repetition maximums for bench and leg press. The results showed no significant difference between the supplement and placebo groups. The majority of these studies support the hypothesis that caffeine has a notable effect on muscular performance, specifically muscular strength.

There were a variety of similarities and differences among the studies, in terms of the composition and amount of supplementation used, methods of collecting data, and results. Overall, the studies have not yet clearly determined whether caffeine has a significant effect on muscular performance in young males.

**METHODS**

The studies examining caffeine and muscular performance varied, and the majority of the studies attempted to determine whether caffeine affects muscular performance in regards to endurance and strength in a similar fashion. In most cases, the effect on muscular endurance was determined by instructing participants to perform as many repetitions until failure as possible post supplementation, although there were variations. For example, in the study organized by Michael J. Duncan et al. the participants were told to complete repetitions until failure for bench press, deadlift, prone row, and back squat at 60% of their one repetition maximum, whereas in the study conducted at the US Sports Academy, the participants were instructed to perform repetitions until failure for bench press and leg press at 75% of their one repetition maximum. Similarly, the majority of the studies on muscular strength gathered data following completion of their one repetition maximum, also with some variations. On the other hand, other studies tested muscular endurance and strength in completely different ways. For example, the study conducted by Gallo-Salazar C et al. tested muscular strength through hand grip strength, maximal velocity serve, and instantaneous running speeds. Furthermore, in the study carried out by Glaister M. et al. the men participated in seven 10 second maximal intensity sprints in order to collect data on muscular strength.

In general, participants were instructed to ingest caffeine supplements 60 minutes prior to performing their corresponding trials. This is an ideal time frame because it takes roughly 60 to 90 minutes for caffeine levels to peak in your blood stream following consumption. However, the study performed by Kendall KL et al. directed the participants to ingest their
supplements 20 minutes before completing their trials. This could have been detrimental to the results of the study, as the caffeine levels would not have peaked in the participant’s bloodstream at this point. Lastly, there was a common trend in regards to the current physical state of the participants prior to the study. In every case, the participants were required to be in good shape physically, and all of them exercised regularly.

**Supplementation Used/Levels**

Most of the studies pursued a unique approach regarding the supplementation they used, in terms of the ingredients involved and the amount of caffeine administered to the participants. Usually, the participants ingested an energy drink that contained a specific dose of caffeine per kilogram of body mass, but in the trial conducted at the US Sports Academy by Kendall KL et al., the researchers decided to utilize a pre-workout supplement powder that contained a variety of different substances including BCAA’s, creatine, β - alanine, and citrulline. These substances do not allow the impact of caffeine on muscular performance to be isolated because the other substances could mitigate, enhance, or mask its effects. For example, creatine, a central ingredient in this supplement, is an organic amino acid that supplies energy to the body by exchanging phosphate molecules with adenosine diphosphate in order to produce adenine triphosphate (ATP). ATP is required for muscle contractions, and excess amounts of creatine allow the body to synthesize larger quantities of ATP, providing a greater supply of energy to the muscles, thus reducing muscular fatigue. Because the supplement contains both creatine and caffeine, it cannot be determined whether an increase in muscular strength is a direct result of the caffeine and/or creatine in the powder. This is also the case with β - alanine, which is converted into carnosine when ingested, and aids in increasing muscle strength and endurance. The caffeine supplement “Quick Energy” used in the study by Michael J. Duncan et al. also contained a variety of different stimulants and vitamins, which would also have an effect on the results. The study by Glaister M et al. aimed at determining whether there was a dose response to caffeine, and the participants were subjected to varying levels of caffeine. Ultimately the study concluded that there is no notable dose response to caffeine.

The majority of the other studies focused on utilizing a supplement that lacked various other ingredients that would be detrimental to isolating the effects of caffeine on muscular performance. The caffeine content ranged from as low as 2 mg of caffeine per kilogram of body mass, to as high as 10 mg of caffeine per kilogram of body mass. Most commonly, the dose was set between 3 and 6 mg of caffeine per kilogram of body mass.

