Biomedical Engineering: Applications, Basis and Communications, Vol. 32, No. 2 (2020) 2050016 (10 pages)
DOI: 10.4015/S1016237220500167





# THE EFFECT OF BLOOD GLUCOSE ON QUIET STANDING BALANCE IN YOUNG HEALTHY INDIVIDUALS

Scott P. Breloff[*,†,§], Jessica L. Bachman[†], Vipul A. Lugade[‡] and Andrew D. Stuka[†]

[*]*National Institute for Occupational Safety and Health*
*1095 Willowdale Road, MS L-2027*
*Morgantown, WV 26505, USA*

[†]*The University of Scranton*
*Scranton, PA 18510, USA*

[‡]*Control One LLC*
*Albuquerque, NM 87111, USA*

Accepted 28 January 2020
Published 15 April 2020

## ABSTRACT

Falling is one of the leading causes of accidental injury and death among elderly adults and construction workers, with costs exceeding US$31 billion each year. Having good balance reduces the likelihood of falling — therefore it is important to determine which possible factors might influence balance. The purpose of this study was to determine if consuming three different types of breakfast altered blood glucose levels in such a way that young healthy individual's balance control was compromised. Balance was then measured while the subjects completed single- and dual-task standing trials with eyes open and closed. Although changing blood glucose did alter quiet standing balance — as measured by the separation distance between the COG and COP, the velocity of the COM, and the total distance traveled by the COG and COP along the anterior–posterior (AP) and medial–lateral (ML) axes — the results were contradictory to what was hypothesized. Subjects with lower blood glucose swayed less than those with higher blood glucose. This could potentially be due to the habitual skipping of breakfast in young adults. Though the changing of blood glucose did influence quiet standing balance of young healthy adults, it was not in a way which increased the risk of falling.

*Keywords*: Dual task; Center of mass; Center of pressure; Blood glucose.

## INTRODUCTION

Falling is one of the leading causes of injuries in elderly adults,[1] with 27% of non-fatal injuries[2] and 17% of fatal injuries occurring in constructing workers.[3] Medicare costs for falls in these populations exceed US$31.3 billion annually.[4] To investigate the effect of falls, many balance studies focus on cognitive demands[5,6] as a cause and exercise as a response.[7–13] Balance is the body's ability to maintain the center of gravity (COG) within the base of support (BOS).[14] As balance has been

[§]Corresponding author: Scott P. Breloff, Physical Effects Research Branch, Health Effects Laboratory Division, National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, 1095 Willowdale Road, MS L-2027, Morgantown, WV 26505, USA. E-mail: sbreloff@cdc.gov

associated with performance and reduced injuries,[15,16] it is important to examine factors that could have an affect on balance. Dietary intake is one such factor. Food consumption, or lack thereof, could potentially affect balance through its influence on blood glucose (BG) levels. To our knowledge, no studies have investigated how diet might influence balance and risk of falling. The first step in determining if diet can affect balance is to test a population who is at a very low risk of falling — healthy college-age individuals.

Variations in BG levels are partly related to food consumption — as levels increase and decrease depending on whether food is consumed.[17] The Glycemic Index (GI) is a method of ranking foods according to what influence they have on BG levels.[17] High GI (HI) foods cause a spike in BG levels followed by a quick descent whereas low GI (LO) foods cause a steady rise then fall in BG levels with a lower peak compared to high GI foods.[18] Therefore, overnight fasting or manipulating the GI of food consumed for breakfast can influence BG levels. What is not known is how changes in BG levels caused by varying dietary intake may influence quiet standing balance. Understanding the effects of skipping or consuming breakfasts of variable GI on balance in young adults is an important first step in determining if diet might increase fall risk due to reduced BG levels that result in reduced balance.

The direct relationship between BG and balance has focused on executive function[19–21] and has been generally tested in patients who have diabetes and diabetic peripheral neuropathy[22–24] although others have also been examined. For example, postural balance and attentional capacities in elderly adult are diminished during the second week of Ramadan fasting[25] and a link between balance and executive function exists in stroke patients.[26] Studies in healthy young adults found that glucose levels can affect executive function[20,21] during a Stroop test.[21] When executive function in healthy adults is divided — via dual-task paradigms — quiet standing balance is diminished.[14,27] What is not known is to what extent quiet standing balance is affected by the interaction of BG changes and dual-task conditions. By incorporating dual-task tests on young healthy individuals who have consumed different breakfast options after an overnight fast, it can be determined if quiet standing balance is altered from a combination of both factors.

Therefore, the purpose of this study was to determine if consuming three different types of breakfast [no breakfast (NO), high GI breakfast, or low GI breakfast] altered BG levels in such a way that young adults' balance control was compromised. It was hypothesized that skipping breakfast would result in the lowest BG levels which would reduce postural balance and increase sway. Additionally, it was hypothesized that consuming a high GI breakfast would result in the highest BG, followed by the low GI breakfast, and then no breakfast, and both breakfast conditions would result in increased postural balance and reduced sway compared to the no breakfast condition. Finally, it was hypothesized that a perturbation to executive function (dual task) in combination with altered BG would lead to a decrease in quiet standing balance.

## METHODS

### Design

This study was a randomized, counterbalanced, crossover repeated measures design and all subjects signed an informed consent which was approved by the University of Scranton's Institutional Review Board prior to enrollment in the study.

### Participants

Thirteen subjects (six males and seven females; mean age $= 20.3 \pm 1.1$ years; mean weight $= 71.3 \pm 9.2$ kg; mean height $= 174.6 \pm 6.6$ cm) were recruited from the university community. Participants did not report any history or clinical evidence of neurological, musculoskeletal, or other medical conditions affecting balance performance, such as stroke, head trauma, neurological disease (i.e. Parkinson's, diabetic neuropathy), or visual impairment uncorrectable by lenses and dementia. Additionally, participants' did not report any food allergies or diseases (i.e. anorexia/bulimia nervosa) which would restrict or influence the participants' ability to consume the presented food.

