International Journal of
Cognition and Behaviour

RESEARCH ARTICLE

Employing Kinect for Cognitive-Motor Assessment: A Feasibility Study

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Abstract

This study examined the feasibility of the Microsoft Kinect sensor for assessing mediolateral trunk sway and its associations with cognitive abilities. To this end, young adults and elderlies were sampled and performed various gait and balance tasks under single- and dual-task paradigms. Although reliable, Kinect's ability to assess cognition through movement was not conclusive. Specifically, the Kinect distinguished between young- and old-adults gait, but not between young-adults with and without attention-deficit-disorder. However, gait under divided-attention and balance in the absence of visual-information interacted and affected performance in the Trail Making Test (TMT). The simple-effects showed that TMT-performance among participants with better stability in the absence of visual information was not affected by increased attentional demands. In contrast, attentional demands ill-affected TMT-performance among those who did not maintain their stability in the absence of visual information. We discuss these findings in terms of interoceptive attention, awareness, and control over movement.

Keywords

Postural stability, Executive functions, Static balance, Dynamic balance, Interoceptive attention

Introduction

Motor control is inherently associated with cognitive abilities [1]. That is, one's ability to execute movement, to withhold it, or to maintain balance (either while standing or moving), require attentional and monitoring resources [2]. For example, Beauchet, et al. [3] instructed older adults to walk 20 meters with and without naming out loud as many names of animals they can (i.e., verbal fluency task) or counting backwards. Such dual-task paradigms are widely employed in order to examine participant's performance under scarce cognitive resources [4], and typically result in slower and less stable walk as compared to performing solely the walking task [5]. Indeed, Beauchet, et al. [3] found that as compared to single task performance, dual task increased the number of steps and time needed to complete the distance.

Similarly, van Iersel, et al. [6], instructed older adults to walk on an electronic walkway while wearing sensor measuring mediolateral (ML) and anteroposterior trunk sway. Participants walked the walkway with and without a secondary task, and their performances were correlated with common measures of executive control, as the Trail-Making Test (TMT) and Stroop task. It was found that, as compared to single task, dual task resulted with slower walk speed and higher ML variability. Furthermore, under dual-task, ML velocity was associated with increased set-shifting cost in the TMT, suggesting that a decrease in the availability of cognitive resources may increase trunk sway among older adults with less efficient executive functions. Therefore, availability and manageability of attentional resources are intimately related to control over movement. Increasing attentional demands, nonetheless, may benefit or impair postural stability, depending on task prioritization (i.e., the amount of attentional resourced allotted to the motor and the distracting tasks [7]).

In line with this notion, examination of movement among participants who suffer from Attention Deficit Disorder, with or without Hyperactivity (ADD/H), typically revealed less stable motor performance. For example, children with ADD/H symptoms were

Citation: Levi U, Laslo-Roth R, Rosenstreich E (2017) Employing Kinect for Cognitive-Motor Assessment: A Feasibility Study. Int J Cogn Behav 1:003.

Accepted: November 19, 2018; **Published:** November 21, 2018

more likely to have balance problems, especially in maintaining static (standing) and dynamic (walking) balance with eyes closed [8,9]. In another study, children with ADD/H were compared to age and sex matched non-ADD/H controls in trunk sway during static balance tasks [10]. It was found that ADD/Hs performed with less stability than controls. Interestingly, in contrast to the authors prediction, when the balance task was performed simultaneously with an auditory memory task (i.e., dual-task paradigm), both groups showed a more stable performance. The authors concluded that increasing attentional demand promoted the activation of an automatic balance control system, thus resulting in more stable posture.

Such findings raise the possibility of employing the assessment of movement in order to evaluate or predict cognitive abilities, especially among populations in the focus of concern, as the elderly and children [11]. Nonetheless, movements assessing methods may be inaccurate or high-cost, thus may not be appropriate for a non-academic or professional use. For example, in the common Timed Up & Go (TUG) assessment of movement, participants-typically older adults-are instructed to get up from a chair, walk a short distance, turn back, and sit back again; performance is assessed as the time (in seconds) needed for the participant to complete the task. However, the TUG was suggested to be more accurate if movement was assessed using accelerometers [12]; this way, performance time, velocity, and trunk sway are integrated into a clearer picture of the participant's motor ability. Put differently, continuous measurement of trunk sway may be more predictive of elderly fallers than the traditional TUG [12,13], but the machines required for such precision measurements are not accessible or affordable by the common person or community healthcare services.

In this context, off-the-shelf cost-effective 3D sensors may be employed at home environment for simple and frequent monitoring of at-risk populations. In the focus of the current study is the Microsoft Kinect sensor, which was originally designed to serve as a remote game controller designated to assessing participants' body position and movement in space. Recent studies showed that the Kinect sensor may be a reliable and efficient method to examine movement in and out of the lab [14-17]. Although the Kinect's validity for assessing kinematic properties is in question, comparing movement data collected by the Kinect to a gold standard typically reveals good spatiotemporal validity [15,18].

However, to the best of our knowledge, no study to date has conducted a cognitive validation for the Kinect. That is, whereas it may not serve as an accurate lab-based instrument for motor assessment, the Kinect may still be sensitive enough for its assessment of movement to be correlated with differences in cognitive performance. Guided by this notion, the present study sought to analyze Kinect data through cognitive perspectives, as single vs. dual tasks, availability of visual information, correlations with common measures of executive control, and comparisons between groups that differ in their cognitive abilities. To this end, participants' ML trunk sway was assessed using Kinect sensor for Xbox 360 (also known as Kinect v.1), while performing various motor tasks over an approximately 3 × 1.5 m testing space. Executive control was assessed using the TMT, and between group comparisons were conducted between students with and without attention deficit, and between young and old adults.

