Effects of Caffeine on Exercise Responses and Performance in Children and Youth

Abstract: Extensive research has been performed investigating the effects of caffeine during exercise in adults with many reviews published in just the past 10 years. Limited research has been conducted in children despite the fact that they are one of the fastest growing consumers of caffeine. In light of the limited research, in writing this review no inclusion or exclusion criteria were used, as the aim of the review is to provide as wide a research base as possible. This review will present the data that has systematically investigated the acute effects of caffeine in children and youth during exercise.

Keywords: children; youth; exercise; caffeine

Introduction

Caffeine is considered one of the most widely consumed legal stimulants in all age groups.^{1,2} Notably, children are one of the fastest growing consumers of caffeine.^{1,3,4} Currently, soft drinks are considered their number one source of caffeine.^{1,4,8} But with increased marketing of sports and energy drinks to children,⁹⁻¹⁴ this may be changing. Despite the growing trends there has been very limited research on the effects

of caffeine in children during exercise.¹⁴ With such limited research no inclusion or exclusion criteria were used in writing this review, with the purpose of providing a review with as wide a research base as possible.

Caffeine Consumption

The exact amount of caffeine children consume is not well established. Mean intake values ranging from 14 to 109 mg caffeine per day (0.4-2.0 mg caffeine/kg

consume caffeine. In 619 young children (1-5 years of age) in the United States, Knight and Knight⁶ reported that 56% consumed caffeinated beverages. In 228 children (5-12 years old) Warzak et al²⁰ found that caffeine was consumed in 75% of the population. Using data from the US Department of Agriculture, Frary et al¹ reported that 86% of 6- to 11-year-old children consume caffeine. Temple et al⁴ reported that 96% of 52 adolescents (26 boys and 26 girls) reported using

Notably, children are one of the fastest growing consumers of caffeine.

of body mass) have been reported.^{1,6,7,15-20} It is clear, however, that many children consume caffeine on a regular basis. Pollak and Bright⁸ reported that in 191 seventh to ninth graders caffeine was consumed 2817 of the 3951 days (71%) they were surveyed. Similarly, from food diaries in 6- to 10-year-old boys and girls (n = 96) Ellison et al¹⁷ reported that caffeine was consumed on 79% of the 713 days data were collected. In addition, it is reported that the majority of children

caffeine at least on occasion. In 1135 US 5- to 18-year-olds, Morgan et al¹⁸ reported that 98% reported consuming caffeine. Although the amount of caffeine consumed by children and youth is unclear from these data, it is clear that the majority of them regularly consume caffeine.

Sources of Caffeine

Soft drinks have been the number one source of caffeine intake in children.^{1,4,8}

DOI: 10.1177/1559827614554593. Manuscript received January 23, 2014; revised August 12, 2014; accepted August 14, 2014. From Department of Exercise & Sport Sciences, Harding University, Searcy, Arkansas. Address correspondence to Kenneth R. Turley, PhD, FACSM, Department of Exercise & Sport Sciences, Harding University, Box 12281, Searcy, AR 72149; e-mail: krturley@harding.edu.

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This is evolving, though, as there is an increase in the marketing of both caffeinated sport and energy drinks to children.⁹⁻¹⁴ Recent work reports an exponential growth in the sport/energy drink market,¹³ with this market being the “fastest growing sector of U.S. beverage industry.”¹⁰ Bramstedt et al¹⁰ specifically mentioned a sports drink that is marketed just for children as part of this industry. Of interest are studies from both the United States²¹ and Canada,¹⁴ which reported that 27% of youths (11-19 years old) surveyed admitted to using caffeine to enhance performance. Seifert et al²² recently reported in a review of the literature from self-reported surveys that sports and energy drinks were consumed by 30% to 50% of adolescents.