### Task Procedures

Subjects came to the laboratory on three separate occasions, with each session separated by at least one week. During the three visits, subjects were allocated to one of the three breakfast conditions: HI (white flour bagel), LO (dried apples), and NO. The amount of food each participant consumed was 0.5 g of carbohydrate per 1 kg of body weight and was consumed within 5 min. Subjects were randomly assigned to one of the six orders (ABC, ACB, BAC, BCA, CAB, and CBA; A = NO, B = HI, and C = LO) and were blinded to which breakfast they would receive before each visit to prohibit them from altering their normal diet prior to testing.

In order to guarantee the subjects entered each trial under similar conditions, they were asked to complete a food journal for 24 h leading up to their first trial, then consumed similar food prior to the two subsequent tests.

Subjects arrived after fasting overnight for at least 12 h prior to their scheduled start time. Blood glucose — Glucometers (Bayer Contour 9545C, Bayer Healthcare LLC, Mishawaka, IN, USA) and test strips (Bayer Healthcare LLC, Mishawaka, IN, USA) — was taken immediately upon subject arrival (prior to any breakfast option) to establish a baseline BG measure, and every 30 min until the subjects started the postural testing — postural sway testing started 90 min after breakfast consumption and took approximately 60 min to complete.

## Data Recording and Analysis

Three-dimensional analysis was completed with a 12-camera Kestrel motion capture system (Motion Analysis Corp., Santa Rosa, CA) and a force platform (Advanced Mechanical Technology, Inc., Watertown, MA), on which subjects stood for all trials. Motion capture data were synchronized in the Cortex Software© provided by Motion Analysis Corp. allowing simultaneous start transistor–transistor logic signals to be sent to both the cameras and force plate to ensure time-matched data. Subjects completed four quiet standing tasks during the postural sway test with both feet on the force plate: eyes open (EO), eyes closed (EC), eyes open dual task (EODT), and eyes closed dual task (ECDT). The dual-task protocols required subjects to spell five-letter words backwards, list the months of the year in reverse order, and given a certain number, subtract by sevens.[28] All trials were 30 s in length. During the dual-task trials, if the subjects completed the task before 30 s, they were immediately given a second prompt to ensure they were dual tasking during the entire trial.

## Outcome Measures

Whole-body center-of-mass (COM) values were calculated using marker position data recorded from the Kestrel motion capture system. These marker position data then utilized Zatsiorsky coefficients[29] and completed the calculation in Cortex Software© provided by Motion Analysis Corp. Center-of-pressure (COP) values were calculated with the analog voltage data recorded with the synchronized AMTI force plates. Excitation values and the calibration matrix were input to Cortex Software© and COP calculations were completed with this software. The exported COM and COP values were imported to a custom-built MATLAB© (MathWorks®, Natick, MA) code where the following variables were calculated: the maximum separation distance between the COG and COP, the maximum velocity of COM, and the ranges of COG and COP. All variables were analyzed along the anterior–posterior (AP) and medial–lateral (ML) axes.

Outcome measures were evaluated using both the raw and normalized values. The normalization procedure calculated percent change by utilizing the NO condition as the reference and dividing the HI and LO conditions by NO.

## Statistical Analysis

Each outcome measure (COM–COP separation, COM velocity, COM range, and COG range) was compared using a $3 \times 4$ (raw) or $2 \times 4$ (normalized) ANOVA with breakfast type (HI, LO, or NO; *raw* or HI/NO, LO/NO; *normalized*) and task (EO, EC, EODT, and ECDT) as within the subject factors. Fisher's least significant difference (LSD) post-hoc pairwise comparisons were used to determine specific difference between conditions. Alpha levels were set to 0.05 and all analysis was completed on SPSS 22 (IBM, USA).

# RESULTS

Blood glucose was the same for all subjects at each trail's baseline measurement ($p = 0.25$) and was significantly different immediately prior to the postural measurements between each breakfast trial — HI ($97 \pm 20$ mg/dL), LO ($87 \pm 12$ mg/dL), and NO ($78 \pm 9$ mg/dL) — ($p = 0.009$). Therefore, any changes in quiet standing variables can be associated to the changes in BG. Data for different breakfast types and task types along the anterior–posterior and medial–lateral axes are shown in Tables 1 and 2 and Figs. 1 and 2. The results summarizing raw and normalized interactions and the main effect $p$-values along the anterior–posterior and medial–lateral axes are shown in Table 3.

There was no breakfast $\times$ task interaction for raw COM–COG separation along the anterior–posterior axis — however, the main effects for breakfast and task were significant. Pairwise comparisons of breakfast did not have any significant differences — though NO to HI and LO to HI were trending toward significance ($p = 0.070$ and $p = 0.074$, respectively). Task *post-hoc* showed eyes closed ($19.77 \pm 11.14$ mm) was significantly smaller than eyes open dual task ($25.51 \pm 20.82$ mm),