Because the main objective of the study was to investigate the feasibility of employing the Kinect for assessing cognitive-related aspects of movement, it was predicted that a) Less ML variability will be observed during gait performance among young- compared to old-adults, and that b) Young-adults diagnosed with ADD/H will show more variability than non-ADD/H in dynamic and static balance tasks, especially under dual-task gait. Furthermore, it was predicted that c) Dynamic and static balance tasks will be associated with executive functions as assessed by the TMT, such that more variability in these tasks will be associated with poor TMT performance. Finally, it was predicted that the effect of dual-task gait and the effect of the availability of visual information on static balance, will be associated with the TMT, such that poor performance under dual- (compared to single-) task gait, or at the absence of visual information, will both be associated with poor TMT performance.

Method

Participants

Young adult sample: The main sample comprised of a total of 123 students and administration staff at the Peres Academic Center (PAC) enrolled to the study in exchange to course credit or cash equivalent of 5 USD. Students who reported on having chronic gait or balance problems of any sort (*n* = 5) or that consumed a cognitive-affecting drug up to 12 hours prior to participation (e.g., cannabis or medications for attention deficit, bipolarity, schizophrenia, etc.; *n* = 6), were excluded from the study. We also excluded from the study participants with body mass index (BMI) of 17 and below (*n* = 2) or of 30 and above (*n* = 4). Hence, a total of 106 students participated in the study (age ranged 21-55, *M* = 26.46, *SD* = 5.43; 97% females; 93.5% right-foot dominant; mean BMI = 22.69, *SD* = 3.78), of which 32 participants (31.1%) reported to be officially diagnosed with attention deficit disorder (with or without hyperactivity; ADD/H). Most participants (93.3%) reported to be generally in a good or very good health.

Older adult sample: The second sample consisted of 33 older community-dwelling adults (age: *M* = 78.97, *SD* = 6.71, range 66-95; 23 females; 90.9% right-foot dominant; mean BMI = 23.18, *SD* = 2.93). Most reported to be generally in reasonable to very good health (70%). This sample was not screened for medications, drugs, or gate problems, yet participants were approached and invited to participate only if they seemed to be able to walk without an aid of any sort. Participants were approached in a day recreational center for the elderly, located in a large city at the center of Israel, and were invited to participate in the study. No compensation was offered for participation. Participants in both samples gave their written consent to participate, and the study was approved by the PAC ethics committee.

Tasks and measures

Movement and balance: Participants' ML variability was assessed using a Microsoft Kinect for Xbox 360 sensor connected to a Core-i3 laptop computer running Windows 7, and of a Microsoft SDK based software which sampled ML trunk displacement (in degrees) from the body center. The efficient capture range of the sensor used in this study vary from 0.9-3.2 m, and previous study reported similar sensors to have a 1 cm depth resolution at 2 m distance [19]. Although the system's sampling rate could be set up to 60 Hz, based on a pretest and following Kee, et al. [20] the system was set to 10 Hz. Thus, during the 25 s long motor tasks, 250 ML displacement data points were collected per task per participant. Performance was assessed during nine motor tasks presented in fixed order (due to time and budget constraints, the elderly sample was assessed only in the first two tasks):

1. Sitting-standing-walking-turning-walking-sitting (Timed Up & Go; TUG; [21]). The TUG is a simple task designed to measures participant's ability to stand up, sit down and walk. Participants were asked to stand up from a chair, walk forward a 2 m distance at a normal yet relaxed pace, turn around, return to their seat and to sit down. Performance was assessed by the time (in seconds) needed to complete the task. Although TUG is typically carried over a 3 m distance, is this study a 2 m distance was employed for better capture of TUG performance by the Kinect sensor. Test-retest reliability was 0.98 in previous studies.

2. Paced slow tandem walk under full attention for 25 s. Walking heal-to-toe over a 2 m line (marked with tape) at a pace of one step every four seconds, paced by a metronome set to 15 BPM.

3. Paced slow tandem walk under divided attention for 25 s. This was a dual task [22], in which participants were instructed to repeat Task 2 while continuously subtracting 3 from 189 and from the outcome (i.e., 189, 186, 183 and so on).

4. Standing on dominant foot with eyes open for 25 s. Here participants were instructed to put their hands at the sides of their body and to stand on their dominant foot while slightly lifting their non-dominant foot.

5. Standing on non-dominant foot with eyes open for 25 s. Similar to Task 4.

6. Standing on dominant foot blindfolded for 25 s. This task examined participants' reliance on visual information in order to preserve postural stability.

7. Task 2 again (in order to examine test-retest reliability).

8. Task 4 again (in order to examine test-retest reliability).

9. Standing on dominant foot, tiptoe, for 25 s. This task examined participants' ability to reach balance while standing on a narrow base. Participants were instructed to stand on dominant foot with eyes open, and then to push up with their toes trying to reach as high as possible.

Trail Making Test: The Trail Making Test (TMT; [23]) was employed in order to assess participants' ability to shift between mental sets and to withhold response towards irrelevant mental set. The TMT is a pencil and paper test which consists of two stages. In the first stage (TMT part A), participants were requested to connect dots numbered from 1 to 24 in an ascending order. In the second stage (TMT part B), participants were presented again with 24 dots, half of which are numbered from 1 to 12 and the other half are marked with letters from a to l (the Hebrew alphabet counterparts of these letters were used). Participants' task was to draw a line between the dots while switching between numbers and dots back and forth. That is, starting with the dot numbered '1', the next dot should be 'a', then '2', then 'b', and so on. Therefore, whereas performance in TMT part A is a product mainly of automatic processes, performance in TMT part B requires planning and inhibitory controlled processes. In this study a third stage of TMT was also carried (TMT part C), in which a 24 number-letter set (as in TMT part B) was presented, but participants were to connect the letters from end to start while ignoring the numbers. Completion time (in seconds) in each of the tasks was measured using a stopwatch, and participant's performance was calculated as the ratios between TMT part B and TMT part A, and between TMT part C and TMT part A. Hence, ratio higher than 1 indicates of less efficient executive control.

