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ARTICLE

Effects of blueberry supplementation on measures of functional mobility in older adults

Matthew A. Schrager, James Hilton, Richard Gould, and Valerie E. Kelly

Abstract: Limited functional mobility in older adults has been associated with declines in tests of motor, psychomotor, and executive function. Animal studies have demonstrated reversals in indices of motor and psychomotor function via supplementation with polyphenolic-rich foods such as blueberries. The purpose of this study was to examine whether 6 weeks of daily consumption of 2 cups of frozen blueberries affects functional mobility in older adults. Pre- and post-intervention assessments of grip strength, simple reaction time, adaptive gait, and executive function were completed for older adults (age >60 years) partially randomly assigned to a blueberry (BB) supplementation or a carrot juice drink control (CAR) group. Paired *t* tests were used to assess within-group effects for outcome variables in each supplementation group, and a mixed-model analysis of covariance (ANCOVA) was used to determine group (CAR vs. BB) differences. Mixed-model analysis indicated that the BB group demonstrated significant improvements relative to the CAR group in performance (i.e., number of step errors) of a challenging dual-task adaptive gait test that were independent of differences in gait speed. Within only the BB group, significant improvements were also seen in 3 other measures (i.e., usual gait speed; number of step errors during single-task adaptive gait; and gait speed during dual-task adaptive gait). These preliminary findings support the hypothesis that blueberry supplementation may provide an effective countermeasure to age-related declines in functional mobility and serve as justification for an expansion to larger trials to more fully assess this nonpharmacologic approach to maintaining optimal mobility and independence.

Key words: polyphenols, anthocyanins, antioxidants, aging, adaptive gait.

Résumé : La mobilité fonctionnelle limitée chez les personnes âgées est indiquée selon des études par une baisse de performance à des tests moteurs, psychomoteurs et d'exécution. Des études animales révèlent des inversions des indices des fonctions motrices et psychomotrices dues à la supplémentation en aliments riches en polyphénols tels que les bleuets. Cette étude se propose d'examiner l'effet d'une supplémentation journalière consistant en deux tasses de bleuets congelés sur la mobilité fonctionnelle de personnes âgées. Avant et après la période de l'administration du traitement, on évalue la force de préhension manuelle, le temps de réaction simple, la démarche adaptative et la fonction d'exécution chez des personnes âgées de plus de 60 ans partiellement réparties de façon aléatoire en deux groupes : supplémentation en bleuets (« BB ») ou en jus de carotte (« CAR ») en guise de contrôle. On utilise des tests t pour mesures appariées afin d'évaluer les différences entre les valeurs des variables dépendantes dans chaque groupe et on utilise un modèle mixte d'analyse de covariance pour vérifier les différences entre les deux groupes (CAR vs BB). Le modèle mixte d'analyse révèle dans le groupe BB par rapport au groupe CAR des améliorations significatives de la performance (p.ex., nombre d'erreurs de foulée) dans une double tâche difficile de démarche adaptative, ces différences étant indépendantes de la vitesse de marche. Seul le groupe BB présente des améliorations significatives de trois autres variables (vitesse habituelle de marche, nombre d'erreurs de foulée au cours d'une simple tâche de démarche adaptative, vitesse de marche lors de la double tâche de démarche adaptative). Ces résultats préliminaires appuient l'hypothèse selon laquelle la supplémentation en bleuets pourrait constituer une mesure efficace pour contrer le déclin de la mobilité fonctionnelle associé à l'âge; de plus, cette étude justifie la réalisation d'essais plus imposants pour mieux évaluer l'approche non médicamenteuse pour le maintien d'une mobilité optimale et de l'autonomie. [Traduit par la Rédaction]

Mots-clés : polyphénols, anthocyanines, antioxydants, vieillissement, démarche adaptative.

Introduction

Maintaining functional mobility is critical for preserving quality of life and independence in older adults. At the level of muscle function, established contributors to declines in functional mobility and mobility disability include sarcopenia (i.e., the age-associated loss in muscle mass) and, more importantly, dynapenia (i.e., the age-associated loss in muscle strength/motor performance) (Rantanen et al. 1994; Visser 2011). In addition, recent research indicates that the domains of psychomotor function and executive function — encompassing the ability to think abstractly and to plan, initiate, sequence, monitor, and stop complex behaviors — are also critical to maintaining functional mobility and independence (Kelly et al. 2008; Rosenberg and Miller 1992; Shukitt-Hale et al. 1998, 2005; Vazzana et al. 2010).