**Table 1. Averages for All Outcome Measures in Both Planes of Motion during All Conditions.**

| | | Single Task | | | | Dual Task | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Eyes Open | | Eyes Closed | | Eyes Open | | Eyes Closed | |
| | | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| No Breakfast | | | | | | | | | |
| Anterior–Posterior | Separation (mm) | 24.75 | 11.09 | 22.47 | 7.75 | 24.97 | 9.05 | 28.93 | 27.05 |
| | Velocity (mm/s) | 134.81 | 106.37 | 135.83 | 93.01 | 125.97 | 85.12 | 395.37 | 1268.81 |
| | COM Range (mm) | 6.64 | 3.22 | 6.83 | 2.86 | 7.63 | 3.98 | 13.36 | 33.12 |
| | COP Range (mm) | 14.16 | 10.65 | 14.95 | 9.56 | 15.38 | 11.02 | 15.78 | 15.27 |
| Medial–Lateral | Separation (mm) | 38.16 | 21.48 | 38.68 | 29.21 | 39.16 | 28.12 | 33.33 | 32.96 |
| | Velocity (mm/s) | 200.59 | 90.06 | 192.05 | 86.37 | 187.83 | 52.56 | 352.07 | 467.44 |
| | COM Range (mm) | 19.65 | 7.84 | 18.9 | 6.97 | 19.55 | 11.21 | 22.56 | 25.68 |
| | COP Range (mm) | 36.26 | 21.94 | 37.55 | 19.94 | 35.19 | 29.69 | 36.09 | 21.02 |
| High Glycemic Index Breakfast (Bagel) | | | | | | | | | |
| Anterior–Posterior | Separation (mm) | 14.03 | 11.98 | 14.04 | 12.08 | 22.24 | 29.34 | 21.36 | 12.57 |
| | Velocity (mm/s) | 99.3 | 46.06 | 87.69 | 33.65 | 96.21 | 33.94 | 103.43 | 61.42 |
| | COM Range (mm) | 7.12 | 4.00 | 7.01 | 4.05 | 13.35 | 17.77 | 12.55 | 12.91 |
| | COP Range (mm) | 15.78 | 15.27 | 16.91 | 8.82 | 17.23 | 9.85 | 36.24 | 46.43 |
| Medial–Lateral | Separation (mm) | 42.85 | 12.17 | 34.82 | 9.7 | 17.83 | 31 | 15.96 | 27.81 |
| | Velocity (mm/s) | 206.65 | 82.62 | 196.97 | 65.91 | 199.7 | 99.9 | 195.65 | 102.15 |
| | COM Range (mm) | 21.66 | 12.21 | 19.72 | 7.2 | 32.81 | 27.87 | 34.51 | 25.61 |
| | COP Range (mm) | 45.83 | 25.53 | 42.31 | 16.27 | 76.85 | 64.78 | 75.92 | 54.78 |
| Low Glycemic Index Breakfast (Apples) | | | | | | | | | |
| Anterior–Posterior | Separation (mm) | 26.6 | 17.04 | 22.8 | 13.6 | 29.33 | 24.09 | 25.75 | 17.49 |
| | Velocity (mm/s) | 85.77 | 23.37 | 80.33 | 14.39 | 102.59 | 51.98 | 92.21 | 25.35 |
| | COM Range (mm) | 11.67 | 10.22 | 9.62 | 7.95 | 22.48 | 31.79 | 15.31 | 15.87 |
| | COP Range (mm) | 33.31 | 34.78 | 25.37 | 22.15 | 45.24 | 48.05 | 40.08 | 39.44 |
| Medial–Lateral | Separation (mm) | 41.11 | 13.84 | 43.32 | 10.34 | 22.84 | 29.9 | 24.27 | 22.71 |
| | Velocity (mm/s) | 189.28 | 70.07 | 185.95 | 65.54 | 214.69 | 119.1 | 209.57 | 72.56 |
| | COM Range (mm) | 24.42 | 10.78 | 24.49 | 9.62 | 34.73 | 25.61 | 31.79 | 20.65 |
| | COP Range (mm) | 52.53 | 21.76 | 56.09 | 22.82 | 76.44 | 52.21 | 74.99 | 45.87 |

**Table 2. Normalized Averages for All Outcome Measures in Both Planes of Motion during All Conditions.**

| | | Single Task | | | | Dual Task | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Eyes Open | | Eyes Closed | | Eyes Open | | Eyes Closed | |
| | | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| High Glycemic Index Breakfast/No Breakfast | | | | | | | | | |
| Anterior–Posterior | Separation | 1.01 | 1.4 | 0.96 | 1.04 | 1.03 | 1.62 | 1.1 | 1.01 |
| | Velocity | 0.92 | 0.32 | 0.83 | 0.29 | 0.9 | 0.34 | 0.97 | 0.56 |
| | COM Range | 1.38 | 1.14 | 1.3 | 0.94 | 3.87 | 2.56 | 4.29 | 33.12 |
| | COP Range | 1.34 | 1.12 | 1.22 | 0.91 | 3.47 | 2.83 | 4.19 | 15.27 |
| Medial–Lateral | Separation | 1.9 | 7.94 | 0.39 | 0.92 | −1.01 | 11.57 | −0.04 | 2.59 |
| | Velocity | 1.18 | 1.14 | 1.09 | 0.38 | 1.04 | 0.53 | 0.86 | 0.47 |
| | COM Range | 1.17 | 0.67 | 1.29 | 0.85 | 2.63 | 3.5 | 2.37 | 3 |
| | COP Range | 1.17 | 0.8 | 1.1 | 0.61 | 2.84 | 3.25 | 2.35 | 2.84 |
| Low Glycemic Index Breakfast/No Breakfast | | | | | | | | | |
| Anterior–Posterior | Separation | 1.6 | 1.62 | 1.24 | 0.9 | 1.42 | 1.32 | 1.42 | 1.74 |
| | Velocity | 0.87 | 0.43 | 0.79 | 0.39 | 0.99 | 0.44 | 0.9 | 0.39 |
| | COM Range | 2.06 | 1.87 | 1.53 | 1.03 | 3.74 | 4.55 | 2.34 | 2.54 |
| | COP Range | 2.02 | 1.66 | 1.45 | 1.13 | 3.22 | 2.94 | 2.86 | 2.89 |
| Medial–Lateral | Separation | 1.61 | 6.05 | 0.55 | 0.96 | −1.04 | 10.74 | −0.06 | 2.51 |
| | Velocity | 1.03 | 0.45 | 1.05 | 0.41 | 1.2 | 0.7 | 0.99 | 0.58 |
| | COM Range | 1.38 | 0.68 | 1.46 | 0.75 | 2.63 | 2.81 | 1.91 | 1.53 |
| | COP Range | 1.39 | 0.62 | 1.4 | 0.73 | 2.72 | 1.96 | 2.14 | 1.36 |