Demographics and general information: All participants were asked to report their age, height, weight, and their general health. The main, young-adults, sample was further asked to report any posture-related problems whether they were currently medicated, and whether they were previously formally diagnosed with attention deficit disorder with or without hyperactivity.

Procedure

The young-adult sample was tested at the Peres Academic Center conference room due to the need for a wide and quiet room clear of obstacles (the

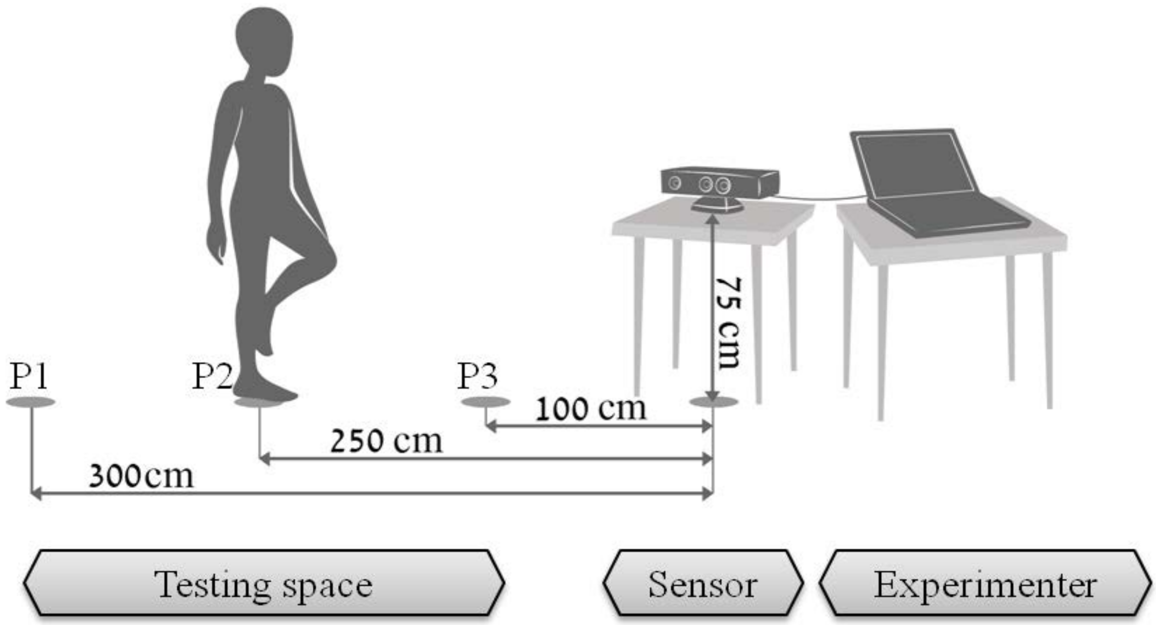

Figure 1: Schematic illustration of the lab setting. P1-3 are three positions marked on the floor by the experimenter. See Procedure for details.

procedure for older-adult sample is described below). The study was carried by trained female experimenters who received several hours of training by the authors on the Kinect system and the research protocol prior to the study. At the beginning of each testing day (data was collected between May to September 2015), the experimenter placed the Kinect sensor on a small coffee table about 75 cm high and used a paper masking tape to mark three positions, aligning on a straight line in front of the sensor (see Figure 1 for illustration). The start position (P1 in Figure 1) was marked about three meters from the sensor. The end position (P3 in Figure 1) was marked about two meters from P1, towards the sensor. Finally, the standing position (P2 in Figure 1) was marked about 50 cm from P1, towards P3.

Participants were tested individually and gave their written consent to participate in the study. At the beginning of the study, participants took off their shoes and received a brief description of the upcoming tasks and their purpose. Each participant was assigned with a two-letter code (e.g., BG) which was used later to cross participant's data while assuring anonymity. The nine motor tasks were then performed consequently in the order presented above (older-adults only performed the first two tasks). Dynamic balance tasks (Tasks 1, 2, 3, and 7) were performed with the participant standing at P1 and walking towards P3. Static balance tasks (Tasks 4, 5, 6, 8, and 9) were performed with the participant standing at P2. Participants were prompt by the experimenter when to start or to finish each task. The motor tasks were followed by the TMT and general information questionnaire. Upon completion, participants were thanked and were given the option to receive updates of the results via email. Data collection in the young-adult sample was about 30 minutes long. The older-adult sample was "field tested" and did not went through all the above tasks and measures. Specifically, each participant was tested individually in a large designated room at the recreational center. Following a brief description of study purposes and the tasks ahead, participants completed Tasks 1 and 2. However, because most of the participants found it difficult to hear the metronome, their tandem-walk strides in Task 2 were not paced. Upon completion, participants were thanked and were informed that a brief report of the study will be published at time on the recreation center bulletin board. Data collection in the older-adult sample was about 5 minutes long.

Statistical overview

To examine the association between trunk sway and cognitive performance, data was first cleaned for outliers. Then, exploratory factor analysis was conducted to determine whether the Kinect was sensitive enough to distinguish between different motor tasks. Pearson correlations were employed to examine the associations between TMT and trunk sway, and multivariate analysis of covariance was employed to examine age group differences. Finally, several hierarchical regression analyses were conducted to examine whether attentional cost over gait and visual-information availability over static balance interacted in predicting TMT performance.