A potential mechanism contributing to declining functional mobility may be a reduced ability to mount an adequate antioxidant response to protect muscle and neuronal cells against the damage caused by excessive and unopposed production of reactive oxygen species production (Hollander et al. 2000; Ji 2002). The proposed inability of skeletal muscle to resist oxidative stress is consistent with Harmon's free radical theory of aging, and in the

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M.A. Schrager, J. Hilton, and R. Gould. Department of Integrative Health Science, Stetson University, 421 N. Woodland Boulevard, DeLand, FL 32723, USA.
V.E. Kelly. Department of Rehabilitation Medicine, University of Washington, Seattle, WA 98195-6490, USA.
Corresponding author: Matthew A. Schrager (e-mail: mschrage@stetson.edu).

case of muscle, this mechanism can result in mitochondrial DNA deletion, dysfunction of the electron transport chain, energy inefficiency, apoptosis, and muscle fiber loss (Morley et al. 2001). Although the mechanism explaining age-associated cognitive, executive, and psychomotor decline is not completely understood, oxidative stress is also hypothesized to be a major contributor to such decrements (Joseph et al. 1999; Scalbert et al. 2005; Shukitt-Hale et al. 1998). Consequently, increasing scientific interest has developed regarding dietary supplementation with polyphenol/antioxidant-rich foods such as blueberries.

In animal models, research demonstrates a relationship between aging and psychomotor function that appears to be modified by antioxidant status/supplementation. Performance in challenging psychomotor tasks, including a series of "plank walk" and "wire suspension" tests to evaluate balance and coordination, showed declines relatively early in the lifespan of the male Fischer-344 rat (i.e., between 6 and 12 months of age) (Shukitt-Hale et al. 1998).

In a follow-up study at age 19 months, Joseph et al. (1999) demonstrated that a diet high in antioxidant activity including blueberry extract was more successful than diets including strawberry or spinach in mitigating age-associated decrements in psychomotor tasks. This finding was further supported by improved performance of similar psychomotor tasks in older rats given Concord grape juice (Shukitt-Hale et al. 2006). Processes that increase temperature (e.g., pasteurization) or extract juice can lower anthocyanin content, as shown previously in grapes (Mori et al. 2007) and blueberries (Skrede et al. 2000). Therefore, whole grapes or other fruits such as blueberries may have greater motor performance effects than processed products such as grape juice because of the greater amounts and/or diversity of anthocyanins they contain, as discussed previously by Shukitt-Hale et al. (2006).

Like grape juice, blueberries contain high levels of flavonoids such as anthocyanins (Gao and Mazza 1995; Kalt et al. 2001; Prior et al. 2001; Rodriguez-Mateos et al. 2012), which may be particularly effective in minimizing oxidative damage to muscle myotubules (Hurst et al. 2010) and neurons (Kelsey et al. 2011; Shukitt-Hale et al. 2006). Finally, a dose-dependent benefit of polyphenolic- and antioxidant-rich walnut supplementation in aged rats was shown using similar tests of dynamic balance (Willis et al. 2009). Together, these findings from animal studies suggest that motor and psychomotor dysfunctions that characteristically develop with aging may be at least partially reversed through supplementation with foods rich in antioxidants such as blueberries (Joseph et al. 1998, 1999; Shukitt-Hale et al. 2006, 1998).

Little research exists on the effects of antioxidant supplementation on motor or psychomotor function in humans. However, in a cross-sectional study, Cesari et al. (2004) evaluated dietary intakes of vitamin C, vitamin E, β-carotene, and retinol in 986 individuals aged ≥65 years enrolled in the InCHIANTI study. In support of their primary hypothesis, plasma antioxidant concentrations correlated positively with knee extensor strength and measures of physical performance (e.g., gait speed and tests of standing and balance ability). Other studies of the effect of antioxidant supplementation on motor function have had mixed results. However, these were primarily focused on younger athletic populations, with the intent to evaluate whether antioxidant supplementation attenuates rates of oxidation, promotes faster recovery from muscle damage created by eccentric muscle contractions or aerobic exercise training, enhances immune function and response to acute exercise bouts, or reduces inflammation and oxidative stress during recovery from 3 days of heavy running (Balakrishnan and Anuradha 1998; Bunnell et al. 1975; Clarkson and Thompson 2000; McLeay et al. 2012; Nieman et al. 2013; Rokitzki et al. 1994; Takanami et al. 2000).