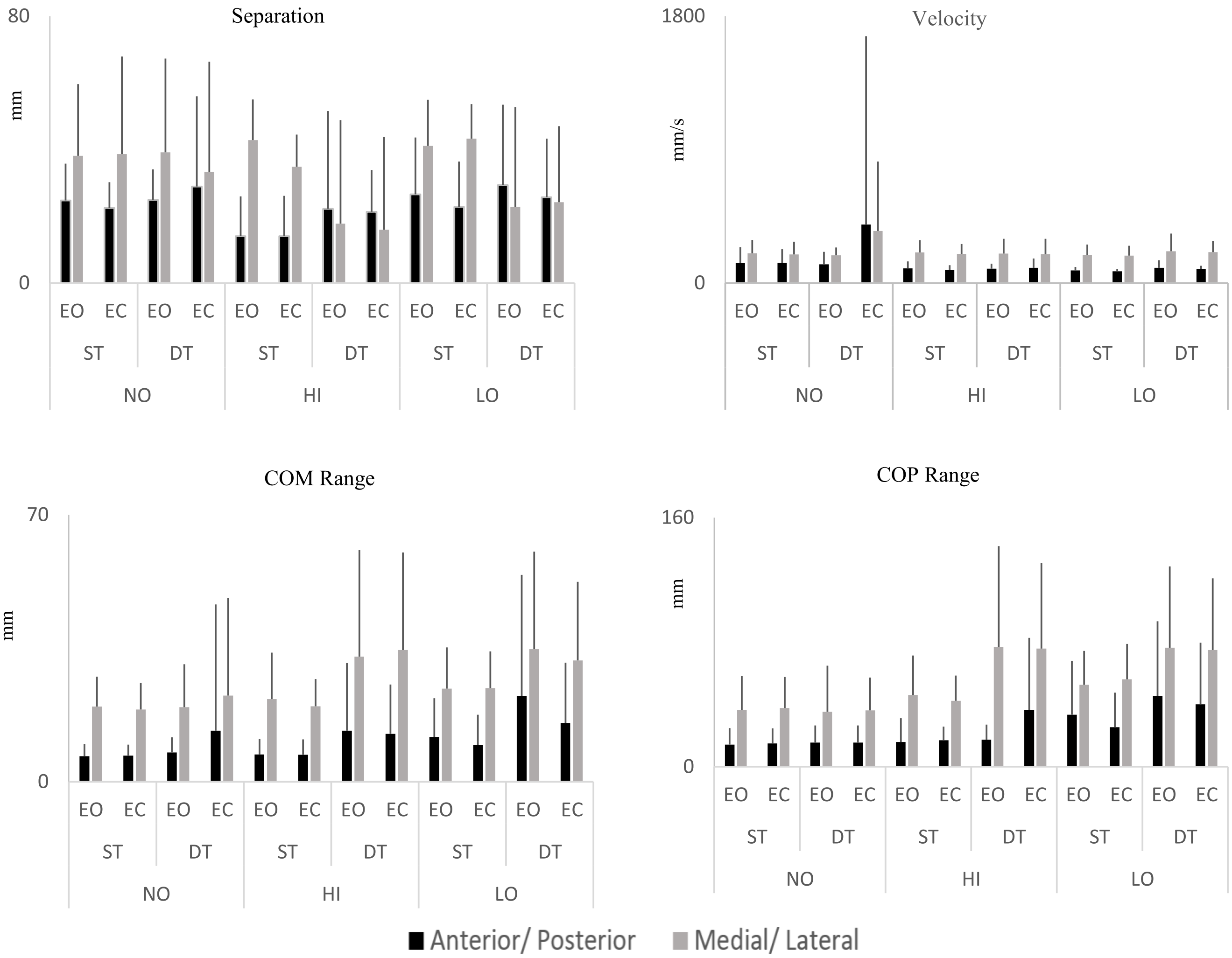


**Fig. 1** Averages for all outcome measures in both planes of motion during all conditions.

and was significantly smaller than eyes closed dual task ($25.34 \pm 19.01$ mm); $p = 0.044$ and $p = 0.026$, respectively.

There was no breakfast × task interaction for normalized COM–COG separation along the anterior–posterior axis — the breakfast main effect was significant. LO divided by NO had $1.43 \pm 1.42$ times higher separation than that for HI divided by NO which was $0.996 \pm 1.24$.

There was no breakfast × task interaction for raw COM range along the anterior–posterior axis — however, the main effects for breakfast and task were significant. No breakfast ($8.61 \pm 10.79$ mm) was significantly smaller than low GI breakfast ($14.77 \pm 16.46$ mm). Task's main effects were significant ($p = 0.004$). Eyes open ($8.49 \pm 5.81$ mm) was significantly smaller than eyes open dual task ($14.48 \pm 17.84$ mm); $p = 0.016$. Eyes closed ($7.82 \pm 4.95$ mm) was significantly smaller than eyes open dual task; $p = 0.009$. Similarly, eyes closed was significantly smaller than eyes closed dual task ($13.74 \pm 20.63$ mm); $p = 0.039$.

There was no breakfast × task interaction for normalized COM range along the anterior–posterior axis — however, the main effects for task were significant. Eyes open dual task was larger ($4.062 \pm 0.974$) than the eyes open ($1.720 \pm 0.196$) and eyes closed ($1.394 \pm 0.142$) conditions.

There was no breakfast × task interaction for raw COP range along the anterior–posterior axis — however, the main effects for breakfast and task were significant. No breakfast ($15.07 \pm 11.63$ mm) was significantly smaller than both high GI ($25.92 \pm 24.01$ mm) and low GI ($35.45 \pm 36.11$ mm) breakfasts; $p = 0.030$ and $p \leq 0.001$, respectively. Eyes open ($20.72 \pm 18.08$ mm) was significantly smaller than eyes open dual task ($32.28 \pm 35.16$ mm); $p = 0.037$. Eyes open was significantly smaller than eyes closed dual task ($29.72 \pm 28.55$ mm); $p = 0.033$. Eyes closed ($19.18 \pm 13.85$ mm)

