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RUNNING HEAD: *Older people's estimates of their step length*

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ABSTRACT

Background/Study Context: Advancing age is associated with a decrease in step length. In line with previous studies showing that older adults often overestimate their motor abilities, we investigate whether older adults overestimate the length of their first step during gait initiation. The underlying effect could be a failure to update the internal model of motor action as a function of age-related motor decline.

Methods: Without taking a step, community-dwelling older women (n = 22, age range: 68–87 years) and younger women (n = 19, age range: 19–33 years) estimated the length of their first step for both preferred step length and largest step length, which were performed without endangerment. Thereafter, the participants performed real gait initiation for both types of steps. The estimated step lengths were compared to the actual step lengths.

Results: Older adults judged their first step as larger than it was (mean error: 30% for the preferred step and 9% for the largest step). A fine-grained analysis showed that this effect mainly concerned those for whom an increased risk of falling was suspected. These older adults were also among those who performed the shortest steps, and they presented with a slight decrease in cognitive functioning. Younger participants underestimated their preferred step length. Overall, the estimates were more accurate for the largest steps than for the preferred-length steps.

Conclusion: Step length estimation revealed powerful evidence for overestimation in older adults. Those who overestimated step length presented with more signs of motor decline. While this result sustains the idea of an insufficient actualization of the motor-action model, the explanation also refers to more global appraisal processes. Further research should explore the relevance of this task as a clinical laboratory tool for assessing gait capacity and the risk of falling.

Walking abilities of older adults have received considerable attention from researchers and clinicians who have sought to preserve this population's independent living for as long as possible. Their objective is to reduce the risk of falling (RoF), which is critical in approximately one-third of adults over the age of 75 living in the community, with severe consequences in almost one-quarter of cases (Tinetti, Speechley & Ginter, 1988). Walking is not a simple, automatized motor task, and cognitive functions are involved in the regulation of even routine walking; walking may become a complex cognitive task for older adults (Hausdorff, Yogev, Springer, Simon, & Giladi, 2005). Older adults' metacognition of their own gait characteristics should thus be questioned. The present study focused on step length estimation.

Even in the absence of a specific disease, advancing age modifies walking patterns. Among age-related changes, preferred step length has been repeatedly measured as shorter in older adults than in younger adults (cf. Aboutorabi, Arazpour, Bahramizadeh, Hutchins & Fadayevatan, 2016), including during gait initiation (Mbourou, Lajoie, & Teasdale, 2003). Furthermore, the step length of older fallers is smaller than that of non-fallers (Mbourou et al., 2003). Medell and Alexander (2000) have shown that the maximal lunge significantly decreases with age in healthy older adults. This maximal step length (MSL) is obtained by asking participants to step maximally with one leg while keeping the other leg in its initial position. MSL is significantly related to clinical balance and fall risk measures (Cho, Scarpace, & Alexander, 2004; Lindemann, Lundin-Olsson, Hauer, Wengert, Becker, & Pfeiffer, 2008; Fujimoto et al., 2015; Medell & Alexander, 2000). Whether older adults accurately estimate their step length is motivated by the idea that they could be unaware of or underestimate their age-related physical declines. As suggested previously (Caçola, Roberson, & Gabbard, 2013; Lafargue, Noël, & Luyat, 2013), this could result from the failure to update internal models of action, where the brain simulates the possible outcomes and consequences of an action before its execution (Jeannerod, 1994; Wolpert, Ghahramani, & Jordan, 1995). In such cases, older adults should overestimate their motor performance.

