Three-level rating of turns while walking

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Abstract

Research concerning the assessment of turns during walking in healthy older adults is scarce. This study compared three independent assessments of entry and exit points of turns during walking; participant, clinical rater, and a computer algorithm. Nineteen non-demented and nondisabled older adults (mean age 75.40 ± 5.52 years) participated in the current study. Results revealed that overall the three assessment methods were consistent (68 – 100 % agreement). However, participants determined their turn exit point before the algorithm, (-304.53 ± 326.67 ms), $t(18) = -4.06$, $p = .001$, 95% CI [-461.98, -147.08], and clinical rater, (-225.79 ± 303.79 ms), $t(18) = -3.24$, $p = .005$, 95% CI [-372.21, -79.37]. The differences in turn determination between the algorithm and rater were significant at turn entry points (131.24, ± 127.25 ms), $t(18) = 4.50$, $p < .001$, 95% CI [69.91, 192.58]) but not at turn exit points (-78.74 ± 259.66 ms), $t(18) = -1.32$, $p < .20$, 95% CI [-203.89, -46.41]). Greater time discrepancies in assessing turn exit points between the participants and both the algorithm and clinical rater were associated with worse visuospatial performance. Despite the relatively small difference among the three assessments of turns, they were consistent and can be utilized interchangeably. Further studies are necessary to determine whether differences in the ability to accurately determine turns entry and exit points are related to fall risk in normal and disease populations.

Keywords

older adults; walking turns; visual perception

Approximately a third of the steps taken throughout the day involves turns while walking [1]. The limited research on turns has focused on idiopathic Parkinson's disease (IPD) [2]. Individuals with mild IPD display difficulty with turning, but maintain normal walking in a

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straight line [2]. However, little is known about turns in aging and no studies examined the individuals' perspective of turns. Understanding the individuals' awareness of turns could provide important insight into the phenomenology, risk assessment and interventions of falls.,

To address these knowledge gaps, we compared three assessments of turns while walking in older adults: participant, clinical rater and computer-based algorithm. We further examined whether differences between the three assessments were associated with visuospatial performance, which is known to affect turning abilities [3].

Methods

Participants

Nineteen participants were recruited from a cohort study titled "Central Control of Mobility in Aging" [4].. Written informed consent was obtained from the participants in person according to study protocols approved by the institutional review board.

Measures and Procedures

Walking protocol—Participants walked on a 4×14 foot instrumented walkway (Zenometrics, LLC; Peekskill, NY) for two blocks. Each block consisted of three loops; each loop contained two 180° left turns and two straight walks, yielding a total of six turns and six straight segments. The walkway was embedded with pressure sensors and Protokinetics Movement Analysis Software (PKMAS) was utilized to quantitatively assess gait. The outline of the walking area was demarcated by black tape. No indicators were placed on the recording surface to indicate the turn points. Participants began and ended each block in the right proximal corner of the walkway, relative to the clinical rater. Walking started with the instruction "begin," and ended with the instruction "stop."

Turns assessments—Turns were operationally defined as 'a change in direction while walking.' The turn includes an entry point, curved path, and an exit point.

<u>**1. Algorithm:**</u> The computerized algorithm determines the first footfall entering or exiting a turn by analyzing the changes of footfall angles of the same limb. It then defines the turn entry or exit point as the beginning of the swing phase of the opposite limb (last contact of opposite limb; Figure 1).

<u>**2. Participant rating:**</u> The participants held a switch in their right hand while walking, and were instructed to press the button on the device upon turn-entry, hold it down during the turn, and release it at the turn-exit. Pressing and releasing the switch sent a time-stamped TTL pulse to the PKMAS software in real time. In Block 1, participants walked at their normal pace while indicating entry- and exit-points of each turn using the switch. In Block 2, participants walked while holding the switch without assessing entry- and exit-points to determine the effect of the switch on walking. The order of the two blocks was counterbalanced.

3. Clinical rater: The clinical rater received the same instructions as the participants for rating turns using an identical switch. The clinical rater was stationed at the far end of the walkway affording an unobstructed view for each turn.

Covariates—The Repeatable Battery for the Assessment of Neuropsychological Status (RBANS) measures attention, language, visuospatial skills and, memory. It also provides a global cognitive function score [5]. The 30-item Geriatric Depression Scale (GDS) was used to assess depressive symptoms [6].