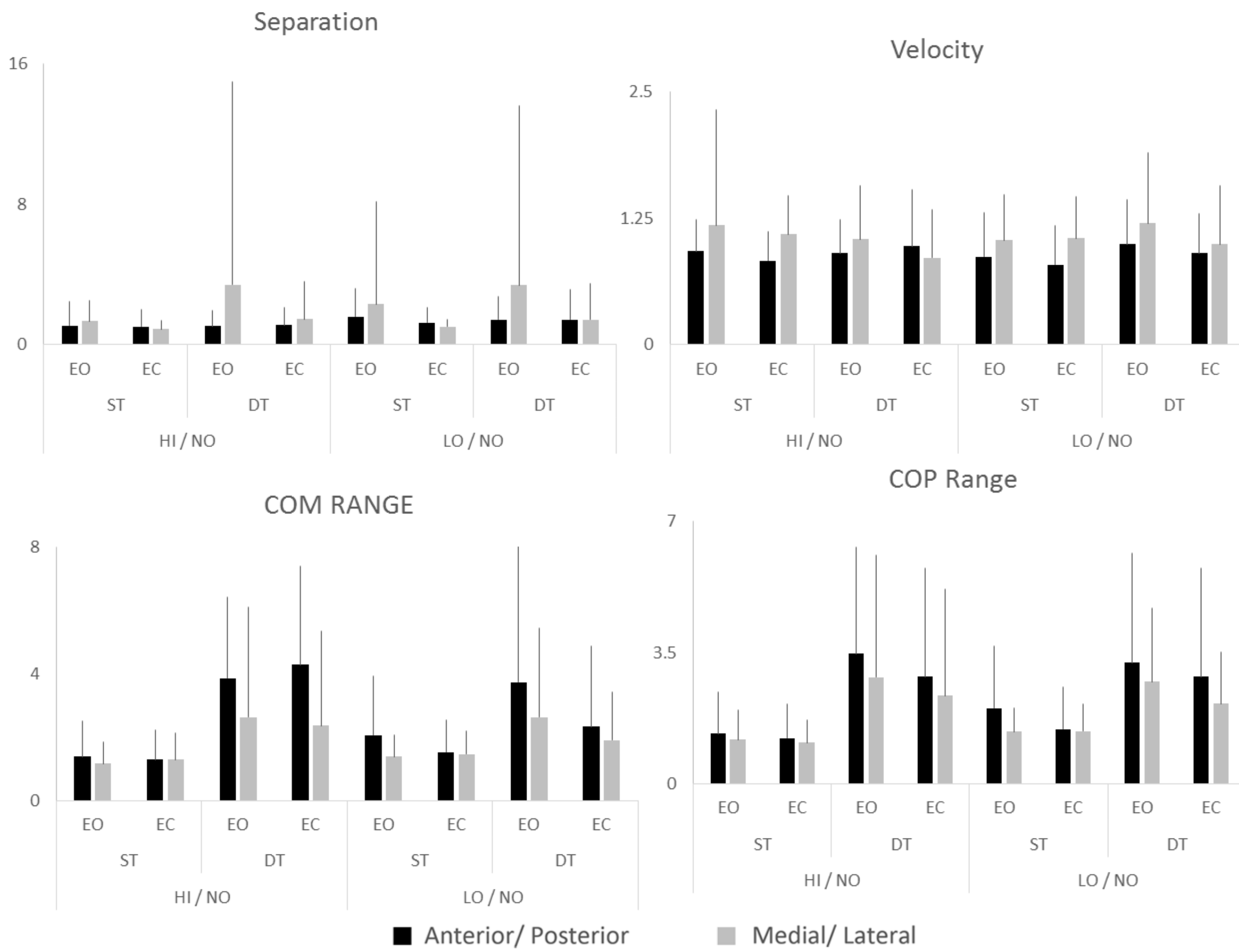


**Fig. 2** Averages for all outcome measures in both planes of motion during all conditions: normalized.

was significantly smaller than eyes open dual task; $p = 0.008$. Similarly, eyes closed was significantly smaller than eyes closed dual task; $p \leq 0.001$.

There was no breakfast × task interaction for normalized COM range along the anterior–posterior axis — however, the main effects for task were significant. Eyes open dual task was larger ($4.037 \pm 1.345$) than the eyes open ($1.362 \pm 0.225$) and eyes closed ($1.210 \pm 0.183$) conditions.

There was a breakfast × task interaction for raw COM–COG separation along the medial–lateral axis — additionally, the main effects for task were significant. Eyes open ($40.70 \pm 15.83$ mm) was significantly larger than both the eyes open dual task ($26.61 \pm 29.67$ mm) and eyes closed dual task ($24.52 \pm 27.82$ mm); both $p \leq 0.001$. Eyes closed ($38.94 \pm 16.43$ mm) was significantly larger than both the eyes open dual task and eyes closed dual task (both $p \leq 0.001$).

There was no breakfast × task interaction for raw COM range along the medial–lateral axis — however,

**Table 3. Probabilities of Statistical Significance of Interactions and Main Effect for All Data.**

| | | Interaction | Breakfast ME | Task ME |
|---|---|---|---|---|
| Raw | | | | |
| Anterior–Posterior | Separation | 0.471 | 0.027* | 0.014* |
| | Velocity | 0.208 | 0.059 | 0.212 |
| | COM Range | 0.235 | 0.043* | 0.004* |
| | COP Range | 0.128 | 0.001* | 0.001* |
| Medial–Lateral | Separation | 0.003* | 0.179 | ≤0.001* |
| | Velocity | 0.059 | 0.200 | 0.061 |
| | COM Range | 0.086 | 0.037* | ≤0.001* |
| | COP Range | 0.007* | 0.001* | ≤0.001* |
| Normalized | | | | |
| Anterior–Posterior | Separation | 0.592 | 0.027* | 0.517 |
| | Velocity | 0.237 | 0.997 | 0.128 |
| | COM Range | 0.476 | 0.935 | 0.014* |
| | COP Range | 0.430 | 0.907 | 0.002* |
| Medial–Lateral | Separation | 0.206 | 0.461 | 0.101 |
| | Velocity | 0.153 | 0.987 | 0.073 |
| | COM Range | 0.244 | 0.695 | 0.001* |
| | COP Range | 0.233 | 0.807 | 0.001* |

*Indicates statistically significant differences at ($p \leq 0.05$). ME = Main Effects.

the main effects for task were significant. No breakfast ($20.17 \pm 12.92$ mm) was significantly smaller than low GI breakfast ($28.86 \pm 16.66$ mm), $p = 0.009$. Task's pairwise comparisons revealed eyes open ($21.91 \pm 10.27$ mm) to be significantly smaller than eyes open dual task ($28.99 \pm 21.56$ mm) and eyes closed dual task ($29.61 \pm 23.98$ mm); $p \leq 0.001$ and $p = 0.002$, respectively. Eyes closed ($21.03 \pm 7.93$ mm) was significantly smaller than both the eyes open dual task ($p \leq 0.001$) and eyes closed dual task ($p = 0.001$).

There was no breakfast × task interaction for normalized COM range along the medial–lateral axis — however, the main effects for task were significant. Eyes open dual task ($2.780 \pm 0.44$) and eyes closed dual task ($2.237 \pm 0.321$) were larger than the eyes open ($1.300 \pm 0.087$) and eyes closed ($1.366 \pm 0.122$) conditions.