Caffeine and Exercise in Adults: Brief Overview

In adults, much research has focused on the acute effects of caffeine on both aerobic and anaerobic exercise.²³ In general, low to moderate doses of caffeine (3-6 mg/kg) increases aerobic-based performance with no further enhancement at higher doses (ie, 9 mg/kg).²³ The mechanism by which enhanced aerobic performance occurs is likely multifactorial²³ and is likely mediated through some combination of increased fat oxidation and muscle glycogen sparing, central nervous system stimulation via adenosine antagonism, and/or the direct effect on skeletal muscle.²⁴⁻²⁶ The effects of acute caffeine administration on anaerobic-based performance is less clear with no effect, improvement, and diminished responses reported.^{27,28} In studies that show improvements in anaerobic-based exercise, some potential mechanisms are a direct effect on skeletal muscle or its effect as an adenosine antagonist on the central nervous system.²⁷ As with aerobic exercise, caffeine's exact mechanistic effect on anaerobic exercise is equally unknown and also likely multifactorial.²⁷

The acute effects of caffeine on physiological responses to exercise in adults are varied. The effects of caffeine on metabolic and respiratory responses

to exercise in adults are inconsistent with studies reporting both increases and no change in ventilatory responses and oxygen consumption and carbon dioxide production.²⁹ The effects of caffeine on cardiovascular responses to exercise in adults are more consistent. Most studies report no change in heart rate with acute caffeine administration during exercise, although some have reported higher heart rates.²⁹ The most consistent effect of caffeine during exercise is a consistently elevated blood pressure.²⁹

Caffeine and Exercise in Children

Preface

The ethics and or health consequences of caffeinated drinks in children are beyond the scope of this review. This concern must be recognized though, because children may be more vulnerable to the negative effects of caffeine.^{13,14} A number of recent reviews are available on these topics.^{9,12,13,22,30,31} In recognition of the potential health consequences of caffeine consumption in children, the purpose of this review is to report what is currently understood in terms of the effects that caffeine has on children during exercise. However, there is no intent to encourage or support its use in children and youth.

Caffeine and Aerobic Exercise in Children

It is clear that many children regularly consume caffeine, often times to enhance performance. Yet there are very limited data investigating the acute effects of caffeine on children during exercise.¹⁴ Only 2 groups have systematically investigated the effects of caffeine during exercise in children.^{19,32-34}

In the first study that investigated the effects of caffeine during aerobic exercise in children, Barta et al³² administered both a placebo and a single dose (4 mg/kg) of caffeine on separate visits to 16 obese and 6 normal-weight 10- to 14-year-old children 20 minutes before 4 minutes of stepping exercise. They measured blood lactate, glucose, and free fatty acids before and after

exercise and found that in both groups there was no significant change in glucose or free fatty acid levels with caffeine. In the normal children there was no effect of caffeine on the lactate response either, but in the obese there was a significantly ($P < .01$) smaller increase in lactate with caffeine following exercise. Although the study did not directly investigate whether caffeine could increase the children's ability to perform the step test (performance) they concluded that the lower lactate levels in the obese would increase their ability to perform work similar to that of “children under training.”

More recently Turley and Gerst³⁴ tested 52 children (7- to 9-year-old; 26 boys and 26 girls) in a double-blind, double-crossover, randomized study. The children received twice each either a placebo or 5 mg/kg caffeine 60 minutes before performing aerobic exercise on a cycle ergometer at both 25 W (~45% VO_2max) and 50 W (~70% VO_2max) while physiological responses to exercise were measured. They reported that exercise heart rate was lower (6.7 and 4.7 beats/min) and both diastolic (3.0 and 3.0 mm Hg) and systolic (3.7 and 3.0 mm Hg) blood pressure were significantly higher on caffeine versus placebo in boys and girls, respectively. Both tidal volume (mL/breath) and ventilation (L/min) were also significantly higher on caffeine in boys and girls. Furthermore, they reported no effects of caffeine on oxygen consumption (VO_2) or respiratory exchange ratio (RER), a marker of substrate use. The effects of caffeine were not different between the genders. As with Barta et al,³² Turley and Gerst³⁴ did not directly measure performance. But one of the potential ergogenic mechanisms of caffeine reported in adults is the “glycogen sparing” effect.²⁶ Based on the lack of change in RER in these boys and girls with 5 mg/kg caffeine, there was no apparent glycogen sparing effect during aerobic exercise. Thus, comparing this children's data to previous adult findings it seems that caffeine may have differing effects on physiological responses to aerobic exercise in these groups.