Results

Preliminary data analyses

First, ± 2 SD outliers were excluded from analyses for each participant and in each of the nine motor tasks. Due to their low rate (< 5%), outliers were not replaced by the mean or median. Then, ML trunk sway variability was calculated for each participant in each of the motor tasks. Next, these scores were submitted for test-retest and split-half reliability analyses. Specifically, test-retest reliability could be calculated for paced slow walk under full attention (Task 2) and standing on dominant foot with eyes open (Task 4), because only these tasks were presented twice. Pearson correlation analyses revealed satisfactory test-retest reliability for Task 2 ($r = 0.717$, $p < 0.001$), and for Task 4 ($r = 0.683$, $p < 0.001$). Split-half reliability was calculated by analyzing the correlations between the mean performance in the first half of each task (that is, performance in the first 12.5 seconds or 125 data points) and its corresponding mean performance in the second half. These correlations were then submitted to Spearman-Brown split-half correction formula (S-B) [24]. These analyses revealed high split-half reliability for Task 2 ($r = 0.799$, $p < 0.001$, $S\text{-}B = 0.888$), for Task 3 ($r = 0.816$, $p < 0.001$, $S\text{-}B = 0.899$), for Task 4 ($r = 0.695$, $p < 0.001$, $S\text{-}B = 0.820$), for Task 5 ($r = 0.900$, $p < 0.001$, $S\text{-}B = 0.947$), for Task 6 ($r = 0.783$, $p < 0.001$, $S\text{-}B = 0.878$), and for Task 9 ($r = 0.836$, $p < 0.001$, $S\text{-}B = 0.911$).

Next, Task 2 to Task 9 variability scores were submitted to exploratory factor analysis (EFA) with Oblimin rotation, in order to examine whether the different tasks cluster into meaningful dimensions. The analysis revealed two factors with eigenvalues larger than 1, and one factor with eigenvalue of 0.95. Because the eigenvalue = 1 cutoff is arbitrary, we included the borderline factor in the solution. Rotated solution of the EFA is presented in Table 1.

Table 1 reveals that the EFA solution explained 77.33% of the performance variance in the motor tasks. More important, Factor 1 was loaded with Tasks 4, 5, 8, which were tasks of static balance. Factor 2 was loaded with Tasks 6 and 9, which were difficult or complex tasks of static balance. Finally, Factor 3 was loaded with Tasks 2 and 3, which were tasks of dynamic balance. Task 7, a dynamic balance task, was exceptional in that it loaded onto both Factors 1 and 3, probably due to the very slow pace participants were instructed to adopt. Overall, it seems that data was loaded onto the factors in accordance with the nature of the motor tasks (static, dynamic, or effortful), hence suggesting that the Kinect may be sensitive enough to distinguish between varieties of gross motor performances.

Finally, six motor performance scores were calculated for each participant. *Dynamic* score was calculated as mean variability in Tasks 2, 3, and 7; *Static* score was calculated as mean variability in Tasks 4, 5, and 8; *Effortful* score was calculated as mean variability in Tasks 6 and 9; *Attention* score was calculated as the difference between Task 3 variability and mean variability in Tasks 2 and 7 (i.e., dual-task cost); *Vision* score was calculated as the difference between Task 6 variability and mean variability in Tasks 4 and 8 (i.e., lack-of-vision cost); *Base width* score was calculated as the difference between

Table 1: Rotated factor loadings and explained variances of the three extracted factors.

	Extracted factors		
Motor task	**1**	**2**	**3**
Task 8	0.881		
Task 4	0.876		
Task 5	0.832		
Task 7	0.534		-0.453
Task 3			-0.911
Task 2			-0.681
Task 6		0.872	
Task 9		0.784	
Rot. EV	3.40	2.12	2.43
Explained variance (%)	50.89	14.57	11.87

Note: Rot. EV: Rotated Eigenvalue.

Table 2: Means, (SDs), and Pearson coefficients for the correlation between motor performance, TUG, and TMT among young adults (N = 102).

Motor performance		**TUG**	**TMT part A**	**TMT part B**	**TMT part C**	**TMT ratio B/A**	**TMT ratio C/A**
	M (SD)	15.51 (3.69)	57.39 (17.22)	69.59 (18.82)	57.47 (22.77)	1.25 (0.27)	1.03 (0.31)
Task scores							
Task 1	5.38 (4.16)	-0.113	-0.05	0.069	-0.062	0.148	-0.06
Task 2	2.17 (1.27)	-0.114	-0.074	0.006	0.177[b]	0.127	0.270**
Task 3	2.46 (1.23)	-0.164	-0.201*	-0.041	-0.039	0.259**	0.143
Task 4	1.29 (1.09)	0.005	0.091	0.110	0.196*	0.079	0.152
Task 5	1.37 (1.26)	-0.025	0.255**	0.340**	0.268**	0.115	0.039
Task 6	2.83 (1.91)	0.048	-0.119	-0.088	-0.076	0.060	0.052
Task 7	1.98 (1.15)	-0.034	-0.086	0.033	0.056	0.194*	0.153
Task 8	1.34 (1.03)	0.047	-0.035	0.025	0.078	0.106	0.184[b]
Task 9[a]	5.00 (2.43)	0.047	-0.155	-0.072	0.053	0.110	0.195[b]
Performance scores							
Dynamic	2.20 (1.04)	0.007	0.129	0.186[b]	0.213*	0.115	0.136
Static	1.33 (0.99)	-0.123	-0.141	-0.001	0.077	0.225*	0.221*
Effortful	3.76 (1.83)	0.053	-0.143	-0.089	-0.008	0.092	0.145
Attention	0.39 (1.05)	-0.105	-0.144	-0.070	-0.172[b]	0.121	-0.078
Vision	1.52 (1.90)	0.034	-0.137	-0.127	-0.154	0.009	-0.041
Base width[a]	3.68 (2.37)	0.024	-0.199[b]	-0.139	-0.033	0.070	0.131

Note: Motor performance was assessed as ML sway variability; TUG and TMT performance was measured in seconds; TUG: Timed Up & Go; TMT: Trail Making Test; [a]$N = 88$; [b]$p < 0.08$; *$p < 0.05$; **$p < 0.01$.

Task 9 variability and mean variability in Tasks 4 and 8. In addition, two TMT ratio scores were calculated; one TMT ratio score was calculated by dividing TMT part B performance (i.e., controlled processes) by TMT part A performance (automatic processes) (i.e., TMT ratio B/A), hence high ratio score was an indicator of poor ability to switch between mindsets. Another TMT ratio score was calculated by dividing TMT part C performance (i.e., inhibitory processes) by TMT part A performance (i.e., TMT ratio C/A), hence high ratio score was an indicator of poor ability to ignore irrelevant distractors. Based on the TMT ratios, three participants with scores exceeding 2 SDs above the mean were excluded from further analyses. Descriptive statistics and Pearson correlations between motor and cognitive variables are presented in Table 2.