There was a breakfast × task interaction for raw COP range along the medial–lateral axis — additionally, the main effects for breakfast and task were significant. No breakfast ($36.27 \pm 23.08$ mm) was significantly lower than both the high GI breakfast ($60.23 \pm 40.34$ mm) and low GI breakfast ($65.02 \pm 35.67$ mm); $p = 0.005$ and $p \leq 0.001$, respectively. Eyes open ($44.87 \pm 23.08$ mm) was significantly smaller than both the eyes open dual task ($62.82 \pm 48.89$ mm) and eyes closed dual task ($62.33 \pm 40.55$ mm); both $p \leq 0.001$. Eyes closed ($45.31 \pm 19.58$ mm) was significantly smaller than both the eyes open dual task ($p \leq 0.001$) and eyes closed dual task ($p \leq 0.001$).

There was no breakfast × task interaction for normalized COP range along the medial–lateral axis — however, the main effects for task were significant. Eyes open dual task ($2.981 \pm 0.362$) and eyes closed dual task ($2.364 \pm 0.305$) were larger than the eyes open ($1.306 \pm 0.103$) and eyes closed ($1.221 \pm 0.098$) conditions.

## DISCUSSION

Balance is an important component of fall risks and rehabilitation.[15,16,30–36] One variable that has been previously linked to balance is BG levels,[19–21] which can be affected by dietary intake and fasting.[37] As 31 million Americans skip breakfast[38] it is unknown how this lack of food intake can affect their balance. This study was the first to compare how different GI breakfast types HI, LO, and NO in healthy young adults influenced quiet standing balance. It was hypothesized that skipping breakfast (NO) would result in the lowest BG levels and participants would demonstrate reduced balance when compared to the HI and LO breakfast types — furthermore, there would be balance differences between HI, LO, and NO breakfast types. It was also hypothesized that a perturbation to executive function (dual task) in combination with altered BG would lead to a decrease in quiet standing balance.

As predicted, breakfast manipulation resulted in different BG levels with NO having the lowest BG followed by HI and LO. Different breakfasts did have varying effects on quiet standing balance; but the effects were not as clear as expected. Generally, NO did not show more sway in quiet standing balance than HI and LO. Subjects swayed more during the breakfast conditions (HI, LO) compared to the no breakfast condition, which is inconsistent with the hypothesis. It is possible that young healthy adults who have had breakfast are more confident and have a larger area in which they can control their COM within their base of support whereas the no breakfast group is more reserved and must keep their COM well within the base of support. Regardless, these data suggest that skipping breakfast in young adults might have no influence on fall risk — however, a dynamic study should be conducted to further investigate.

The separation of COM and COG has been used previously to determine how attention can influence postural control.[39–45] In this study, it was used to determine if the type of breakfast consumed would affect BG to alter "balance" as measured by the COM–COG separation. The COM–COG separation means were slightly higher and had more variability than the previous studies[39–45] — suggesting if BG is altered and coupled with an executive function perturbation (dual task) the COM–COG separation will be greater than the solely perturbing executive function as has been shown previously.

Breakfast-altered BG does not influence COM velocity. COM velocity is generally used to describe ankle stiffness[44,46] and is incorporated into an inverted pendulum model.[44,45] Therefore, using the COM velocity by itself might not be a useful measure to determine if BG can affect quiet standing. A possible future approach might be to use phase plots.[47] Of note, the magnitude of eyes closed dual task for no breakfast COM velocity appears to be larger than any other condition — though not significant — these data could be indicative of dual task being more difficult to control COM when having no food.

Center-of-mass range detected differences between some of the different breakfast types. The data indicate subjects' COM moved less during the LO breakfast condition compared to the no breakfast condition — opposite to the hypothesis. The COM range has extensively been used to compare young and old during a standing turn[48] — therefore this measure would be advantageous in a dynamic test of balance. The range of the COP was able to show differences in quiet standing balance in both the anterior–posterior and medial–lateral directions. In both axes, for the no breakfast condition the COP had less movement than the breakfast conditions. The ML axis had a particularly higher COP motion if breakfast was consumed (HI, LO) and was a dual task. Both of these findings were contradictory to the hypotheses. The consumption of breakfast caused an increase in COM and COP motion. It is unclear why this happened, one explanation may be that young healthy adults so often do not consume breakfast such that potentially they are accustomed to functioning normally at a lower BG level and therefore balance was not affected. Of interest would be to examine if individuals who habitually skip breakfast are differentially affected by modifying breakfast compared to those who normally consume this meal.

The data in this study — AP and ML axes for the separation as well as the COM range and COP range variables — were in agreement that when the executive function is divided in a dual task, the balance of individuals is compromised.[14,21] Though human balance is reliant on the synergy of the proprioceptive, vestibular, and visual sensory systems–however with impaired or reduced vision, vision has a greater influence on postural control.[49] This signifies that the level of BG will not change the reliance of vision on quiet standing balance.

Many different measures have been used to quantify postural control and quiet standing balance.[44–50] Though the variables used in this study were able to consistently detect differences in both breakfast type and task, in the future, it would be advantageous to apply some of these other measures — used to quantify postural control and quiet standing balance — to better understand how changing BG might influence quiet standing balance.

A continuation of this study would be an investigation into how balance would be influenced during a dynamic situation, i.e. gait, under different breakfast conditions. Subjects would again consume several different categories of breakfasts then would complete gait tasks under single- and dual-task conditions, as outlined by previous investigations.[28,51–56] Another further study would be the incorporation of electromyography (EMG) to determine which balance strategy (hip or ankle) was used to maintain balance during the different breakfast types.

In this study, the BG of the subjects was measured 90 min following breakfast type, as balance was one of the several performed tests in order to understand how breakfast type influences the body. Though the BG data were different between conditions, the timing at which quiet standing balance was measured could have profound difference on the results. In the future, repeating the balance tests at various intervals would provide insight into the timing of how BG can influence balance.

