EFFECT OF CAFFEINE ON STANDING BALANCE DURING PERCEPTUAL-COGNITIVE TASKS

Mehmet Kara[1], Suleyman Patlar[1], Thomas A. Stofferen[2], and Nurtekin Erkmen[1*]

[1]Faculty of Sport Sciences, Selçuk University, Konya, Turkey
[2]School of Kinesiology, University of Minnesota, Minneapolis, MN, USA

[*]E-mail: nerkmen@selcuk.edu.tr

Abstract

Previous research has not identified a consistent, robust effects of caffeine on standing body posture in healthy adults. We evaluated standing balance performance in healthy adults without caffeine and after ingestion of caffeine. During balance testing, the eyes either were open or closed. In addition, participants performed a variety of perceptual-cognitive tasks during balance testing. Consistent with previous studies, we found no statistically significant main effects of caffeine on balance performance. However, we found statistically significant improvements in balance performance under certain individual experimental conditions. Our results, together with those of previous studies, suggest that caffeine can exert subtle effects on balance performance in relation to specific perceptual-cognitive conditions.

Keywords: Caffeine, dual task, postural sway

Introduction

Balance is a capability for having the desired body position during static or dynamic movements. Balance requires motor activity, but that activity depends upon connections between the visual, proprioception, and vestibular systems (Madras and Barr, 2003). A failure of any of these systems can cause a lack of harmony in movements (Guyton and Hall, 2006).

In daily life and sporting activities, postural control and dynamic balance are necessary for appropriate performance (Cote, Brunet, Gansneder and Shultz, 2005). In particular, many changes occur when balance is combined with simultaneous non-postural activity (often referred to as the dual-task paradigm; Woollacott and Shumway-Cook, 2002). Changes in postural and/or non-postural activity when the two are combined typically

have been interpreted in terms of information processing models. A common view is that postural and non-postural activities each require attention, and that they compete for a limited pool of central processing resources. Under this interpretation, when the difficulty of one or both tasks increases or the attention capacity decreases, breakdowns will be experienced in practicing one or both of the tasks (Kim and Brunt, 2007).

The classical interpretation of dual task situations is widespread, but not without problems. One problem is empirical. The results of some studies are consistent with predictions derived from the dual task model, but for many studies the predicted effects have not been found. In a major review of the dual task literature, Woollacott and Shumway-Cook (2002) concluded that effects relating to competition between postural and non-postural tasks for a limited pool of central processing resources "appear to be small". In some cases, the results have yielded effects diametrically opposed to predictions derived from the dual task model (for a review, see Stoffregen, Hove, Bardy, Riley, and Bonnet, 2007).

Postural control can be affected not only by task factors, but also physiological factors such as the introduction of external substances into the neuromotor system. An example is caffeine. Caffeine is used as a stimulant, and can aid in keeping awake, increasing cognitive performance and overall alertness. Research has documented many effects of caffeine on the circulatory system, the respiratory system and the endocrine system as well as the central nervous system. It is known that athletes become more awake and healthy due to the stimulant effects of caffeine (Hewlett and Smith, 2007); caffeine accelerates the heart rate and increases vasodilates, which can lead to greater energy available at the cellular level (Mellion, Walsh, Madden, Putukian, and Shelton, 2002).

Several studies have examined the effects of caffeine on postural sway in healthy adults (Enriquez, Sklaar, Viirre, and Chase, 2009; Liguori and Robinson, 2001). None of these studies identified statistically significant effects of caffeine on standing body sway in healthy adults. Each study evaluated posture in eyes-open and eyes-closed conditions. However, none varied perceptual-cognitive tasks engaged in during the stance. In the present study, we attempted to determine whether caffeine would alter parameters of postural sway during the performances of mental, visual and verbal tasks.

Methods

Participants

Fifteen recreationally active males (mean age = 20.50 ± 0.67 years, mean height = 177.0 ± 7.40 cm, mean weight = 65.91 ± 5.71 kg) participated on a volunteer basis. Each participant stated they had not had any low extremity injury in the past 6 months. Participants gave informed consent prior to their participation. The research protocol was confirmed by the Committee of Local Ethics and carried out in conformity with the Helsinki Declaration.

We used a within-participants design, in which each participant performed each task in each condition on three different days, with an interval between test sessions of at least two days. One day was devoted to each of the caffeine conditions (*Caffeine, Water,* and *Control*) and the order of caffeine conditions was randomized across participants.