One study of older persons with mild cognitive impairment showed improved memory after 12 weeks of blueberry supplementation (Krikorian et al. 2010). Declines in cognitive, psychomotor, and executive function also negatively impact the quality of life of older individuals and occur even in the absence of neurodegenerative diseases such as Parkinson's disease or Alzheimer's disease. Impairments in executive function may result in unsafe prioritization of tasks under dual-task conditions where concurrent cognitive or motor tasks are performed while walking (Kelly et al. 2008, 2012), and executive function impairments have recently been directly linked to poor functional mobility (McGough et al. 2011; Vazzana et al. 2010).

Despite the promising findings from a number of studies (Joseph et al. 1998, 1999; Krikorian et al. 2010; McAnulty et al. 2011), no studies have directly assessed the possible effects of blueberry supplementation on motor, psychomotor, or executive function related to functional mobility in older humans. Therefore, the objective of this relatively short-term study was to test whether a 6-week intervention period of daily supplementation with a volume of 2 cups of frozen blueberries would result in better performance on a battery of motor, psychomotor, and executive function tests related to functional mobility than 6 weeks of daily supplementation with 15.2 ounces of a commercially available pasteurized carrot juice drink.

Materials and methods

Participants

Participants were randomly assigned to either a placebo/carrot juice drink (CAR) (n = 7) or blueberry (BB) (n = 13) group. Carrot juice was selected as a placebo because of its perceived health benefits and lack of anthocyanins. The age range of the sample was 61–81 years, and the mean (SD) age was 69.1 (8.6) years. Exclusion criteria included inability to walk without assistance from an assistive device or another person, legal blindness, inability to follow instructions because of cognitive impairment, and 1 or more falls in the prior 12 months as described previously in related studies (Kelly et al. 2008; Schrager et al. 2008). In response to a confidential health history questionnaire, no participants reported diagnosis of heart disease or any treated glucose metabolism disorders (e.g., diabetes, hypoglycemia) that could be affected by potential anti-diabetic properties of blueberries (Martineau et al. 2006). Written informed consent was obtained from each participant, and all experimental procedures were approved by Stetson University's Institutional Review Board.

Research design

Individually flash-frozen blueberries were delivered to BB group participants every week in 6-cup (48 ounce (1.4 kg)) bags to minimize degradation and provide participants a product type that a participant might easily purchase. Seven bottles of carrot juice drink were delivered every week to CAR group participants. The intervention comprised 6 weeks of daily consumption of either blueberries or carrot juice drink with assessments of motor, psychomotor, and executive function at pre-treatment baseline and during the 2 days immediately after cessation of the 6-week treatment. Participants were provided adequate supply of either prepackaged, frozen highbush (*Vaccinium corymbosum*) blueberries or prepackaged carrot juice and instructed to distribute ingestion of their prescribed daily intake of carrot juice drink or blueberries fairly evenly over the course of each day. Compliance was tracked through discussions with participants about the amount of product remaining, either during deliveries of product or through frequent phone calls between deliveries.

Participants were asked to make no alterations to their usual dietary practices, including dietary/antioxidant supplementation. This was verified by detailed pre- and post-intervention food frequency questionnaires that included 4 questions on fruit and vegetable intake. No participants approached the highest category of fruits and vegetable intake, as defined in the Nurses' Health Study as 8 or more servings per day (Hung et al. 2004) (mean intake of fruits and vegetables for the current sample was approximately 2.5 per day (range 2.0–3.3)). This relatively low intake of antioxidant-rich foods suggests that this sample had potential to experience any effects of the dietary intervention. Participants were instructed not to cook/bake the blueberries; cooking/baking has recently been shown to affect anthocyanin levels in blueberries (Rodriguez-Mateos et al. 2014). Pre- and post-treatment assessments of motor, psychomotor, and executive function occurred within 2 days of the first and last day of dietary supplementation, respectively. Pre- and post-tests were performed as closely to the same time of day as possible, with feeding status consistent across trials.

Motor function

Grip strength was measured with a JAMAR handheld dynamometer (Therapeutic Equipment, Clifton, N.J., USA). Participants were asked to perform the task 3 times with each hand, and the maximum strength attained during the 6 trials was used for analyses. Previous research has demonstrated that handgrip and lower extremity muscle strength are similarly affected by aging and that these measures are equally effective at identifying poor mobility (Lauretani et al. 2003).

Participants performed 4 trials of usual gait over a 6.1-m walkway, and mean usual gait speed was calculated based on times obtained with a stopwatch. Usual gait speed is an established indicator of health and an independent predictor of mortality (Hardy et al. 2007).