## CONCLUSION

This was the first study to correlate changes in BG to quiet standing balance. Blood glucose — as altered by breakfast type — produced differences in quiet standing balance as measured by the COM–COG separation, COM range, and COP range. Surprisingly, these results were opposite to what was hypothesized for different breakfast conditions. It is uncertain why this is the case, perhaps young adults skip breakfast frequently enough since they have adapted to have better quiet standing balance with lower blood sugar. As was expected the reduction in vision and the inclusion of a task did reduce the quiet standing balance of the subjects.

The inclusion of other measures of quiet standing balance, different timings of the measures, and the addition of dynamic tasks would provide a more conclusive understanding regarding how a change in BG will affect the balance of young healthy adults. This study provided the first insights into this relationship — based on the observed changes, deviations in BG in conjunction with executive function perturbation and vision changes do change quiet standing balance, but not in such a way as to put young healthy individuals at the risk of falling.

## ACKNOWLEDGMENTS

Funding was provided by the University of Scranton research initiation funds. The authors wish to thank Lauren A. Luginsland for the help with data collection. The findings and conclusions in this report are those of the author(s) and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention.

## REFERENCES

1. Bergen G, Stevens M, Burns E, Falls and fall injuries among adults aged ≥ 65 years — United States, 2014, *MMWR Morb Mortal Wkly Rep* **65**:993–998, 2016.
2. U.S. Bureau of Labor Statistics, *Nonfatal Occupational Injuries and Illnesses Requiring Days Away from Work*, Washington, DC, 2017.
3. U.S. Bureau of Labor Statistics, *Census of Fatal Occupational Injuries Charts, 1992–2014 (Revised Data)*, Washington DC, 2016.

4. Burns ER, Stevens JA, Lee R, The direct costs of fatal and non-fatal falls among older adults: United States, *J Safety Res* **58**:99–103, 2016.
5. Brauer SG, Woollacott M, Shumway-Cook A, The interacting effects of cognitive demand and recovery of postural stability in balance-impaired elderly persons, *J Gerontol A, Biol Sci Med Sci* **56**:M489–M496, 2001.
6. Wolfson LI, Whipple R, Amerman P, Kaplan J, Kleinberg A, Gait and balance in the elderly. Two functional capacities that link sensory and motor ability to falls, *Clin Geriatr Med* **1**:649–659, 1985.
7. Tsang WW, Hui-Chan CW, Effects of exercise on joint sense and balance in elderly men: Tai Chi versus golf, *Med Sci Sports Exerc* **36**:658–667, 2004.
8. Sauvage, Jr. LR, Myklebust BM, Crow-Pan J, Novak S, Millington P, Hoffman MD, Hartz AJ, Rudman D, A clinical trial of strengthening and aerobic exercise to improve gait and balance in elderly male nursing home residents, *Am J Phys Med Rehabil* **71**:333–342, 1992.
9. Barnett A, Smith B, Lord SR, Williams M, Baumand A, Community-based group exercise improves balance and reduces falls in at-risk older people: A randomised controlled trial, *Age Ageing* **32**:407–414, 2003.
10. Province MA, Hadley EC, Hornbrook MC, Lipsitz LA, Miller JP, Mulrow CD, Ory MG, Sattin RW, Tinetti ME, Wolf SL, The effects of exercise on falls in elderly patients: A preplanned meta-analysis of the FICSIT trials, *JAMA* **273**:1341–1347, 1995.
11. Lord SR, Ward JA, Williams P, Strudwick M, The effect of a 12-month exercise trial on balance, strength, and falls in older women: A randomized controlled trial, *J Am Geriatr Soc* **43**:1198–1206, 1995.
12. Campbell AJ, Robertson MC, Gardner MM, Norton RN, Tilyard MW, Buchner DM, Randomised controlled trial of a general practice programme of home based exercise to prevent falls in elderly women, *BMJ* **315**:1065–1069, 1997.
13. Hill MW, Higgins MF, Price MJ, The effect of high-intensity cycling training on postural sway during standing under rested and fatigued conditions in healthy young adults, *Eur J Appl Physiol* **116**:1965–1974, 2016.
14. Winter DA, *A.B.C. (Anatomy, Biomechanics and Control) of Balance During Standing and Walking*, Waterloo Biomechanics, Waterloo, ON, 1995.
15. Hrysomallis C, Relationship between balance ability, training and sports injury risk, *Sports Med* **37**:547–556, 2007.
16. Hrysomallis C, Balance ability and athletic performance, *Sports Med* **41**:221–232, 2011.
17. Strubbe JH, Steffens AB, Blood glucose levels in portal and peripheral circulation and their relation to food intake in the rat, *Physiol Behav* **19**:303–307, 1977.
18. Wolever TM, Jenkins DJ, Jenkins AL, Josse RG, The glycemic index: Methodology and clinical implications, *Am J Clin Nutr* **54**:846–854, 1991.
19. Galioto R, Alosco ML, Spitznagel MB, Strain G, Devlin M, Cohen R, Crosby RD, Mitchell JE, Gunstad J, Glucose regulation and cognitive function after bariatric surgery, *J Clin Exp Neuropsychol* **37**:402–413, 2015.
20. Weinstein G, Maillard P, Himali JJ, Beiser AS, Au R, Wolf PA, Seshadri S, DeCarli C, Glucose indices are associated with cognitive and structural brain measures in young adults, *Neurology* **84**:2329–2337, 2015.
21. Gluck ME, Ziker C, Schwegler M, Thearle M, Votruba SB, Krakoff J, Impaired glucose regulation is associated with poorer performance on the Stroop Task, *Physiol Behav* **122**:113–119, 2013.
22. Simoneau GG, Ulbrecht JS, Derr JA, Becker MB, Cavanagh PR, Postural instability in patients with diabetic sensory neuropathy, *Diabetes Care* **17**:1411–1421, 1994.
23. Zhang Y, Critchley L, Tam Y, Tomlinson B, Short-term postural reflexes in diabetic patients with autonomic dysfunction, *Diabetologia* **47**:304–311, 2004.
24. Ahn S, Song R, Effects of Tai Chi Exercise on glucose control, neuropathy scores, balance, and quality of life in patients with type 2 diabetes and neuropathy, *J Altern Complement Med* **18**:1172–1178, 2012.
25. Laatar R, Borji R, Baccouch R, Zahaf F, Rebai H, Sahli S, Effects of Ramadan fasting on postural balance and attentional capacities in elderly people, *J Nutr Health Aging* **20**:553–560, 2016.
26. Liu-Ambrose T, Pang MY, Eng JJ, Executive function is independently associated with performances of balance and mobility in community-dwelling older adults after mild stroke: Implications for falls prevention, *Cerebrovasc Dis* **23**:203–210, 2006.
27. Silsupadol P, Siu K-C, Shumway-Cook A, Woollacott MH, Training of balance under single- and dual-task conditions in older adults with balance impairment, *Phys Ther* **86**:269–281, 2006.
28. Howell DR, Osternig LR, Chou L-S, Dual-task effect on gait balance control in adolescents with concussion, *Arch Physi Med Rehabil* **94**:1513–1520, 2013.
29. Zatsiorsky VM, *Kinematics of Human Motion*, Human Kinetics, Champaign, IL, 1998.
30. Davlin CD, Dynamic balance in high level athletes, *Percept Mot Skills* **98**:1171–1176, 2004.
31. Tropp H, Askling C, Gillquist J, Prevention of ankle sprains, *Am J Sports Med* **13**:259–262, 1985.
32. Caraffa A, Cerulli G, Projetti M, Aisa G, Rizzo A, Prevention of anterior cruciate ligament injuries in soccer: A prospective controlled study of proprioceptive training, *Knee Surg Sports Traumatol Arthrosc* **4**:19–21, 1996.
33. Wester JU, Jespersen SM, Nielsen KD, Neumann L, Wobble board training after partial sprains of the lateral ligaments of the ankle: A prospective randomized study, *J Orthop Sports Phys Ther* **23**:332–336, 1996.
34. Söderman K, Werner S, Pietilä T, Engström B, Alfredson H, Balance board training: Prevention of traumatic injuries of the lower extremities in female soccer players?, *Knee Surg Sports Traumatol Arthrosc* **8**:356–363, 2000.
35. Verhagen E, Van der Beek A, Twisk J, Bouter L, Bahr R, Van Mechelen W, The effect of a proprioceptive balance board training program for the prevention of ankle sprains: A prospective controlled trial, *Am J Sports Med* **32**:1385–1393, 2004.
36. Emery CA, Cassidy JD, Klassen TP, Rosychuk RJ, Rowe BH, Effectiveness of a home-based balance-training program in reducing sports-related injuries among healthy adolescents: A cluster randomized controlled trial, *CMAJ* **172**:749–754, 2005.