Statistical Analysis

The first five turns were used for statistical analyses. The sixth turn was not fully completed and thus omitted. The outcomes of interest included the timing of entry and exit and duration of turns (milliseconds). Differences in the three assessments were calculated by subtracting time points for the entry and exit of turns. Differences were averaged across the five turns per participant. Hence, each participant had one difference score for their entry, exit, and duration of turns relative to the algorithm and clinical rater.

One-sample t-tests examined differences between participant determined turns' entry/exit points, and those of the algorithm, and clinical rater. One and two SDs of the mean differences among assessment pairs were used to determine agreement.

Pearson r correlations examined whether greater time discrepancies in assessing turn exit points among ratings were associated with worse visuospatial performance.

Results

The sample consisted of 19 non-demented participants (mean age=75.37y; mean education=14.25y; 47% female), with no clinical evidence of stroke, Parkinsonian signs or clinical gait abnormalities as determined by the study clinician. Two participants reported a previous fall.

Block 1 vs. Block 2 comparison revealed that pressing the switch did not affect walking performance (Table 2).

Agreement between the participants and algorithm for turn entry ranged from 68.42% to 100% for 1 and 2 SDs of the difference (M=62.11±340.41 ms) respectively. Agreement for turn exit ranged from 84.21% to 94.74% for 1 and 2 SDs of the difference (M=−304.43±326.67 ms), respectively. Agreement between the clinical rater and the algorithm for turn entry ranged from 73.68% to 94.74% for 1 and 2 SDs of the difference (M=131.24±127.25 ms) respectively. Agreement for turn exit ranged from 68.42% to 94.74% for 1 and 2 SDs of the difference (M=− 78.74±259.66 ms), respectively. Bland-Altman plots demonstrated good agreement between the three rating methods (not shown). Comparisons of the three turn assessments are summarized in Table 2.

The differences between participants and algorithmically determined turn-exit-points were negatively correlated with RBANS line orientation scores (r=−.47, p=.04). Differences between the participants and clinical rater in determining turn-exit-points showed a negative

trend with line orientation scores ($r=-.45$, $p=.06$). To explore the influence of age on the relationship between visuospatial abilities and turns the sample was stratified by median split. Differences between older participants and algorithmically determined turn-exit-points showed a negative trend with line orientation scores ($r=-.59$, $p=.13$). Differences between the participants and clinical rater in determining turn-exit-point were negatively correlated with line orientation ($r=-.71$, $p=.05$). Differences between younger participants and the algorithm or clinical rater for turn entry or exit were not associated with visuospatial abilities.

Discussion

The present study evaluated algorithmic, individual and rater determinations of turns during walking. These assessments of turns were in reasonable agreement and therefore can be utilized interchangeably. Participants, however, determined turn exit points earlier than both the algorithm and clinical rater though the differences were small. The tendency for participants to determine turn-exit-points earlier than the other two assessments may represent anticipation and planning for the completion of a turn.

Worse visuospatial abilities were associated with greater differences between the participants' determination of turn-exit-points and algorithm. A similar trend was observed for the association between visuospatial abilities and differences between the participants' and rater's determination of turn-exit-points. Exploratory stratified analyses revealed that the associations of visuospatial abilities with differences in turn determination between the participants and the other two methods were more evident among the older participants. These findings provide preliminary evidence for age-related higher order cognitive control of turns, and should be further evaluated.

Future research should examine extrinsic/intrinsic factors including but not limited to cognitive functions and individual awareness of turns that influence turning in more diverse and larger samples in the laboratory and in naturalistic settings. Knowledge about modifiable factors that impact turns will provide insights into fall mechanisms and potential risk assessment and interventions.