Psychomotor/adaptive gait function

Simple reaction time was assessed using a computer-based test (Chen et al. 2009; Human Benchmark 2014), which was completed by clicking a computer mouse when the red box changed to green. For familiarization with the reaction time test, participants were given 2 practice trials. Reaction time is an established predictor of falls risk and functional declines (Lajoie and Gallagher 2004).

For adaptive gait tests, participants were assessed and videotaped while walking barefoot at a self-selected comfortable pace within a narrow, 6.1-m-long path, both without (single task) and with a concurrent cognitive task (dual task; see Executive function section below), as described previously (Kelly et al. 2008; Schrager et al. 2008). This adaptive gait testing was employed for its similarity to previous tests (e.g., plank walking; accelerating rotorod) used in supplementation studies in rats (Joseph et al. 1998, 1999, 2009; Shukitt-Hale et al. 2006). Participants performed 4 trials in both the single- and dual-task conditions. Width of the path was normalized to 50% of the distance between the participant's anterior superior iliac spines to create a similar challenge for individuals across the range of body sizes. Two bright yellow ropes on the floor outlined the narrow path, and participants were instructed to walk within the roped path. Mean gait speed was calculated for both the single- and dual-task conditions across the known length of the path. Step errors were detected either through extended video observation or in real time, visually or tactilely, by a trained technician who placed his or her fingers on 1 end of each rope during trials. Step errors were summed across the 4 trials for each participant under each condition (single or dual task).

Executive function

Executive function was assessed with the dual-task portion of the adaptive gait test described above, which included a moderately challenging cognitive task (i.e., reciting the days of the week in reverse order). This task is similar to the real world situation of "walking while conversing", as described in a previous study of a similar population of healthy, older persons (Kelly et al. 2008). Participants were simply asked to perform both tasks as well as possible, and mean gait speed and step error number were obtained as described above.

Table 1. Pre-intervention participant characteristics.

	CAR	BB	*p*
Sex ratio (male:female)	3:4	6:7	na
Age (y)	68.4±7.7	69.5±9.3	ns
Height (m)	1.71±0.13	1.73±0.13	ns
Weight (kg)	77.0±3.1	79.1±3.7	ns
BMI (kg/m²)	26.2±3.2	26.4±3.9	ns

Note: Values are means ± SD. BB, blueberry group; BMI, body mass index; CAR, carrot juice (control) group; na, not applicable; ns, nonsignificant (analyzed using unpaired t tests).

Executive function was also assessed using the Trail Making Test, part B (TMT-B). Using a pencil, participants were timed while connecting 25 jumbled, encircled numbers and letters in numerical and alphabetical order, alternating between numbers and letters (i.e., 1-A, 2-B, 3-C, etc.) (McGough et al. 2011). One trial was performed after brief instruction and practice.

Statistical analysis

Before statistical analyses were performed, box plot analyses were evaluated for the presence of outliers, as defined as being more than 2 standard deviations away from the mean. Paired t tests were used to determine within-group changes for each of these variables in the BB and CAR groups separately. To determine whether the blueberry dietary supplementation had a beneficial effect on outcome measures of motor function, psychomotor performance, and executive function, mixed-model analysis of covariance (ANCOVA) was used to determine group (CAR vs. BB) differences. In addition to age and sex, the pre-intervention value of each outcome measure was included as a covariate to account for individual differences at baseline. The analysis of gait speed-adjusted step error data was based on findings suggesting that gait speed affects balance control, and may therefore influence step accuracy in this study (Helbostad and Moe-Nilssen 2003; Shkuratova et al. 2004). Effect sizes were calculated using Cohen's f values (small = 0.10, medium = 0.25, large = 0.40). All analyses were performed using Stata MP, version 13 (Statacorp, College Station, Tex., USA).

Results

Participants were randomly assigned to receive a placebo/carrot juice drink (CAR) or frozen blueberries (BB). The unbalanced design was a result of several participants' strong distaste for carrot juice. Table 1 illustrates the similarity in sex distribution, age, physical characteristics, and gait speed across CAR and BB groups. Mean age for both groups was approximately 69 years, and on average, participants were classified within the overweight body mass index range in both groups. Two participants in each group missed a single day of supplementation during the 6-week period because of inconvenience of consumption while traveling.

Motor function

No significant changes in grip strength with supplementation were found in either the CAR or BB groups based on within-group analysis (Table 2) or mixed-model analysis (Table 3). Baseline usual gait speed ranged from 0.91 to 1.42 m/s, and the mean (SD) was 1.17 (0.18) m/s, with no difference between supplementation groups. These values are similar to those reported in other studies of older populations with normal functional capacity (Hardy et al. 2007; Schrager et al. 2014; Studenski et al. 2011). In the BB group, usual gait speed increased significantly from 1.18 m/s to 1.28 m/s (Table 2). However, the mixed-model analysis did not show a significant group effect of CAR versus BB for this measure ($p = 0.202$; Cohen's effect size, $f = 0.283$) (Table 3).