Table 2 reveals that TUG performance (time) was associated with none of the motor tasks or the motor performance scores. TMT ratio B/A was positively correlated with Task 3, Task 7, and the dynamic scores, suggesting that less stability during gait was also manifested in poorer ability to shift between mental sets. Furthermore, TMT ratio C/A was positively correlated with Task 2 and the dynamic scores, and trended with Tasks 8 and 9, suggesting that less stability during gait was also manifested in poorer ability to ignore visual distractions and to inhibit irrelevant responses. Interestingly, Task 5, in which participants were instructed to stand on the non-dominant foot, was consistently positively correlated with all three TMT task scores (but not with the ratio scores), suggesting that less stable performance in this task was also accompanied by poor overall executive control over attention.

Between groups comparisons

Next, we turned to examine whether Kinect data could be employed to distinguish between groups that are known to differ in their attentional abilities. To this end, two comparisons were conducted. First, a multivariate analysis of covariance (MANCOVA) was conducted in order to examine the differences between young and older adults in TUG, Task 1, and Task 2 scores, while controlling for sex, BMI, dominant foot, and general health. Descriptive statistics is presented in Table 3. The MANCOVA showed a significant effect for group, Wilks' Lambda = 0.808, $F(6,258) = 4.83$, $p < 0.001$, $\eta^2 = 0.101$. Further analyses of covariance (ANCOVA) revealed that the groups differed solely in Task 2 ML variability, $F(2,131) = 14.85$, $p < 0.001$, $\eta^2 = 0.185$, and Bonferroni's post hoc analyses revealed that older adults were significantly less stable during this paced gait task than young adults with or without ADD/H. No differences were observed between the young adults sub-groups.

In the second between groups comparison, we compared motor performance of students diagnosed with ADD/H to students who were not diagnosed. Here

Table 3: Adjusted means (and SEs) for between group comparisons.

	Young adults		
	Non-ADD/H	**ADD/H**	**Elderly**
Motor tasks			
TUG	15.9 (0.49)	15.51 (0.75)	15.16 (0.86)
Task 1	5.68 (0.46)	5.13 (0.70)	5.63 (0.80)
Task 2	2.28 (0.24)	2.48 (0.37)	5.08 (0.42)
Task 3	2.30 (0.14)	2.73 (0.24)	-
Task 4	1.28 (0.12)	1.39 (0.20)	-
Task 5	1.42 (0.17)	1.44 (0.28)	-
Task 6	2.94 (0.26)	2.58 (0.42)	-
Task 9	4.80 (0.30)	5.52 (0.51)	-
Balance scores			
Static	1.50 (0.14)	1.59 (0.24)	-
Dynamic	2.69 (0.16)	3.26 (0.26)	-
Effortful	4.83 (0.30)	5.02 (0.49)	-
Ratio scores			
Attention	0.38 (0.13)	0.30 (0.22)	-
Vision	1.65 (0.25)	1.19 (0.42)	-
Base width	3.52 (0.30)	4.13 (0.49)	-

Table 4: Standardized regression coefficients in the 3-way models with dynamic, static, and effortful performance scores as predictors.

Predictors	**Predicted variables**	
demographics	**TMT ratio B/A**	**TMT ratio C/A**
Sex	-0.091	0.083
Age	-0.039	-0.257*
BMI	-0.104	-0.010
Dominant foot	0.240*	0.007
Hebrew proficiency	0.012	0.092
Performance scores		
Dynamic	0.322*	0.370*
Static	-0.085	-0.004
Effortful	0.005	0.159
Interactions		
Dyn. X Stat.	-0.317	-0.066
Dyn. X Eff.	-0.191	-0.280
Stat. X Eff.	0.053	0.260
Dyn. X Stat. X Eff.	0.413	-0.198
Model R^2	0.143	0.165
Model F	1.23	1.47
Model p	0.274	0.151

Note: Dyn.: dynamic; Stat.: static; Eff.: effortful; $^*p < 0.05$.

also, MANCOVAs were employed for this comparison. Specifically, the first MANCOVA was conducted with Tasks 3 to 9 (repeated tasks-Tasks 4 and 8-were averaged) as the dependent variables and with sex, age, BMI, dominant foot, and general health as covariates. Descriptive statistics is presented in Table 3. The MANCOVA showed no effect for group, Wilks' Lambda = 0.932, $F(5,78) = 1.14$, $p = 0.348$, $\eta^2 = 0.068$. A second MANCOVA was conducted with three performance scores-dynamic, static, and effort-as the dependent variables, yet again no effect was found for group, Wilks' Lambda = 0.973, $F(3,98) = 0.92$, $p = 0.433$, $\eta^2 = 0.027$. Finally, A third MANCOVA was conducted with three

Table 5: Standardized regression coefficients in the 3-way models with attention, vision, and base width performance scores as predictors.

Predictors	**Predicted variables**	
demographics	**TMT ratio B/A**	**TMT ratio C/A**
Sex	-0.105	0.121
Age	-0.121	-0.251*
BMI	-0.122	-0.005
Dominant foot	0.266*	0.005
Hebrew proficiency	-0.045	0.080
Performance scores		
Attention	0.316*	-0.016
Vision	-0.062	-0.236
Base width	0.134	0.237*
Interactions		
Att. X Vis.	0.331*	0.055
Att. X Base	-0.239^b	-0.232^a
Vis. X Base	0.006	0.013
Att. X Vis. X Base	-0.273*	-0.197
Model R^2	0.253	0.168
Model *F*	2.12	1.26
Model *p*	0.025	0.261

Note: Att.: attention; Vis.: vision; Base: base width; $^a p < 0.08$; $^b p < 0.06$; $^* p < 0.05$.

performance scores-attention, vision, and base width-as the dependent variables, yet again no effect was found for group, Wilks' Lambda = 0.957, $F(3,81) = 1.20$, $p = 0.315$, $\eta^2 = 0.043$.