Procedure

In the *Caffeine* condition*,* each participant took 6 mg/kg of caffeine powder (Sigma-Aldrich Inc.) per kg of body weight mixed with 250 ml water 1 hour before testing (Foskett, Ali, and Gant, 2002; Goldstein, Jacobs, Whitehurst, Penhollow, and Antonio, 2010). In the *Water* condition*,* participants drank only 250 ml water 1 hour before balance testing. In the *Control* condition*,* participants received neither caffeine nor water.

Balance Performance

We used the Biodex Balance System, or *BBS* (Biodex Medical Systems Inc, Shirley, NY) to measure balance performance. The BBS has been shown to be reliable as a measure of dynamic balance (Baldwin, VanArnam, and Ploutz-Snyder, 2004; Cachupe, Shifflett, Kahanov, and Wughalter, 2001; Scmitz and Arnold, 1998). The BBS has a moving platform, which may be inclined from the horizontal axis +/- 20°. The platform has 12 levels of resistance to movement. Level 1 has the least resistance, while level 12 has the most resistance. The manufacturer's proprietary software computes an Overall Stability Index (OSI) for each participant. OSI scores scale with postural instability. A high OSI score indicates low postural stability (Cachupe et al., 2001; Arnold and Schmitz, 1998; Costa, Graves, Whitehurst, and Jacobs, 2009; Erkmen, Taskin, Kaplan, and Sanioglu, 2009; Hinman, 2000; Lee, Lee, and Park, 2014).

We evaluated balance performance during unipedal stance, while participants stood on their dominant foot. The dominant foot was determined by asking each participant, "Which foot do you prefer to kick a ball?" Participants were tested barefoot. They were required to hold the non-dominant foot and lower leg at an angle of approximately 90º flexion to their knee, and to stand with their arms crossed and each hand on the opposite shoulder, while looking at a target 1 m from their eyes. In this test position, the unlocked platform was adjusted so that the center of gravity was set in the center of the platform. Meanwhile, the subjects were presented with realtime feedback from the BBS screen about the motion of the body's center of gravity. Then the platform was locked and the BBS protocol was conducted. The subjects were not allowed to change their foot positions during the trial. The measurement of balance performance was taken separately with eyes open and eyes closed. In the eyes open condition, the resistance level of the BBS was set to 8. In addition, the BBS screen was turned off so that participants had no feedback from the device during these trials. In the eyes closed condition, the resistance level of the platform was adjusted to 10. During each trial, the goal was to maintain upright, unipedal stance for 30 s.

On each testing day, balance was assessed during performance of four separate cognitive tasks: *No Task*, *Mental Task*, *Visual-Mental Task,* and *Auditory-Verbal Task.* For the mental task, participants were required to count backwards by 8, beginning with a

number from 80-99, provided by the Experimenter (Jamet, Deviterne, Gauchard, Vancon, and Perrin, 2007). For the visual-mental task, a set of pictures (affixed to a card) was shown before each trial. During the trial the participant was required to state, out loud, the items seen on the card. In the auditory-verbal task, participants listened and responded to a series of questions; for example, *What do you call the sister of your uncle?* Each task was performed 4 times with eyes open, and 4 times with eyes closed, for a total of 8 trials per day. Resting time of 5 min was given after each trial. The subjects were allowed to have 3 practice trials before the experimental trials.

Statistical Analysis

The measured values were presented as means and standard deviations using SPSS version 22.0. Normality and homogeneity of data was affirmed with Shapiro-Wilk's test and Levene's test, respectively. To elicit the effects of independent variables, we used a two-way repeated measures ANOVA on factors conditions (caffeine, water, and control) and tasks (not task, mental task, visual task, and auditory task). We used Tukey HSD to evaluate differences between conditions and least significant differences (LSD) to determine timing differences. The criterion alpha was set at $\alpha = 0.05$.

Results

The results are summarized in Figure 1. In the 'eyes open' condition, the difference between the conditions was significant ($F_{(2,66)} = 5.078$; $p < 0.05$). Paired comparisons revealed that, during the No Task condition OSI scores were lower in the Caffeine condition than in either the Control or Water conditions. During the Mental task, OSI scores were lower for the Caffeine condition than for the Water condition. During the Auditory-Verbal task, OSI scores were lower in the Caffeine condition rather than the Water condition, each at $p < 0.05$. There were no other significant effects.

With eyes closed, OSI scores were lower for the Caffeine condition than for the Control condition, but only during performance of the Mental Task, $F_{(2,66)} = 4.814$; $p < 0.05$. There were no other significant effects.