Table 2. Unadjusted mean values for pre-intervention (pre-) and post-intervention (post-) measures of motor, psychomotor, and executive function.

	CAR			BB		
Outcome measure	Pre-	Post-	*p*	Pre-	Post-	*p*
Grip strength (kg)	30.52±10.80	31.14±12.38	0.603	36.70±16.53	38.60±16.40	0.101
Reaction time (ms)	319.04±54.32	288.71±10.73	0.165	336.54±64.34	303.54±27.77	0.066
Usual gait speed (m/s)	1.16±0.18	1.20±0.14	0.350	1.18±0.16	1.28±0.24	0.021*
TMT-B (s)	48.71±9.69	47.39±13.70	0.804	60.92±27.28	57.04±24.73	0.356
Adaptive gait						
Single task gait speed (m/s)	1.02±0.29	1.02±0.30	0.999	0.93±0.26	1.04±0.26	0.058
Single task total no. of step errors (*n*)	2.43±1.27	3.43±2.07	0.111	6.54±6.59	3.08±4.29	0.012*
Dual-task gait speed (m/s)	0.95±0.34	0.93±0.14	0.796	0.76±0.36	0.90±0.37	0.002**
Dual-task total no. of step errors (*n*)	5.14±5.15	4.71±4.27	0.510	8.23±7.27	5.08±5.25	0.003**

Note: Values are means ± SD. TMT-B, Trail Making Test B.
*Significantly different from pre-intervention value at the 0.05 level.
**Significantly different from pre-intervention value at the 0.01 level (analyzed using paired *t* tests).

Table 3. Mean values for post-intervention values, adjusted for age, sex, and pre-intervention values.

Outcome measure	CAR	BB	*p*	ES
Grip strength (kg)	35.06±1.49	36.45±1.09	0.467	0.193
Reaction time (ms)	288.98±8.81	302.44±6.36	0.236	0.318
Usual gait speed (m/s)	1.21±0.05	1.28±0.04	0.202	0.283
Trail Making Test B (s)	53.74±5.32	53.77±3.84	0.997	<0.001
Adaptive gait				
Single-task gait speed (m/s)	0.99±0.07	1.07±0.05	0.345	0.297
Single-task total no. of step errors (*n*)	4.81 (0.99)	2.34 (0.72)	0.065	0.514
Gait speed-adjusted single-task total number of step errors (*n*)	4.81 (1.02)	2.38 (0.74)	0.082	0.501
Dual-task gait speed (m/s)	0.82 (0.06)	0.96 (0.04)	0.079	0.410
Dual-task total no. of step errors (*n*), mean (SE)	6.09 (0.66)	4.26 (0.48)	0.042*	0.576
Gait speed-adjusted dual-task total no. of step errors (*n*), mean (SE)	6.08 (0.68)	4.25 (0.49)	0.048*	0.580

Note: Values are means ± SE. *p* values for between group effects using ANCOVA. Effect size (ES) was calculated using Cohen's *f*.
*Significant group difference at the 0.05 level.

Psychomotor function

No significant changes in simple reaction time with supplementation were found in either the CAR or BB groups based on within-groups analysis (Table 2) or mixed-model analysis (Table 3).

In the adaptive gait tests, gait speed was not significantly affected in either supplementation group under the single-task condition (Table 2). Under the dual-task condition, the BB group walked significantly faster after supplementation (Table 2). However, the mixed-model analysis showed that relative to the CAR group, this improvement in gait speed during the dual-task test in the BB group was no longer significant ($p = 0.079$; Cohen's effect size, $f = 0.410$) (Table 3, Fig. 1A). Significant within-group improvement in single-task step errors was found in the BB group (Table 2) but not in the mixed-model analysis (Table 3).

After adjusting for potential effects of gait speed on step errors by adding gait speed as a covariate to the mixed-model analysis, the trend toward a significant improvement in the BB group relative to the CAR group in the single-task condition ($p = 0.065$; Cohen's effect size, $f = 0.514$) shown in Table 3 and Fig. 2A was attenuated ($p = 0.082$; Cohen's effect size, $f = 0.501$) (Table 3).