37. Pereira MA, Erickson E, McKee P, Schrankler K, Raatz SK, Lytle LA, Pellegrini AD, Breakfast frequency and quality may affect glycemia and appetite in adults and children, *J Nutr* **141**:163–168, 2011.
38. Hickey D, 31 Million U.S. consumers skip breakfast each day, reports NPD, Press Releases, NPD, https://www.npd.com/wps/portal/npd/us/news/press-releases/pr_111011b/, 2011.
39. Vuillerme N, Nafati G, How attentional focus on body sway affects postural control during quiet standing, *Psychol Res* **71**:192–200, 2007.
40. Gollhofer A, Horstmann G, Berger W, Dietz V, Compensation of translational and rotational perturbations in human posture: Stabilization of the centre of gravity, *Neurosci Lett* **105**:73–78, 1989.
41. Massion J, Postural control system, *Curr Opin Neurobiol* **4**:877–887, 1994.
42. Horstmann GA, Dietz V, A basic posture control mechanism: The stabilization of the centre of gravity, *Electroencephalogr Clin Neurophysiol* **76**:165–176, 1990.
43. Winter DA, Human balance and posture control during standing and walking, *Gait Posture* **3**:193–214, 1995.
44. Winter DA, Patla AE, Prince F, Ishac M, Gielo-Perczak K, Stiffness control of balance in quiet standing, *J Neurophysiol* **80**:1211–1221, 1998.
45. Masani K, Vette AH, Kouzaki M, Kanehisa H, Fukunaga T, Popovic MR, Larger center of pressure minus center of gravity in the elderly induces larger body acceleration during quiet standing, *Neurosci Lett* **422**:202–206, 2007.
46. Loram ID, Lakie M, Direct measurement of human ankle stiffness during quiet standing: The intrinsic mechanical stiffness is insufficient for stability, *J Physiol* **545**:1041–1053, 2002.
47. Riley PO, Benda BJ, Gill-Body KM, Krebs DE, Phase plane analysis of stability in quiet standing, *J Rehabil Res Dev* **32**:227–235, 1995.
48. Baird JL, Van Emmerik REA, Young and older adults use different strategies to perform a standing turning task, *Clin Biomech* **24**:826–832, 2009.
49. Redfern MS, Yardley L, Bronstein AM, Visual influences on balance, *J Anxiety Disord* **15**:81–94, 2001.
50. Hollman JH, Kovash FM, Kubik JJ, Linbo RA, Age-related differences in spatiotemporal markers of gait stability during dual task walking, *Gait Posture* **26**:113–119, 2007.
51. Chou L-S, Kaufman KR, Brey RH, Draganich LF, Motion of the whole body's center of mass when stepping over obstacles of different heights, *Gait Posture* **13**:17–26, 2001.
52. Chou L-S, Draganich LF, Stepping over an obstacle increases the motions and moments of the joints of the trailing limb in young adults, *J Biomech* **30**:331–337, 1997.
53. Chou L-S, Kaufman KR, Walker-Rabatin AE, Brey RH, Basford JR, Dynamic instability during obstacle crossing following traumatic brain injury, *Gait Posture* **20**:245–254, 2004.
54. Parker TM, Osternig LR, Van Donkelaar P, Chou L-S, Gait stability following concussion, *Med Sci Sports Exer* **38**:1032–1040, 2006.
55. Bachman JL, Deitrick RW, Hillman AR, Exercising in the fasted state reduced 24-hour energy intake in active male adults, *J Nutr Metab* **2016**:1984198, 2016.
56. Betts JA, Richardson JD, Chowdhury EA, Holman GD, Tsintzas K, Thompson D, The causal role of breakfast in energy balance and health: A randomized controlled trial in lean adults, *Am J Clin Nutr* **100**:539–547, 2014.