In the first study to directly compare adult and child responses, Turley et al³³ compared the boys' data from the previous study³⁴ to twenty-six 18- to 29-year-old men who participated in a double-blind, randomized, double-crossover study. The study protocol was the same in that 5 mg/kg caffeine was ingested 60 minutes before exercise, except the men then rode the cycle ergometer at 50 W (~34.0% VO_2max) and 60% VO_2max in order to match both an absolute and relative work rate of the boys. The blood pressure was elevated similarly in boys and men with caffeine at both exercise intensities (1-6 mm Hg). The significant decline in heart rate observed in boys after caffeine consumption was not observed in the adult men. Similar to the boys, there was no change in VO_2 or RER on caffeine in the men.

Each of the previous studies used a single moderate dose of caffeine (4-5 mg/kg). In order to determine if different doses of caffeine have varying effects in children, Turley et al¹⁹ investigated the effects of 0, 1, 3, and 5 mg/kg of caffeine 60 minutes before exercise at 25 W and 60% VO_2max in 20 boys and 20 girls (average age 8.1 ± 0.8 years) in a randomized, double-blind, counterbalanced study. There were no statistical differences in responses between the boys and girls so their data were combined for statistical analysis. Blood pressure was not significantly different with 1, 3, or 5 mg/kg caffeine versus placebo at either exercise intensity. Although, the authors point out that blood pressure was 2 to 6 mm Hg higher at 5 mg/kg caffeine in this study, which is similar to the 2 to 5 mm Hg statistically significant increase reported in an earlier study.³⁴ Heart rate was significantly lower in caffeine at 3 mg/kg (5-6 beats/min) and 5 mg/kg (5-6 beats/min) at both exercise intensities, but it was not statistically different at 1 mg/kg. Furthermore, substrate use (as represented by RER) and VO_2 were not different with any level of caffeine versus placebo. Also, with the exception of a significantly higher tidal volume at 3 mg/kg caffeine at 60% VO_2max , there was no

effect at any level of caffeine on respiratory function at either exercise intensity.

While it is clear that very little research has been conducted on the effects of caffeine on children during aerobic exercise, a few consistent findings/issues arise from these studies. First, none directly measured exercise performance (the ability to perform sport-specific activity). They only measured the acute effects of caffeine on physiological responses to aerobic exercise, therefore the effects of caffeine on aerobic exercise performance in children remains unknown. The most consistent finding is the significant lowering of heart rate in children with both the mild (3 mg/kg) and moderate (5 mg/kg) doses of caffeine^{19,34}; Barta et al³² did not report heart rate data. The lower heart rate on caffeine in children and not adults³³ is reported to be baroreflex mediated.^{19,33-36} Thus, the effect of caffeine on sport-specific activity in children and youth is unknown but at moderate to high doses (3-5 mg/kg), it does affect the cardiovascular system (ie, decreased heart rate) during exercise.

Caffeine and Anaerobic Exercise in Children

Only one study has investigated the effects of caffeine in children during anaerobic exercise. In this study, Turley et al³⁷ tested twenty-four 8- to 10-year-old boys in a double-crossover, counterbalanced, double-blind study where the volunteers received twice each 5 mg/kg caffeine or the placebo on 4 separate occasions. A 30-second Wingate test and static handgrip test were performed 60 minutes following the ingestion of either the placebo or caffeine. They found that Wingate mean power (180 ± 36 vs 173 ± 28 W) and static handgrip maximal voluntary contraction (22.6 ± 3.1 vs 21.9 ± 2.8 kg) were significantly higher on caffeine versus placebo, respectively. Peak power and fatigue index were not statistically different between caffeine and placebo. Thus, from this study a high dose of caffeine increases young boys' ability to perform anaerobic exercise.