In these trials, more specifically the trials in which the caffeine supplementation improved muscular performance, a variety of caffeine doses were used. The lowest amount of caffeine used that still produced an effect was 2.2 mg per kilogram of body mass. Using these results, the caffeine content used in this study by Michael J. Duncan et al. can be compared to that of energy drinks and other caffeinated beverages sold commercially, and determine if they would actually improve muscular performance. A standard 8 oz. can of “Red Bull” contains 1 mg of caffeine per kilogram of body mass, which is less than half of the 2.2 mg per kilogram of body mass. This suggests that ingesting a can of Red Bull would have little or no effect on muscular performance, assuming that caffeine has an effect. “Monster Energy” is sold in a 16 oz. can and contains 2 mg of caffeine per kilogram of body mass (when using the average body mass of 80 kg) which is relatively close to the amount used in the study. If you were to ingest this energy drink, there is a chance that you might see an effect on your muscular performance. Coffee is the most frequently ingested caffeinated beverage worldwide. It has a caffeine content that ranges from 1.2 – 2.5 mg per kilogram of body mass per brewed cup, which shows that drinking coffee has the potential to produce an effect on muscular performance, dependant on the size of the person who drinks it.

**RESULTS**

The supplement containing caffeine, creatine, and β - alanine, among other ingredients, boasted results of increased leg press performance when compared to that of the placebo group, indicating an increase in muscular strength. However, this could be a direct result of the creatine or β - alanine in the supplement, for the aforementioned reasons (creatine supplying more energy to the body, and β – alanine increasing...
### Table 1: Muscular Endurance

<table>
<thead>
<tr>
<th>Study</th>
<th>Caffeine Content (mg/kg of body mass)</th>
<th>Mean Age (years)</th>
<th>Timing of Treatment (min. prior to trial)</th>
<th>Additional Ingredients in Supplement</th>
<th>Type of Study</th>
<th>Significant Effect(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Michael J. Duncan et al, 2012</td>
<td>2.2</td>
<td>23</td>
<td>60</td>
<td>Vitamin B6, vitamin B12, niacin, phenylalanine, malic acid, glucuronolactone</td>
<td>Double-blind study</td>
<td>More repetitions until failure completed for bench press, deadlift, prone row, and back squat in supplement group than placebo group</td>
</tr>
<tr>
<td>Gallo-Salazar C et al, 2014</td>
<td>3</td>
<td>16</td>
<td>60</td>
<td>Not specified</td>
<td>Double-blind study</td>
<td>The supplement group completed more total sprints than the placebo group</td>
</tr>
<tr>
<td>Kendall et al, 2014</td>
<td>3.5</td>
<td>21</td>
<td>20</td>
<td>Creatine, BCAA's, β-alanine, citrulline malate</td>
<td>Double-blind study</td>
<td>No increased muscular endurance</td>
</tr>
<tr>
<td>Woolf K et al, 2008</td>
<td>5</td>
<td>Not specified</td>
<td>60</td>
<td>Not specified</td>
<td>Double-blind study</td>
<td>No increased muscular performance</td>
</tr>
<tr>
<td>Astorino TA et al, 2008</td>
<td>6</td>
<td>23</td>
<td>60</td>
<td>Not specified</td>
<td>Double-blind study</td>
<td>No increased muscular performance</td>
</tr>
</tbody>
</table>