The hypothesis of overestimation is supported by a series of studies that have compared actual motor performance with motor imagery, which consists of consciously imagining oneself in action without any overt motor action. Mostly due to an overlapping of the neural networks underlying imagined and actual actions (for a review, see Hétu, Taschereau-Dumouchel, Meziane, Jackson, & Mercier, 2016), motor imagery is used to investigate the unconscious process of action representation and internal models of action (Jeannerod, 1994; Jeannerod & Decety, 1995). Overestimation has been identified in several tasks requiring whole body movements. Overestimation may occur when older adults must estimate the maximal height they can step over (Noël, Bernard, & Luyat, 2011; Lafargue et al., 2013, Sakurai, Fujiwara, Ishihara, Higuchi, Uchida, & Imanaka, 2013; Sakurai et al., 2014, 2016, 2017a). Overestimation predominates when older adults must estimate whether they can stand on an inclined plane (Lafargue et al., 2013) or must estimate their maximal forward reach without losing balance (Liu-Ambrose, Ahamed, Graf, Feldman, & Robinovitch, 2008; Okimoto, Toriyama, Deie, & Maejima, 2017; Robinovitch & Cronin, 1999). There is also converging evidence for the overestimation of actions that fully or partly relate to walking speed; this effect is often limited to very old adults (Beauchet et al., 2010; Bridenbaugh, Beauchet, Annweiler, Allali, Herrmann, & Kressig, 2013; Fujimoto et al., 2015; Naveteur, Delzenne, Sockeel, Watelain, & Dupuy, 2013; Sakamoto & Ohashi, 2016, 2017; Sakurai et al., 2017b; Schott, 2012; Schott & Munzert, 2007; Zivotofsky, Eldror, Mandel, & Rosenbloom, 2012). Misjudgment seems to increase in older adults who have an inactive life style (Sakurai et al., 2014), an increased RoF (Beauchet et al., 2010; Butler, Lord, Taylor, & Fitzpatrick, 2014; Sakurai et al., 2013), or a fear of falling (Sakurai et al., 2017b).

Concerning step length, two experiments are relevant. One is the condition called "river" by Kluft, Bruijn, Weijer, van Dieën and Pijnappels (2017a). In this experiment, older and younger participants walked along a tapered piece of paper, starting at the widest end. They had to step across the piece of paper once they decided they could do this action. The crossing position provided their perceived MSL (here, different from maximal lunge since the non-dominant foot is not planted), which was compared to their actual MSL; the actual MSL was separately determined by stepping inside a target. Overestimation seems to be the most frequent misjudgment. No age-related effect arose, possibly due to an insufficient sample size, as underlined by the authors. Additionally, the requirement to perform the task as fast as possible could counteract the larger overestimation in the older participant group. This study did not distinguish an imaginary-movement phase from a real action phase, as done in the other experiment performed by Fujimoto et al. (2015). MSL (here, maximal lunge) was recorded in two large samples of community-dwelling older adults. Those who had fallen several times during the year were characterized by shorter actual MSLs compared to non-fallers, and their estimated MSLs were larger than their actual MSLs. Furthermore, there was a small but significant underestimation of MSL in non-fallers, and younger controls were not included in this study. Hence, the question of the accuracy of step length estimation with advancing age has not been fully resolved.

Overall, overestimation as reported above is the most frequent conclusion based on the whole sample of older adults, or on subgroups, but underestimation is also sometimes observed. For instance, this was the case for both the ability to walk and walking-time estimates, as tested on a small path width (Kluft, van Dieen, & Pijnappels, 2017b; Personnier, Kubicki, Laroche, & Papaxanthis, 2010), and mixed findings can be found in other tasks, such as some step-over studies (Sakurai et al., 2013, 2014, 2016, 2017a) or in functional reaching tests (Sakamoto & Ohashi, 2016). One way to understand the whole set of findings despite the discrepancies is to consider the performance in terms of precision (unsigned difference). This approach led Saimpont, Malouin, Tousignant and Jackson (2012) to conclude that older adults are more impaired when imagining constraints or difficult actions compared to imagining more simple actions. In the case of whole body movements, the less physically demanding tasks are chronometric tasks, which also require time-related processing in addition to imagery (Naveteur et al., 2013). Therefore, further testing the accuracy of motor representation in less demanding tasks is still required. This justifies investigating the step length estimation in ecological conditions of gait, with the inclusion of a control group comprising younger adults. This also points to the relevance of including step lengths that are considered more or less usual.