Executive function

In contrast with the single-task condition, under the dual-task condition the significant relationship ($p = 0.042$; Cohen's effect size, $f = 0.576$) shown in Table 3 and Fig. 2B between supplementation group and step error number remained ($p = 0.048$; Cohen's effect size, $f = 0.580$) after the adjustment for gait speed's potential effect on balance control (Table 3). This finding indicates improved foot placement and balance control during this challenging test in the BB relative to the CAR group independent of differences in gait speed. Figure 3 shows the pre- and post-intervention single- and dual-task error rates for each participant in the 2 groups. While there was variability across participants for these measures, a greater percentage (76.9%) of participants in the BB group relative to the CAR group (57.1%) had reduced step error numbers, particularly in the dual-task condition.

In response to supplementation, no significant within-group changes were found in the other measure of executive function, TMT-B (Table 2), and no differential effect of CAR compared with BB was found for this measure (Table 3). One outlier was detected for post-test value of a participant in the BB group, but this value was consistent with the pre-test value for this older participant. However, the analyses were also performed without TMT-B data for 1 participant in the BB group because of this participant appearing noticeably distressed during the post-test. The post-test time was 30 s slower than the pre-test value for this participant and likely did not accurately reflect TMT-B performance level. With this potential outlier removed, there was a nonsignificant trend toward improved performance within the BB group (pre-intervention value = 62.41 + 8.06 s vs. post-intervention value = 55.71 + 7.31 s, $p = 0.056$) but no significant group effect in the mixed-model analysis ($p = 0.583$, $f = 0.15$).We were reluctant to exclude this potential outlier from the analyses shown in Table 2 or 3, especially since the value does not exceed the 300-s cutoff time described previously (Vazzana et al. 2010).

Discussion

This study evaluated potential benefits of blueberry supplementation on measures of motor, psychomotor, and executive function in a group of healthy, independently mobile persons aged 61–81 years. Differential effects of blueberry compared with carrot juice supplementation were seen only in a measure of performance of a complex, adaptive gait task involving dual-task performance. Furthermore, this group difference in post-intervention step error rate remained after adjusting for differences in gait speed during this test of adaptive gait. Although 3 other measures — usual gait speed, step errors during single-task conditions, and gait

Fig. 1. (A) and (B): Mean post-intervention gait speed, adjusted for pre-intervention value, age, and sex. This figure shows a trend toward faster gait speed (p = 0.079) after the supplementation period during dual-task conditions in the blueberry (BB) group (n = 13) relative to the carrot juice (CAR) group (n = 7), after accounting for baseline (pre-intervention) individual differences in gait speed and factors of age and sex. Values are means ± SE.

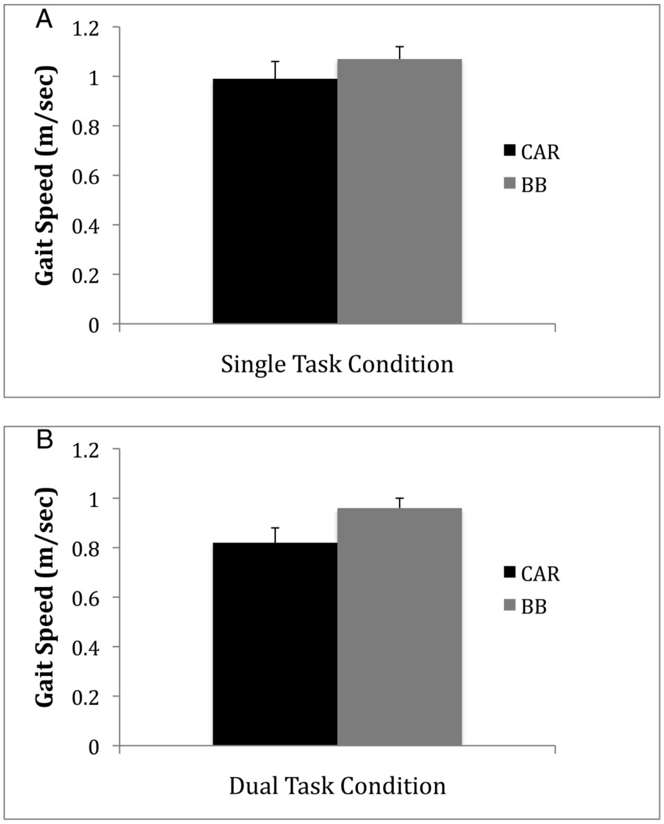
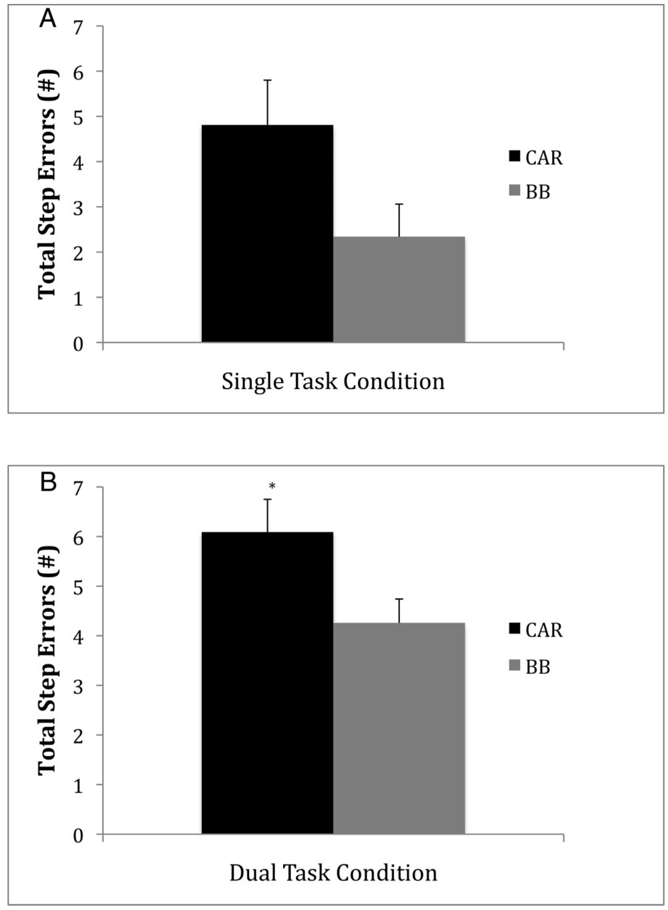