Table 1: OSI scores in EO and EC conditions

Variables	Groups	No Task	Mental Task	Visual-Mental Task	Auditory – Verbal Task
Eyes Open	Control	3.58 ± 1.38	3.65 ± 1.54	3.44 ± 1.50	3.36±1.08
	Placebo	3.19 ± 0.99	3.55 ± 1.39	3.02 ± 0.74	3.44±1.10
	Caffeine	2.24 ± 0.32†‡	2.69 ± 0.58‡	2.87 ± 0.60	2.72±0.59†
Eyes Closed	Control	4.82 ± 0.66	4.86 ± 0.97	4.51±0.79	4.50±1.14
	Placebo	4.45 ± 0.59	4.52 ± 0.70	4.62±0.52	4.30±0.56
	Caffeine	4.37 ± 0.64	4.18 ± 0.70†	4.34±0.64	4.18±0.67

† Significant difference from Control Group (P<0.05), ‡ Significant difference from Placebo
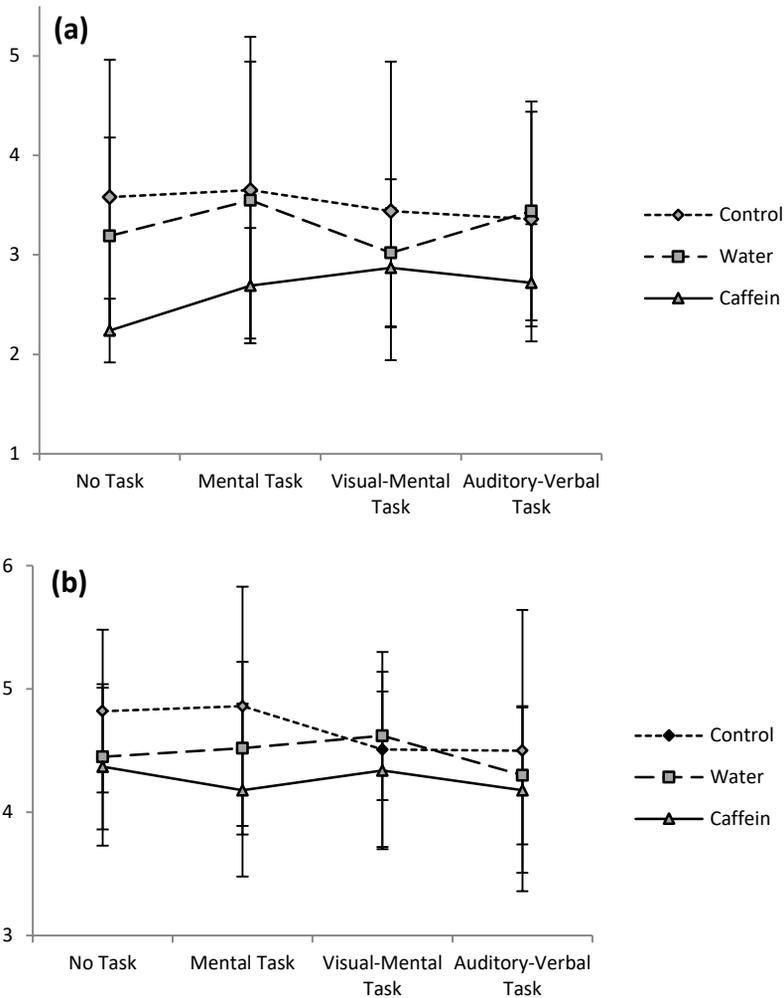
Group (P<0.05), Values are means ± SD.

Figure 1: OSI scores with eyes open (a) and eyes closed (b). Error bars represent the standard deviation of the mean.

Discussion

In a within-participants design, we evaluated the influence of caffeine on postural activity during performance of mental, visual, and auditory tasks. We did not replicate the common findings that perceptual and/or cognitive tasks can influence the control of standing posture. Moreover, caffeine did not lead to statistically significant generalized effects. However, significant effects of caffeine were observed during the performance of specific tasks. When the eyes were closed, caffeine influenced postural activity during performance of the mental task. When the eyes were open, caffeine was associated with reduced postural activity in three of the four task conditions.