Predicting cognitive performance

In order to determine whether Kinect-based assessment of motor performance may be employed to predict cognitive performance, four moderation models were examined using hierarchical regression analyses. In the first two models, the dynamic, static, and effortful performance scores served as predictors along with the interactions between them (three two-way interactions and one three-way interaction); the predicted variables were TMT ratio B/A (Model 1) and TMT ratio C/A (Model 2). All products were z-transformed prior to analysis. Regression coefficients are presented in Table 4.

Table 4 reveals that TMT ratio B/A was positively predicted by foot dominancy, such that left-footed showed poor executive performance relative to right-footed participants. Nonetheless, considering the small number of left-footed participants in this sample (less than 10%), this effect should be treated with care and will not be reported in further analyses. More important, dynamic balance score positively predicted TMT ratio B/A, such that less stability in the three gait tasks (Tasks 2, 3, and 7), was also manifested in poorer ability to switch between mindsets. As for TMT ratio C/A, this ratio was negatively predicted by age, such that younger young-adults had more difficulty to ignore irrelevant distractions relative to older young-adults. More important, dynamic balance score here also positively predicted the ratio, showing that less stability in the three gait tasks was also manifested in poorer ability to inhibit responses and to ignore distractions.

In two other models, the attention, vision, and base width performance scores served as predictors along with the interactions between them (three two-way interactions and one three-way interaction); here also, the predicted variables were TMT ratio B/A (Model 3) and TMT ratio C/A (Model 4). All products were z-transformed prior to analysis. Regression coefficients are presented in Table 5.

Table 5 reveals that attention score was positively correlated with TMT ratio B/A, such that higher attentional cost during gait dual tasking also manifested in poorer ability to shift between mindsets. Moreover, several interactions were observed between motor performance scores. First, a 2-way interaction was found between attention and vision; simple effects are presented in Figure 2 top. Examination of the simple effects revealed that the association between attention and TMT ratio B/A was null when static balance performance in the lack of vision was high (more stability) yet increased as the vision task was performed with less stability.

Another, marginally significant, interaction was found between attention and base width; simple effects are presented in Figure 2 bottom. Examination of the simple effects revealed that performance under narrow base (tiptoes) moderated the association between attentional cost on gait and TMT ratio B/A, such that when base width performance was poor, the association between attention and TMT was null, and it increased as base width performance was more stable.

Finally, a 3-way interaction between motor performance scores was found on TMT ratio B/A; simple effects are presented in Figure 3. Examination of the source of this interaction, revealed that the attention X vision interaction was null when performance under narrow base width was high (more stability), yet strengthened as performance under narrow base width was less stable.

Discussion

This study was aimed at investigating the feasibility of a low-cost and mobile Kinect-based assessment of postural control, in predicting attentional and executive cognitive abilities. Specifically, we employed common motor tasks-TUG, single and dual task gait, open eyes and blindfolded static balance-and compared ML variability collected with the Kinect during these tasks to the TMT assessment of executive control and group differences (by age and by ADD/H). In all, the Kinect showed good reliability and ability to differentiate between static and dynamic balance tasks, and its assessment or movement was correlated with some aspects of the TMT task.

First, we examined age-group differences in TUG time, TUG ML variability (Task 1) and paced tandem