Fig. 2. (A) and (B): Mean post-intervention total step error number, adjusted for pre-intervention value, age, and sex. This figure shows that after supplementation the blueberry (BB) group (n = 13) committed significantly fewer step errors (p = 0.042) during dual-task conditions relative to the carrot juice (CAR) group (n = 7), after accounting for baseline (pre-intervention) individual differences in the number of step errors committed and factors of age and sex. Values are adjusted means ± SE. *, Significantly higher than the BB group.



speed during dual-task conditions — showed significant improvements from pre- to post-intervention assessments in only the BB group, these effects were not significant in the mixed-model analyses. However, effect sizes for the BB group were either medium (i.e., for usual gait speed) or large (i.e., for step errors during single-task conditions and gait speed during dual-task conditions), suggesting that expansion of this preliminary study may be warranted.

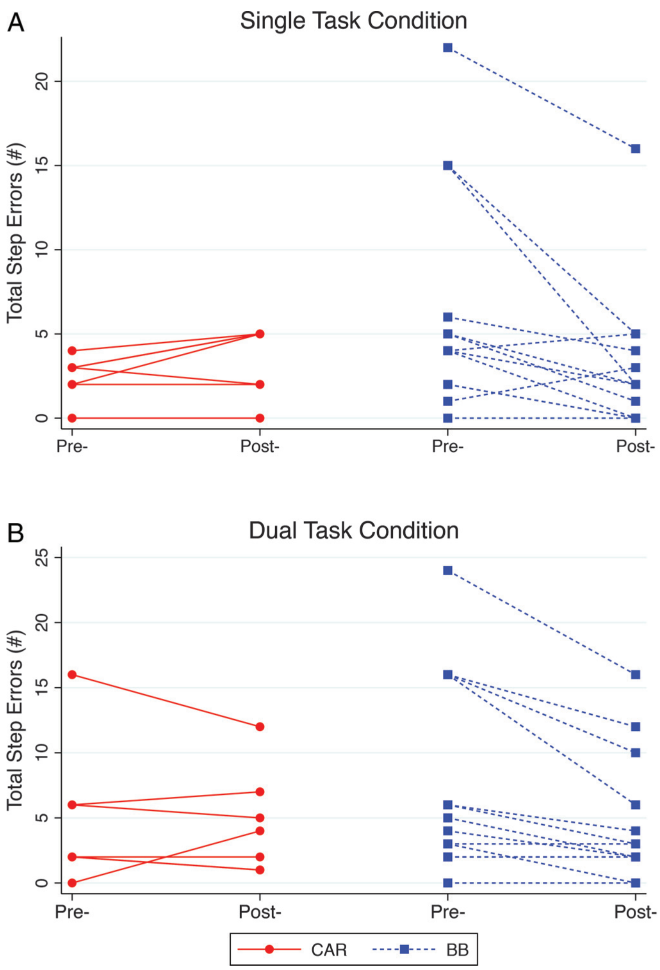
Prior research in rats has suggested that it may be more difficult to induce dietary-based reversals in age-related motor and psychomotor performance than in cognitive performance (Shukitt-Hale et al. 2006). Therefore, it may not be surprising that there were no effects of supplementation on grip strength or simple reaction time in this preliminary study. The apparent improvement mentioned above within the BB group in usual gait speed, while not significant in the mixed-model analysis, is a potentially promising finding given the established relationship between improvements in usual gait speed and reduced mortality, as well as the ease of administration and clinical relevance this test possesses (Hardy et al. 2007).