Acknowledgements

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Research.Highlights

- Examined three turn rating methods: participant, clinical rater and algorithm

- Determined that the three assessment methods were consistent

- Participants determined earlier turn exit than the algorithm and clinical rater

- Visuo-spatial abilities were related to participants' determination of turns

- Anticipation may partially explain the variability in participants' turns assessment
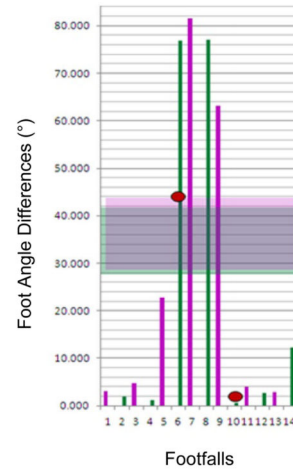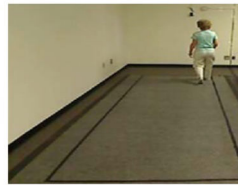
a) Turn Entry

Turn Entry is the earliest time the body can begin to maneuver a limb into first entering a turn. To identify the footfall first entering a turn we calculate and analyze changes in the difference of Footfall Angles of the same limb. After we identify the first footfall entering a turn, we define the Turn Entry Point as the last contact time of the previous footfall of the same limb. This is the same as the beginning of the swing phase of the limb first entering the turn.
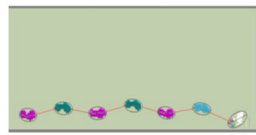
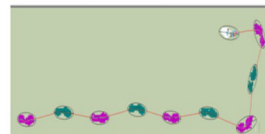The footfall angle difference between footfalls 5 and 7 is not above the mean+SE.
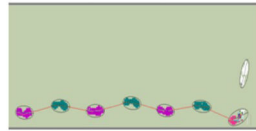
The footfall angle difference between footfalls 8 and 10 exceeds the mean+SE.

b) Turn Exit

Turn Exit is the earliest time the body can begin to maneuver the last limb into exiting a turn. To identify the last footfall exiting a turn we calculate and analyze changes in the difference of the Foot and Toe In/Out Angles between footfalls of the same limb. After we identify the first footfall exiting a turn, we define the Turn Exit Point as the last contact time of the footfall first exiting the turn. This is the same as the beginning of the swing phase of the limb exiting the turn last.

The footfall angle difference between footfall 8 and 10 indicates that footfall 10 is exiting the turn while footfall 9 is still in the turn.
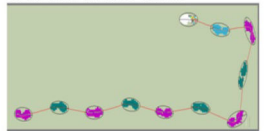
Footfall 11 exits the turn last. We consider the Turn Exit time as the last contact of footfall 10.
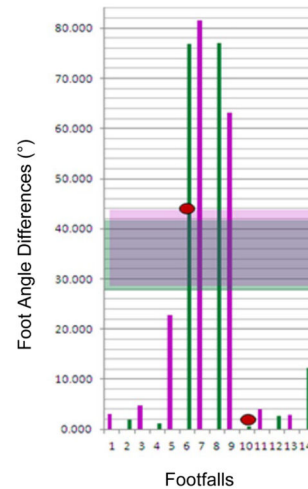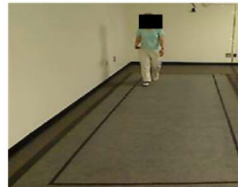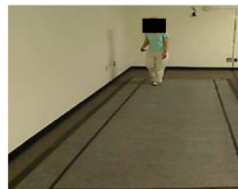
Key: ■ Right Foot ■ Left Foot ● Entry/Exit Points

Figure 1.