The present study investigated whether community-dwelling older adults and younger adults accurately estimate the length of the first step taken at gait initiation. We measured and compared the length of the estimated and actual first step for two types of gait initiation: (1) gait initiation performed by the participants with their own preferred walking characteristics, and (2) gait initiation with the largest steps the participants could take without endangerment. This largest step is physically less demanding than the maximal lunge. The main hypothesis is that older adults are comparatively less accurate than younger adults, particularly by overestimating their step lengths. Overestimation was expected to be stronger in those who presented with increased age-related motor decline. To investigate this point, standardized motor tests were administered to the older group: the Tinetti test (Tinetti, 1986) and the Timed Up-and-Go (TUG; Podsiadlo & Richardson, 1991). Indicators of life style activity level were also collected. The Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) was used to exclude older participants with abnormal cognitive functioning.

Methods

Participants

A total of 41 female volunteers were included in this study. The older group (OG) included 22 participants aged 68 to 87 years (*M* = 74.9, *SD* = 5.4 years). The younger group (YG) included 19 participants aged 19 to 33 years (*M* = 25.2, *SD* = 3.5 years). All the participants were initially contacted through information disseminated among a number of community groups, in particular clubs for the older adults and in the university or hospital for the younger adults. The participants were autonomous in their everyday life, including autonomous ambulation without material aids. A score of at least 6/10 at 3 m on the Monoyer scale for binocular eyesight (with or without correction) was an eligibility criterion. An MMSE score lower than 27 was an exclusion criterion for older participants.

Material

A strip of white linoleum was placed on the floor, part of which served as a screen for a video projector (LG PB60G – JE) fixed on the ceiling. There were no referential visual cues near projection area and the rest of the room was very dimly illuminated. The projected stimulus was a foot trace that moved at the speed of 3 cm/s. The computer program also allowed the experimenter to move the foot trace manually, with every click of the mouse producing a 1-cm displacement of the foot trace. The size of the foot trace was individually adjusted to the foot size of the participant. This material allowed the participants to perform the estimation task without an experimenter being present in their visual field.

The length of the first step performed during actual gait initiation was measured using an optical motion capture system (Vicon Nexus, Vicon Motion Systems, Oxford Metrics, UK) with six T20 cameras. The sample rate was 100 Hz. Eleven reflective markers (1.4 cm diameter) were used: four were on the participants' head, three on each foot (on the tips of the toes, the heel and the external malleolus) and one on the right thigh. An additional marker was used to measure the estimated step length during the step length estimation task, without requiring the experimenter to perform a measurement in front of the participants (see below).

Procedure

A few days before the experimental session, people interested in taking part in the study were met individually and screened for the eligibility criteria. Individuals also received more information about the experiment. They were told to wear comfortable shoes for their upcoming visit in the laboratory. Upon their arrival for the experimental session, the participants gave their informed written consent, and they answered a few questions. They assigned scores between 0 and 10 regarding both the pleasure they experience when walking and their walking-related anxiety as pedestrians. They were asked about the duration of walking they could perform without fatigue (i.e., less than 10 min, between 10 and 20 min, about half an hour, about one hour, more than one hour). They were also invited to comment on any lower extremity injury that would affect their gait currently or in the past, and on previous experience of falling. To determine their dominant foot, the participants were asked to kick an imaginary ball. The participants were then fitted with the reflective markers.

The main part of the experiment consisted of two tasks: a step length estimation (SLE) task and an actual gait initiation task. The SLE task was performed before the actual task given strong immediate improvement of subsequent estimation by practice (e.g.. Yasuda, Wagman, & Higuchi, 2014). The two tasks were separated by a short rest during which the participants sat down in a comfortable chair. Each task included 12 trials. The participants did not receive any feedback concerning the accuracy of their judgments throughout the experiment.