Adaptive gait tasks, narrow base walking under single- and dual-task conditions, were also used to assess psychomotor function. Gait speed increased after supplementation in the BB group under dual-task conditions, and this may indicate increased stability during walking. Although the mixed-model analysis did not show a significant effect of BB on gait speed, the large effect size for this parameter suggests there may be improvement in this aspect of task performance. The decrease in step errors in the BB group under single-task conditions showed a similar pattern. More sophisticated yet safe adaptations of dynamic balance tests like those administered in previous research on rats (e.g., rod walking, plank walking, inclined screen) (Joseph et al. 1998, 1999; Shukitt-Hale et al. 2005, 2006) and additional objective variables such as stride variability, which is an independent predictor of falling (Dubost et al. 2006), should be implemented to detect potential benefits of BB supplementation.

Dual tasking and executive function diminish with aging. It is unclear why no supplementation effects were found in the TMT-B. As noted, the potential outlier for this variable may partially explain this finding. However, previous research has shown that complex walking tasks are more sensitive than simpler tests for identifying early declines in gait function (Shumway-Cook et al. 2007). The added physical and cognitive challenge provided by the dual-task condition of the narrow walk test may reflect a higher degree of difficulty and a greater potential for supplementation-based improvement than a simpler test like TMT-B.

There were several limitations of the current study. The main limitation was a small and unbalanced sample. The significant finding in step error rates should be interpreted with much caution given that BB group improvements were driven substantially by 3 or 4 participants who had relatively high total numbers of step errors (i.e., >15 across 4 trials) — and therefore high potential

Fig. 3. (A) and (B): Individual participant values for number of step errors under single- and dual-task conditions, respectively, for pre- and post-intervention assessments. This figure shows the pre- and post-intervention single- and dual-task error rates for each participant in the 2 groups. A greater percentage (76.9%) of participants in the blueberry (BB) group (n = 13) compared with the carrot juice (CAR) group (n = 7) (57.1%) had reduced post-intervention step error numbers relative to baseline (pre-intervention), specifically in the dual-task condition.



for improvement — in the pre-test, whereas only 1 participant in the CAR group had >15 total pre-test step errors. As noted, future studies should use a larger sample and more sophisticated measures of gait function to better assess potential benefits of blueberries on gait function. Furthermore, a true placebo (e.g., cucumber powder) without antioxidant properties may have provided clearer results than the carrot drink, though the pasteurization/processing of this commercially available drink likely decreased its antioxidant content. In addition, a form (e.g., blueberry juice) that may have greater consistency in anthocyanin content because of standard procedures used for preparation may be preferable; however, the use of whole fruits has its own advantages related to the potential protective properties of various combinations of polyphenolic compounds such as anthocyanins, as noted in studies of grapes, walnuts, blueberries, and other whole foods (Joseph et al. 1999; Shukitt-Hale et al. 2006; Willis et al. 2009). Another limitation was that supplementation was stopped prior to post-testing. This short (<36-h) delay prior to post-testing may have diminished effects of supplementation. Future studies should weigh these practical factors and consider a longer supplementation period, in particular for the detection of possible skeletal muscle changes (Shukitt-Hale et al. 2006).

The preliminary results from the current study suggest that supplementation with blueberries may reverse age-related declines in the performance of adaptive gait tasks, as indicated by fewer step errors. This apparent effect of blueberry supplementation persisted after adjusting for individual differences in gait speed. Because of the limitation of a small sample size, other possible improvements in motor and psychomotor function shown in the within-group analyses for the blueberry group should be assessed within the context of a larger, longer term trial. Overall, this study demonstrates the need for greater exploration of blueberry supplementation as a nonpharmacologic countermeasure to the public health issue of age-related declines in functional mobility and independence.

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