Postural effects of tasks

This study firstly focused on the effects of an additional task on postural control. The main effect of mental tasks was not significant either with eyes closed or with eyes open. When compared to the OSI under the requirement of *No Task,* it was seen that the OSIs did not change during every 3 additional tasks. That is, we did not replicate common findings (Chang, Wade, Stoffregen, Hsu, and Pan, 2010; Prado, Stoffregen, and Duarte, 2007; Ramenzoni, Riley, Shockley, and Chiu, 2007) (cf. Woollacott and Shumway-Cook, 2002). The likely reason for the failure to replicate is the qualitative nature of data produced by the BBS system (cf. SOT scores from moving platform posturography). Other studies have included data on the quantitative kinematics of body sway (Jamet et al., 2007; Pelleccihia, 2003) rather than the summary measures obtained from the BBS system.

Postural effects of caffeine

Several studies have investigated the potential effects of caffeine on standing balance (Enriquez et al., 2009; Liguori and Robinson, 2001). Among healthy adults, none of these studies reported statistically significant effects of caffeine on balance performance. Consistent with this literature, in the present study we did not identify statistically significant main effects of caffeine on postural control.

The novel contribution of our study was to investigate postural effects of caffeine in the context of different perceptual-cognitive tasks. In this respect, we found several novel and statistically significant effects. In each case, OSI scores were lower for the Caffeine condition than for the Water Condition and/or the Control condition. That is, our results indicate that caffeine was associated with improved balance performance during specific tasks. This finding appears to be the first demonstration that caffeine can influence standing balance performance in healthy adults. Moreover, the direction of the effect suggests that the effect of caffeine was to improve balance performance. Such an effect is contrary to the layperson's observation that caffeine tends to make people "jittery".

When the eyes were open, the resistance level of BBS was adjusted to 8, such that the platform was in motion during trials. By contrast, when the eyes were closed, we set the resistance level of BBS such that the platform was stationary. This difference in experimental design would complicate the interpretation of any statistically significant effects related to the eyes-open versus eyes-closed manipulation. We found no statistically significant effects of the eyes open/closed manipulation; accordingly, this interpretive issue is not relevant to our results.

Caffeine has stimulant effects on the central nervous system (Graham, 2001). After caffeine intake, dopamine is released in the brain (Solinas et al., 2002) and neuron firing rise (Kim, Choi, Yoon, and Kwon, 2014). Dopamine release reduces reaction time and can enhance physical performance (Kim et al., 2014). Caffeine has positive effects on memory, reaction time, short and long term attention, and other aspects of cognitive

performance (Aniţei, Schuhfried, and Chraif, 2011). Our results are consistent with these effects, and extend them to the domain of balance performance in healthy adults.

One limitation of this study was the small sample size. This could affect the results of the study. Another limitation was that the sample included only male subjects. Future studies could be conducted with a larger sample and with female subjects or mixed groups.

To summarize, in the present study we provided what may be the first evidence that caffeine can affect the control of standing balance. The effects of caffeine were not general. They were observed in relation to specific combinations of visual input (eyes open vs. eyes closed) and perceptual-cognitive tasks. These effects suggest that effects of caffeine on balance performance exist, but are relatively subtle.

Acknowledgements

References

Aniţei, M., Schuhfried, G., & Chraif, M. (2011). The influence of energy drinks and caffeine on time reaction and cognitive processes in young Romanian students. *Procedia - Social and Behavioral Sciences*, *30*, 662-670.

Arnold, B.L., & Schmitz, R.J. (1998). Examination of balance measures produced by the biodex stability system. *Journal of Athletic Training, 33*(4), 323-327.

Baldwin, S.L., VanArnam, T.W., & Ploutz-Snyder, L.L. (2004). Reliability of dynamic bilateral postural stability on the Biodex Stability System in older adults. *Medicine & Science in Sports & Exercise*, *36*(5), S30.

Cachupe, W.J.C., Shifflett, B., Kahanov, L., & Wughalter, E.H. (2001). Reliability of Biodex Balance System measures. *Measurement in Physical Education and Exercise Science*, *5*(2), 97-108.

Chang, C.H., Wade, M.G., Stoffregen, T.A., Hsu, C.Y., & Pan, C.Y. (2010). Visual tasks and postural sway in children with and without autism spectrum disorders. *Research in Developmental Disabilities, 31*(6), 1536-1542.

Costa, P.B., Graves, B.S., Whitehurst, M., & Jacobs, P.L. (2009). The acute effects of different durations of static stretching on dynamic balance performance. *J Strength Cond Res, 23*(1), 141-147.