### Table 1: Muscular Strength

<table>
<thead>
<tr>
<th>Study</th>
<th>Caffeine Content (mg/kg of body mass)</th>
<th>Mean Age (years)</th>
<th>Timing of Treatment (min. prior to trial)</th>
<th>Additional Ingredients in Supplement</th>
<th>Type of Study</th>
<th>Significant Effect(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glaister M et al, 2012</td>
<td>2-10</td>
<td>24</td>
<td>60</td>
<td>Not specified</td>
<td>Double-blind study</td>
<td>No increased muscular strength at any dose</td>
</tr>
<tr>
<td>Gallo-Salazar C et al, 2014</td>
<td>3</td>
<td>16</td>
<td>60</td>
<td>Not specified</td>
<td>Double-blind study</td>
<td>Hand grip strength was increased by 4.2% ± 7.2% in the supplement group. Maximal velocity and high intensity running pace increased in the supplement group</td>
</tr>
<tr>
<td>Kendall et al, 2014</td>
<td>3.5</td>
<td>21</td>
<td>20</td>
<td>Creatine, BCAA's, β-alanine, citrulline malate</td>
<td>Double-blind study</td>
<td>Significant increase in leg press one repetition maximum weight in supplement group compared to placebo group</td>
</tr>
<tr>
<td>Woolf K et al, 2008</td>
<td>5</td>
<td>Not specified</td>
<td>60</td>
<td>Not specified</td>
<td>Double-blind study</td>
<td>Greater peak power achieved and more chest press weight lifted in the supplement group than the placebo group</td>
</tr>
<tr>
<td>Astorino TA et al, 2008</td>
<td>6</td>
<td>23</td>
<td>60</td>
<td>Not specified</td>
<td>Double-blind study</td>
<td>No sign of increased muscular strength</td>
</tr>
</tbody>
</table>
strength and endurance). This supplement showed no other results pertaining to muscular performance. The studies by Gallo-Salazar C et al. and Woolf K et al. also produced results that suggested an increase in muscular strength, where hand grip strength, peak power, and weight lifted on the bench press were all higher than the placebo groups. Aside from those three instances, no other studies supported the hypothesis that caffeine supplementation has a significant effect on muscular strength. The results from the studies by Gallo-Salazar C et al. and Michael J. Duncan et al. provide evidence that caffeine increases muscular endurance. In these cases, participants were able to complete more sprints and repetitions until failure on the bench press, deadlift, prone row, and back squat when compared to the placebo group. The study conducted by Glaister M et al. demonstrated no significant effect in terms of muscular strength or endurance, even though participants were given varying levels of caffeine. This was the lone study that tried to identify a dose response effect. In addition, the trial by Astorino T et al. showed no signs of caffeine supplementation affecting muscular performance in terms of either muscular endurance or strength. After ingesting 6 mg of caffeine per kilogram of body mass, the subjects were unable to lift more weight during the one repetition maximum trial, and failed to complete more repetitions to failure than the placebo group.

DISCUSSION

Energy drinks are one of the most widely used forms of caffeine supplementation, and although they are promoted as being able to increase physical performance and encourage an active lifestyle, in reality that is not always the case. Taken together, the data indicates that the benefit, if any, from the consumption of energy drinks may be outweighed by its associations with negative behaviours and increased calorie intake.

The results of the studies reviewed in this paper do not entirely support or deny that caffeine supplementation has a beneficial effect, if any, on muscular performance. Although there is some evidence indicating that there might be a beneficial effect on muscular strength but not endurance. An article by Rico Mora-Rodriguez et al., concluded that short term high intensity performance (muscular strength) could be improved by caffeine in a neutral environment, but only when a large amount of caffeine was ingested, although overall the studies examined in this article regarding muscular strength provided mixed results. Six of the 13 studies demonstrated an improvement in muscular strength as a result of caffeine supplementation, whereas the remaining studies showed no effect on performance. They also found that energy drinks would not be beneficial for muscular endurance in warm environments, as they are high in carbohydrates but lack salts. In terms of the studies testing muscular endurance the results were mixed as well, with only half showing an improvement in muscular endurance, and one producing a negative effect. However, there was more evidence that caffeine had a beneficial effect on muscular endurance in the study by Rico Mora-Rodriguez et al. In an article by Judith A. Owens et al., they concluded that there is a slim chance that caffeine has an effect on performance, suggesting that overall caffeine likely has a minimal effect, if any, on muscle performance.