Conclusions

This literature review revealed a paucity of studies that have investigated the effects of caffeine during exercise in children. A summary of the studies presented can be seen in Table 1. Of the studies conducted, the cardiovascular effects most consistently reported are elevated blood pressure and lower heart rate on caffeine (3 and 5 mg/kg) during aerobic exercise in both boys and girls (see Table 1). There seems to be a threshold between 1 and 3 mg/kg of caffeine below which these cardiovascular changes are not seen. The cardiovascular and metabolic effects of 3 and 5 mg/kg doses were similar during aerobic exercise. Whether caffeine increases children's ability to perform aerobic exercise is unknown as no study has directly measured aerobic performance with caffeine in children. The majority of adult studies report that caffeine increases aerobic performance.^{23,28} The one study that investigated the effects of caffeine during anaerobic-based exercise in children reported an increase in average power produced during a 30-second Wingate test and an increase in strength (static handgrip). The results from adult studies on caffeine during anaerobic-based exercise are unclear²⁸ with both increases and no change in high-intensity anaerobic-based exercise performance with caffeine reported.³⁸ Perhaps the most important finding from this review is the need for more research to both confirm what data have been collected and to deepen our understanding of the effects caffeine has on children and youth during exercise. Specifically, studies in children and youth should investigate the mechanism of action of caffeine during both aerobic- and anaerobic-based exercise. Also, studies on the effects of caffeine on the performance of aerobic exercise have not been conducted, and studies that investigate its effects on more sport-specific anaerobic performance are lacking. Furthermore, studies are needed to investigate dose by age effects of caffeine during exercise.

Table 1.

Studies Reporting Effects of Caffeine During Exercise in Children.

Study	Exercise	Age Group	Caffeine	Cardiovascular	Respiratory	Metabolic	Performance
Aerobic							
Barta et al (1982) ³²	4-minute stepping	10-14 years old 16 obese 6 normal weight	4 mg/kg 4 mg/kg	NR NR	NR NR	Lower lactate No effects	NR NR
Turley and Gerst (2006) ³⁴	8-minute cycling	7-9 years old 26 boys 26 girls	5 mg/kg 5 mg/kg	↓HR, ↑BP ↓HR, ↑BP	↑TV, ↑VE ↑TV, ↑VE	No effects No effects	NR NR
Turley et al (2008) ¹⁹	8-minute cycling	8-10 years old ^a 20 boys 20 girls	1 mg/kg 3 mg/kg 5 mg/kg	No effects ↓HR, ↑BP ^b ↓HR, ↑BP ^b	No effects ↑TV No effects	No effects No effects No effects	NR NR NR
Anaerobic							
Turley et al (2012) ³⁷	30-second Wingate Static handgrip	8-10 years old 24 boys	5 mg/kg	↑Peak HR ^c	NR	NR	↑Mean power
			5 mg/kg	NR	NR	NR	↑MVC

Abbreviations: NR, not reported; HR heart rate; BP, blood pressure; TV, tidal volume; VE, ventilation; MVC, maximal voluntary contraction.

^aData of boys and girls were not statistically different so they were combined for analysis.^bBlood pressure was not significantly higher but was elevated to the same degree as Turley and Gerst (2006)³⁴ data.^cHigher peak heart rate likely related to significantly higher work rate.

From a clinical standpoint, this review indicates that an acute low dose of caffeine (ie, 1 mg/kg) has no cardiovascular, respiratory, or metabolic effects in children during exercise. Higher doses (ie, 3 and 5 mg/kg) have no effect on metabolism, a varied effect on respiratory responses, yet consistently result in a 2- to 6-mm Hg increase in both systolic and diastolic blood pressure at rest and during exercise. This is especially pertinent as the prevalence of high blood pressure in youth is increasing.^{39,40} Thus, it is recommended that in children and youth, caffeine intake should at best be <3 mg/kg. This is supported by a review on the effects of caffeine on health where Nawrot et al⁴¹ suggested that caffeine intake in children should be limited to 2.5 mg/kg/d. Furthermore, the International Society of Sports Nutrition's³⁰ current position stand states that energy drinks

and energy shots that contain caffeine should only be "considered" for use in children and adolescents with parental approval. The message of limited caffeine intake and limited use of these types of drinks is especially important to communicate in light of the increased marketing of caffeinated sport and energy drinks to children and youth today. **AJLM**

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