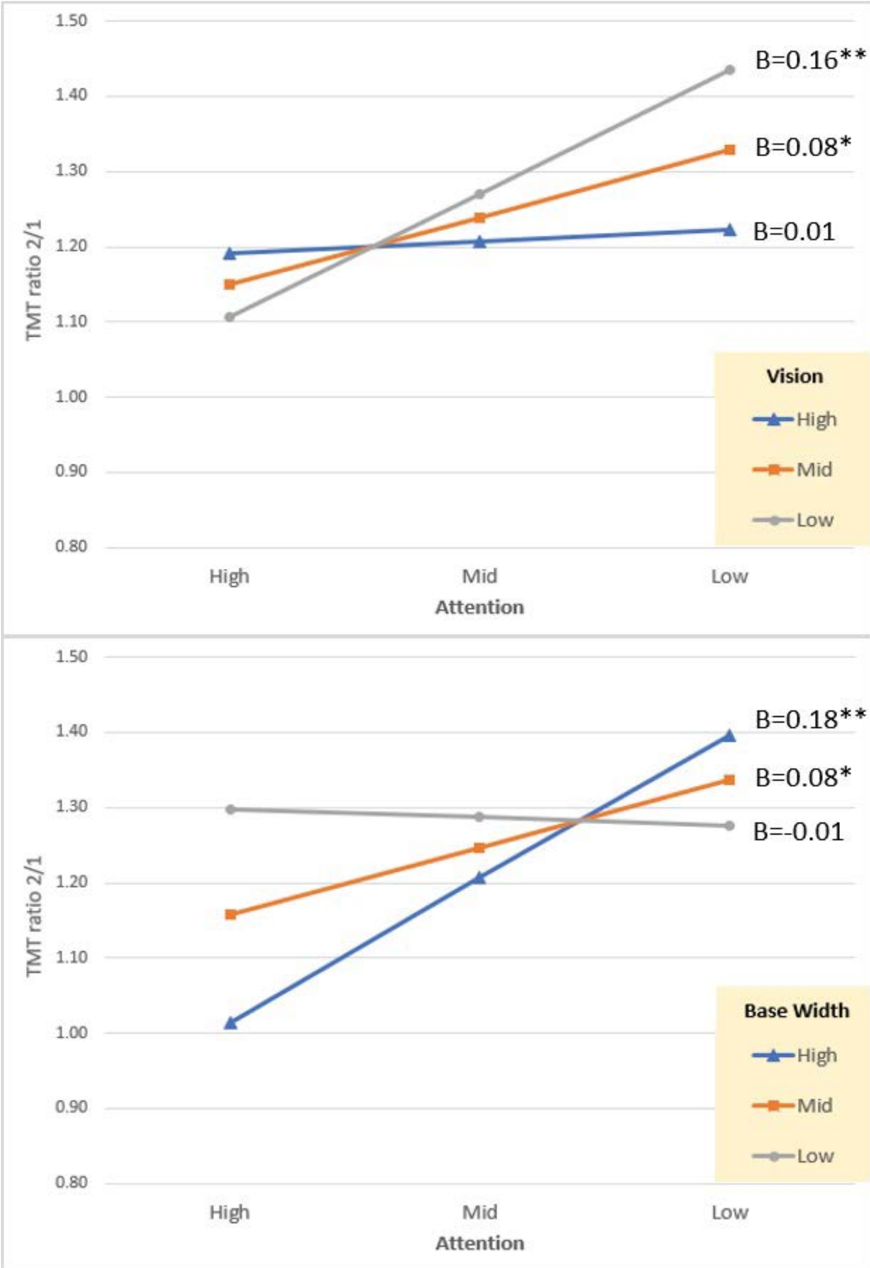

Figure 2: Interactions between motor performance scores on TMT ratio B/A. Top: Interaction between gait performance under divided attention (dual task) and under lack of visual information. Bottom: Interaction between gait performance under divided attention and under narrow base width (tiptoes). High, mid, and low values corresponded with z < -1, -1 ≤ z ≤ 1, and z > 1, respectively. $^{*}p < 0.05$; $^{**}p < 0.01$.

walk (Task 2). As predicted, young adults showed less variability than the elderly in Task 2, thus supporting our notion that the Kinect may be sensitive enough to detect age-related differences in motor performance. However, no differences were found between groups in Task 1, suggesting that young adults were as stable as the elderly during the TUG. This null effect was not in-line with previous studies which showed association between TUG and cognitive abilities [25,26]. Two explanations may account for this lack of group differences. First, considering Kinect's limited validity in capturing kinematics [18], it is possible that the drastic changes in body posture during the TUG (sitting, standing, walking, and siting) were wrongly captured by the Kinect as high ML variability. Another explanation lies in the administration of the TUG. Specifically, participants were instructed to adopt a relaxed pace during the task rather than to walk normally, thus possibly causing a ceiling effect in ML variability. Some support for this notion may be found in that no age-related differences were found for TUG time.

Similarly, no differences were found between young adults diagnosed and not diagnosed with ADD/H. Specifically, in contrast to our prediction, both ADD/H groups showed similar ML variability in dynamic, static, and effortful balance tasks, as well as in the effect of attentional cost on gait, the effects of lack of visual information or base width on static balance. This lack of differences was not in-line with the typical pattern reported in the literature, that ADD/H have less efficient motor control compared to non-ADD/H [9]. However,