CONTROVERSY

An area of debate relating to the topic of caffeine supplementation is whether it is a safe practice for adolescents when exercise is involved. There has been a spike in deaths related to exercise and caffeine ingestion from energy drinks, with 17 deaths being reported since 2012. This has sparked a discussion on whether adolescents should even be drinking these products, as people become more aware of the potentially harmful effects of caffeine supplementation. In response to this concern, laws have been passed limiting energy drinks to 180 mg per can. Research has concluded that, caffeine is a safe stimulant when taken in moderation. Although the laws and recommendations put in place do not completely minimize the risk, the issue of public health versus individual health still exists. Individually, the risk of having a potentially fatal reaction to a seemingly safe dosage of caffeine is very low. When analyzing the general population though, it is impossible to assume that no one will be affected negatively by the same dosage. A variety of different underlying conditions can make individuals more susceptible to harm, as a result of caffeine ingestion.
ingestion, even when the amount is seemingly low. Because of this, a risk still exists involving caffeine supplementation with high intensity exercise.

Another issue surrounding caffeine use is the potential for abuse among children, adolescents and young adults. A study conducted in New Zealand found that after consuming a single retail unit of an energy drink, 70% of children (5-12 years old), and 40% of adolescents (13-19 years old) most likely exceeded the adverse effect level of 3 mg of caffeine per kilogram of body mass per day beyond their baseline dietary caffeine exposure\textsuperscript{15}. This overconsumption of caffeine can lead to a variety of different conditions including liver damage, seizures, nausea and vomiting, hypertension, and death\textsuperscript{15}. Furthermore, a study conducted in the United States determined that among college students, 54% admitted to mixing energy drinks with alcohol. The caffeine in the energy drinks can mask the depressant effects of alcohol\textsuperscript{4}, which can lead to excessive drinking. Individuals who consume alcohol in conjunction with caffeinated beverages such as energy drinks are three times more likely to binge drink, which can result in serious health complications or death\textsuperscript{16}.

Furthermore, weekly energy drink consumption is associated with a variety of fruitless and even dangerous behaviours among young adults\textsuperscript{12}. Men and women who consumed large amounts of energy drinks were more likely to have a higher sweetened soda intake, higher video game use, and binge drink\textsuperscript{12}. In addition, weekly energy drink consumption was linked to trouble sleeping, eating breakfast less frequently, cigarette use, and unhealthy weight control behaviours\textsuperscript{12}. Furthermore, energy drinks also have a high calorie content. In conjunction with the dangerous activities associated with energy drink consumption, this can lead to further health risks such as obesity, and diabetes.

CONCLUSION

After reviewing the different aspects of these unique studies, it is evident that there is still a level of uncertainty in regards to the effects of caffeine supplementation on muscular performance. The majority of the studies that were analyzed indicated that caffeine may have a notable effect on muscular strength, but not endurance. Half of the studies demonstrated a notable increase in participant performance when completing a trial related to muscular strength. On the other hand, only two of the studies produced results that suggested an increase in muscular endurance as a result of caffeine supplementation. Finally, two trials suggested that caffeine had no effect on muscular performance, regardless of the dosage administered to the participants.

This data is especially important when applied to athletics, resistance training, or any other form of physical activity because it allows us to draw conclusions on the effect of caffeine on specific muscle fibres, which are responsible for muscular endurance and strength. The results of these studies suggest that caffeine supplementation may have a greater effect on muscular strength, subsequently displaying that caffeine may have more of an impact on the performance of fast twitch muscle fibres and large motor neurons as they are required for strength related activities. These results also show that caffeine is not likely to have any effect on slow twitch muscle fibres and small motor neurons.

KEY WORDS Caffeine, Supplement, Muscular Performance

ACKNOWLEDGEMENTS

To begin with, I would like to sincerely thank my mentor Dr. Amanda Macfarlane for her continued assistance throughout the process of writing this scientific review. Without her support, attention to detail, and extensive knowledge on nutrition, none of this would have been possible. Furthermore, I would like to thank Adelina Cozma and Ria Oommen for the edits that they made to my rough draft. The comments and corrections that they made allowed me to improve the overall clarity and eminence of my article. Lastly, I would also like to thank Lauren Sykes for connecting me with my fantastic mentor, and keeping me updated on important documents and forms that I needed to complete this article.

REFERENCES


2. Andrea M. Spaeth; Namni Goel; David F. Dinges. Cumulative neurobehavioral and physiological effects of chronic caffeine intake:


DOI: 10.13034 / JSST-2015-025