Table 1

Locations and Foot Angle Differences by Footfalls

	Footfalls	First Contact (s)	Last Contact (s)	Foot Toe X Location (cm)	Foot Toe Y Location (cm)	Foot Heel X Location (cm)	Foot Heel Y Location (cm)	Foot Angle (°)	RIGHT Foot Angle Difference	LEFT Foot Angle Difference
1	Right 1	1.91	2.58	351.47	107.18	377.03	105.75	−3.20		
2	Left 1	2.40	3.06	294.69	100.46	321.39	99.38	−2.32		
3	Right 2	2.95	3.53	240.65	104.89	266.82	104.79	−0.22	2.99	
4	Left 2	3.43	4.03	183.82	98.10	210.07	96.12	−4.30		1.98
5	Right 3	3.88	4.51	131.93	105.56	157.38	103.34	−4.99	4.77	
6	Left 3	4.38	**5.04**	74.72	101.64	101.74	99.10	−5.38		1.08
7	Right 4	4.92	5.77	17.58	106.68	45.41	115.60	17.77	22.76	
8	Left 4	5.58	6.38	17.68	54.96	26.27	80.59	71.48		**76.86**
9	Right 5	6.18	7.03	5.48	36.78	17.41	12.64	−63.70	81.47	
10	Left 5	6.87	**7.54**	43.97	24.72	71.59	22.01	−5.60		77.08
11	Right 6	7.43	7.98	93.88	13.50	120.20	13.24	−0.58	**63.12**	
12	Left 6	7.85	8.38	148.76	25.53	175.23	23.18	−5.08		0.52
13	Right 7	8.28	8.80	205.79	15.00	231.71	12.95	−4.53	3.95	
14	Left 7	8.68	9.23	260.79	20.29	289.05	16.44	−7.77		2.69
15	Right 8	9.12	9.70	311.58	7.08	338.67	6.28	−1.69	2.84	
16	Left 8	9.56	10.10	353.52	11.13	379.10	13.23	4.52		12.29
17	Right 9	9.98	10.64	394.75	0.08	414.54	18.40	42.79	44.48	
18	Left 9	10.47	11.18	406.78	42.08	412.72	69.06	77.58		73.06
19	Right 10	11.03	11.96	400.11	108.77	420.21	92.46	−39.06	81.85	
20	Left 10	11.76	12.41	344.61	101.95	369.78	98.53	−7.73		85.31
21	Right 11	12.30	12.85	290.21	108.22	315.56	108.16	−0.12	38.94	
22	Left 11	12.75	13.27	228.18	104.73	254.51	100.90	−8.29		0.57
23	Right 12	13.18	13.70	171.42	109.74	197.44	110.60	1.89	2.01	
24	Left 12	13.60	14.16	108.72	103.94	137.25	101.25	−5.38		2.92
25	Right 13	14.05	14.63	51.20	112.29	82.38	113.57	2.34	0.45	

26	Left 13	14.5	15.125	21.508	91.244	44.548	105.75	32.19		37.57
27	Right 14	14.98	15.53	11.42	53.55	13.84	79.89	84.76	82.41	
28	Left 14	15.41	16.10	18.23	38.77	28.62	14.64	−66.69		98.88
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								M	35.30	36.61
								SD	34.45	37.82
								SE	6.63	7.28
								M+SE	42.23	43.88
								M−SE	28.67	29.33

Note. Data from the PKMAS software are exported to Excel for analysis. The foot angle is calculated based on the X and Y location for the Heel and Toe. The Absolute Foot Angle Difference between consecutive footfalls of same limb is then computed. For each limb we compute the *M*, *SD*, *SE*, *M+SE* and *M−SE*. When the Absolute Foot Angle Difference exceeds the *M+SE* then the subject is considered to be inside a turn otherwise is on a straight walk.

Table 2

Results

	Paired *t*-test Block A and Block B			95% CI	
	Difference *M* (*SD*) ms	*t*(18)	*p*	LL	UL
Straights	−1048.24 (8622.09)	0.80	.60	−5203.95	3107.48
Turns	−983.58 (8788.28)	−0.49	.63	−5219.39	3252.24

	One-Sample *t*-test Participant and Algorithm			95% CI	
Turn	Difference *M* (*SD*) ms	*t*(18)	*p*	LL	UL
Entry	62.11 (340.41)	0.80	.44	−101.96	226.18
Exit	−304.53 (326.67)	−4.06	**.001**	−461.98	−147.08
Duration	−331.73 (520.07)	−2.78	**.01**	−582.40	−81.07

	One-Sample *t*-test Participant and Rater			95% CI	
Turn	Difference *M* (*SD*) ms	*t*(18)	*p*	LL	UL
Entry	−104.04 (343.14)	−1.32	.20	−269.43	61.35
Exit	−225.79 (303.79)	−3.24	**.005**	−372.21	−79.37
Duration	−121.75 (474.83)	−1.12	.28	−350.61	107.11

	One-Sample *t*-test Rater and Algorithm			95% CI	
Turn	Difference *M* (*SD*) ms	*t*(18)	*p*	LL	UL
Entry	131.24 (127.25)	4.50	**<.001**	69.91	192.58
Exit	−78.74 (259.66)	−1.32	.20	−203.89	−46.41

Duration	−209.98 (251.16)	−3.64	**.002**	−331.04	−88.93

Note. CI = confidence interval; *LL* = lower limit; *UL* = upper limit.