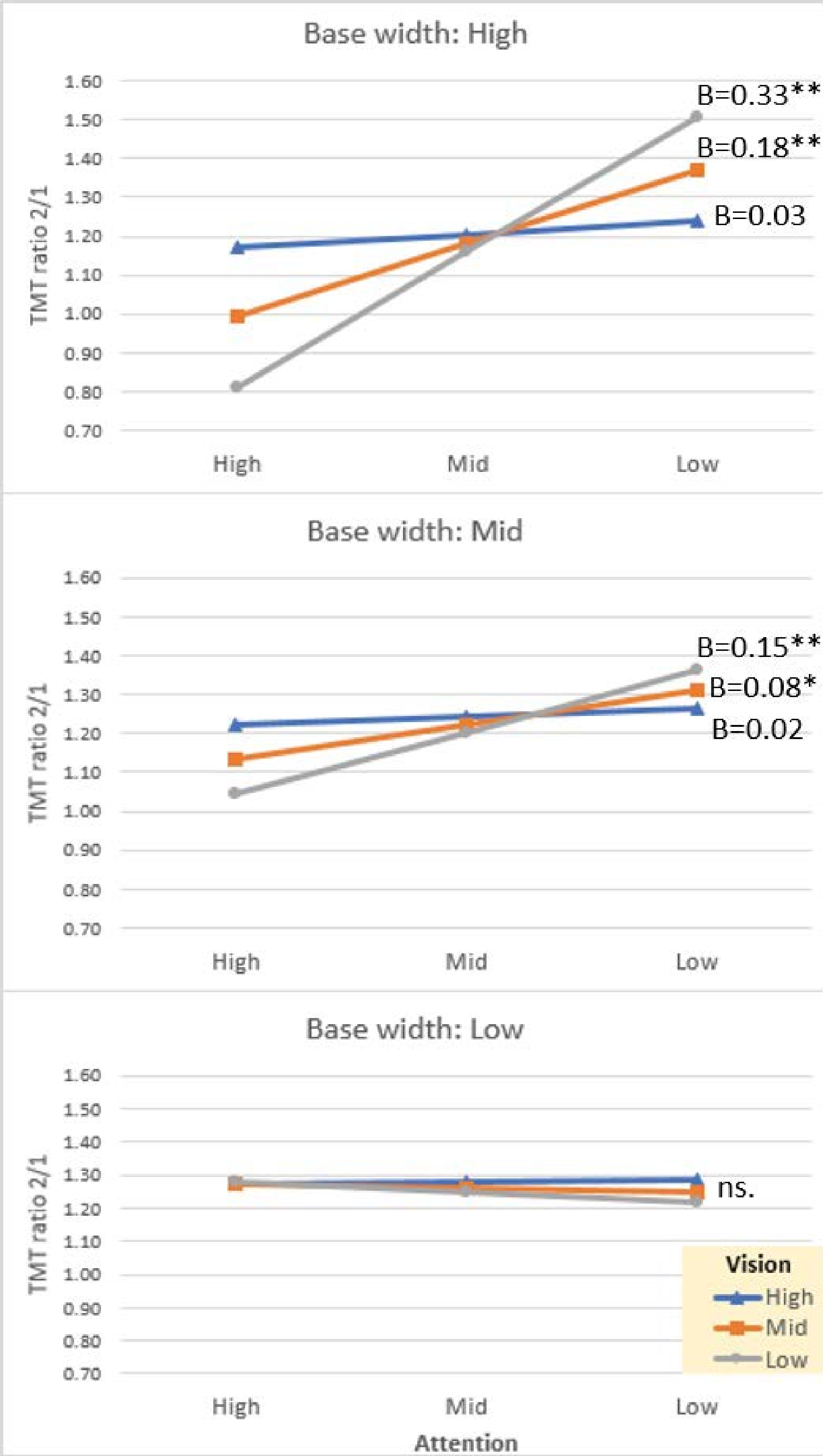

Figure 3: 3-way interaction between attention, vision, and base width on TMT ratio B/A. The interaction between gait performance under divided attention (dual task) and under lack of visual information changes as a function of performance under narrow base width. High, mid, and low values corresponded with z < -1, -1 ≤ z ≤ 1, and z > 1, respectively. $^{*}p < 0.05$; $^{**}p < 0.01$.

some studies showed that differences between ADD/H groups may not be as consistent as apparently seem, such that both groups may perform similarly [10,27]. Manicolo, et al. [27], who examined children aged 7-13, explained the lack of differences in their study by large individual differences in age-typical motor development. Although this may not account for the lack of differences in our study, where the main sample consisted of college students and staff in their cognitive and motor prime, individual differences may explain these findings. In particular, at the end of this study we also collected participants' predisposed mindfulness levels and examined their associations with postural control (we report these data elsewhere) [28]. Indeed, when individual differences in awareness to the present moments were controlled, group differences emerged, showing that high awareness benefited participants with ADD/H compared to their healthy counterparts in maintaining static balance, yet compromised their dual-task gait performance. This may stress the importance of self-report measures of cognition or emotion along with performance-based data.

In-line with our predictions, motor performance scores predicted cognitive performance assessed by the TMT. Specifically, dynamic balance scores (averaged ML variability during single- and dual-task gait) were associated with the TMT, such that less stable gait was accompanied by less efficient executive functions. This finding support previous studies the stressed the inherent link between gait performance and executive function [2]. More important, our findings also showed that TMT performance may be jointly predicted by the effect scores of attentional cost (the difference between dual- and single-task gait) and the availability of visual information (the difference between blindfolded and open-eyes static balance). In particular, for participants with good static balance performance in the absence of visual information, attentional cost did not predict TMT performance. However, the association between attentional cost and TMT became more prominent as participants were more affected by the absence of visual information, such that participants more affected by attentional cost were more likely to perform worse in the TMT.

This moderation effect may be interpreted as a differential contribution of two types of attentional processes underlying motor control; whereas the attentional cost score may represent the ability to allocate attentional resources directed towards ongoing concurrent tasks, the visual information score may represent the ability to attend to interoceptive signals and to employ them for maintaining balance [29]. Indeed, some support for this notion is found in evidence that physical activity performed mindfully may be more beneficial for the actor, compared to simple, mindless activity [1,30,31], and interoceptive attention may play a key role in executive control [29,32]. However, more research is needed in order to better understand the joint contribution of attentional resource availability and interoceptive attention, as manifested in movement, to executive control (for similar notion, see [33]).

Taken altogether, our findings show that the Kinect has a sound potential to predict cognitive abilities through the assessment of movement. However, three caveats limit the strength of this study. First, due to technical constraints, the older-adult sample was not measured nor screened for cognitive deficiencies, executive functions, emotional state, or other variables that could have explained the findings reported here. Put differently, based on the literature we assumed that the hypothesized age differences in gait should mainly due to differences in cognitive abilities, but no cognitive measure was collected to support this assumption. Therefore, more adequate study is needed in order to infer from age differences as captured by the Kinect, to cognition.

A second caveat is that the classification of participants to the ADD/H and non-ADD/H groups was based on participants' report that they were (or were not) officially diagnosed with attention deficit. This serves as a problem for several reasons; first, undiagnosed participants with attention deficit may have been mistakenly allocated to the non-ADD/H, thus decreasing between-groups and increasing within-group differences. Second, given that attention deficit is not a uniform disorder, but may variate in both severity and the ill-functioning attentional mechanism (e.g., focusing of attention, attentional shifting, or executive attention), the ADD/H group in this study was probably prone to large within-group variance. Finally, attention deficit is sometime comorbid with other cognitive problems, as learning disorders, which may be associated with motor performance independently of attention deficit [34]. Because participants were asked to report solely of diagnosis for attention deficit, such comorbidities were not controlled. An ideal solution for these problems is to employ a performance-based assessment of attention along with participants' self-report of difficulties in attention, learning, and other cognitive functions.

Finally, the third caveat limiting our findings is that the gait tasks consisted of slow and paced tandem walk, rather than normal self-paced walk. The rationale behind the use of tandem walk was to make control over movement more prominent, and it was slowed down and metronome-paced in order to enable full 25 seconds of measurement considering the Kinect's ability to "see" only as far as three-meter distance. However, this resulted with some overlap between static and dynamic performances. This overlap was statistically controlled, yet the not-normative walking style and pace make it difficult to generalize our findings to more natural settings.

It is clear that movement assessment by the Kinect may not serve as a stand-alone mean of cognitive monitoring, and its efficiency in predicting cognitive abilities-and in particular cognitive decline-may increase by incorporating its other sensing features, as voice activation and recognition. Such features may be employed for collecting more traditional cognitive measures, as reaction time or verbal fluency, and along with movement assessment, to create a more sound cognitive profile of the person.

Ethic Statement

All procedures performed in this study were in accordance with ethical standards and were approved by the Peres Academic Center institutional ethics committee. All participants gave their written informed consent to participate in this study.

Conflict of Interests

The study was not funded, and the authors declare no conflict of interests.

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