Cote, K.P., Brunet, M.E., Gansneder, B.M., & Shultz, S.J. (2005). Effects of pronated and supinated foot postures on static and dynamic postural stability. *J Athl Training*, *40*(1), 41-46.

Enriquez, A., Sklaar, J., Viirre, E., & Chase, B. (2009). Effects of caffeine on postural stability. *International Tinnitus Journal, 15*(2), 161-163.

Erkmen, N., Taskin, H., Kaplan, T., & Sanioglu A. (2010). Balance performance and recovery after exercise with water intake, sport drink intake and no fluid. *J Exerc Sci Fit, 8*(2), 105-112.

Foskett, A., Ali, A., & Gant, N. (2009). Caffeine enhances cognitive function and skill performance during simulated soccer activity. *Int J Sport Nutr Exe, 19*(4), 410-423.

Goldstein, E., Jacobs, P.L., Whitehurst, M., Penhollow, T., & Antonio, J. (2010). Caffeine enhances upper body strength in resistance-trained women. *J Int Soc Sport Nutr*, *7*, 18.

Graham, T.E. (2001). Caffeine and exercise: metabolism, endurance and performance. *Sports Med*, *31*(11), 785-807.

Guyton, A.C., & Hall, J.E. (2006). *Textbook of Medical Physiology* (11th ed.). Philadelphia, PA: Saunders Elsevier.

Hewlett, P., & Smith, A. (2007). Effects of repeated doses of caffeine on performance and alertness: new data and secondary analyses. *Hum Psychopharmacol Clin Exp*, *22*, 339-350.

Hinman, M.R. (2000). Factors affecting reliability of the biodex balance system: a summary of four studies. *J Sport Rehabil,* 9, 240-252.

Jamet, M., Deviterne, D., Gauchard, G.C., Vancon, G., & Perrin, P.P. (2007). Age-related part taken by attentional cognitive processes in standing postural control in a dual-task context. *Gait Posture, 25*(2), 179-184.

Kim, H.D., & Brunt, D. (2007). The effect of a dual-task on obstacle crossing in healthy elderly and young adults. *Arch Phys Med Rehab, 88*(10), 1309-1313.

Kim, S.V., Choi, C.K., Yoon, S.H., & Kwon, J.Y. (2014). Usual dose of caffeine has a positive effect on somatosensory related postural stability in hemiparetic stroke patients. *Ann Rehabil Med, 38*(6), 775-783.

Lee, D., Lee, S., & Park, J. (2014). Effects of indoor horseback riding and virtual reality exercises on the dynamic balance ability of normal healthy adults. *J Phys Ther Sci, 26*(12), 1903-1905.

Liguori, A., & Robinson, J.H. (2001). Caffeine antagonism of alcohol-induced driving impairment. *Drug and Alcohol Dependence, 63*(2), 123-129.

Madras, D., & Barr, J.B. (2003). Rehabilitation for functional ankle instability. *J Sport Rehabil, 12*(2), 133-142.

Mellion, M.B., Walsh, W.M., Madden, C., Putukian, M., & Shelton, G.L. (2002). *Team Physician's Handbook.* Philadelphia: Hanley & Belfus, Inc.

Pellecchia, G. (2003). Postural sway increases with attentional demands of concurrent cognitive task. *Gait & Posture,* 18, 29-34.

Prado, J.M., Stoffregen, T.A., & Duarte, M. (2007). Postural sway during dual tasks in young and elderly adults. *Gerontology, 53*(5), 274-281.

Ramenzoni, V.C., Riley, M.A., Shockley, K., & Chiu, C.Y.P. (2007). Postural responses to specific types of working memory tasks. *Gait & Posture, 25*(3), 368-373.

Scmitz, R., & Arnold, B. (1998). lntertester and intratester reliability of a dynamic balance protocol using the Biodex Stability System. *J Sport Rehabil, 7*, 95-101.

Solinas, M., Ferre, S., You, Z.B., Karcz-Kubicha, M., Popoli, P., & Goldberg, S.R. (2002). Caffeine induces dopamine and glutamate release in the shell of the nucleus accumbens. *J Neurosci, 22*(15), 6321-6324.

Stoffregen, T.A., Hove, P., Bardy, B.G., Riley, M., & Bonnet, C.T. (2007). Postural stabilization of perceptual but not cognitive performance. *Journal of Motor Behavior, 39*(2), 126-138.

Woollacott, M., & Shumway-Cook, A. (2002). Attention and the control of posture and gait: a review of an emerging area of research. *Gait & Posture*, *16*(1), 1-14.