For the SLE task, the participants were invited to estimate the length of their first step without moving, i.e., without taking any steps. The first six trials corresponded to the preferred gait initiation, the first step of which was thereafter called the “preferred step”. The last six trials corresponded to a gait initiation performed with the largest steps that did not pose any risk in terms of loss of balance or pain (called the “largest step”). The participants stood with the tip of their dominant foot touching a scribe mark on the floor. Their other foot was placed at their convenience regarding the medio-lateral gap to ensure a comfortable stance. During each trial, the participants watched a foot trace on the floor that strode in front of their dominant foot. The participants were instructed to say “stop” when the trace reached the point at which they believed they would have placed their foot in a real gait initiation. They could adjust the place of the trace afterward by asking the experimenter to move the trace slightly in the direction they wanted. Each trial ended when the participants were fully satisfied with the trace position. Then, the experimenter carefully placed a reflective marker at the front edge of the trace, allowing the motion capture apparatus to measure the estimated step length, i.e., the difference between the marker placed on the toes of the foot and the marker placed on the trace. For each type of step (preferred or largest), three trials were conducted with the trace moving away from the participant, and the other three trials were conducted with the trace moving forward. The trace moved away during the first trial, and then the trials alternated between the two moving directions.

For the actual gait task, the rule for the initial placement of the participants at the beginning of each trial was the same as in the SLE task. Then, the participants took a few steps straight ahead, with the instruction to move beyond the linoleum, i.e., 2.4 m away from the scribe mark. This was done for gaits initiated successively with the preferred and largest steps. Six trials were performed for each type of step. The participants decided when to initiate their gait after being allowed to do so by the experimenter. No instruction was given concerning the stepping pace. The participants were free to walk as they chose in order to return to their initial position at the end of a trial.

Before the end of the experiment, the older participants also completed the Falls Efficacy Scale-International (FES-I), which measures fear of falling in the older population (Yardley, Beyer, Hauer, Kempen, Piot-Ziegler, & Todd, 2005; French translation in Mourey, Manckoundia, & Pfitzenmeyer, 2009). The participants also performed the two standardized mobility tests: the TUG test, which measures the time it takes to stand from an armchair, to walk a distance of 3 m, turn, and walk back to the chair, and to sit down (Podsiadlo and Richardson, 1991), and the Tinetti test, which assesses mobility, balance and gait (Tinetti, 1986). Finally, the participants were asked to estimate the number of hours they spent weekly outside their home. Before leaving the room, the participants were invited to comment on the experiment. The full session lasted approximately one hour for the older participants and 30 min for the younger participants. The participants received a small gift in return for their participation.

Data reduction and analyses

The estimated step length was expressed relative to the real step length. The SLE error was computed as follows: (median of estimated step lengths – median of real step lengths) / median of real step lengths*100. Positive and negative SLE errors reflected step length overestimation and underestimation, respectively. To sustain this conclusion, a one-sample *t*-test was used to compare the SLE error in each group to a "0" value, corresponding to a perfect estimation.

The normality of distributions was tested for all the variables using the Kolmogorov-Smirnov test. Descriptive values were expressed as the mean ± standard deviation or as the median with an interquartile range, depending on the distribution. A between-group comparison was performed with either Student's unpaired t test or Welch's t test (when equal variances were not assumed according to Levene's test). A within-group comparison was made using Student's paired t-test. Correlations were assessed using the Pearson's method. For the few statistical analyses that were less hypothesis-driven, a correction for false discovery rate (FDR) was applied using the method developed by Benjamini and Hochberg (1995). Proportions were compared using the Fisher exact test.

Results

Participant characteristics

All the participants reported experiencing pleasure when walking (M = 8.12 / 10; SD = 1.77). Walking-related anxiety as a pedestrian was seldom reported, but a between-group difference arose, with a higher score for the older participants (YG: Mdn = 0 / 10, IQR = 1; OG: Mdn = 2 / 10, IQR = 8, U = 121, Z = 2.30, p = .011, r = .36). For fear of falling measured in the OG, the mean FES-I score was 26.09 (SD = 8.68, range: 17-56 / 64, with low, moderate and high concern for 6, 8, and 8 participants, respectively, according to the classification proposed by Delbaere, Close, Mikolaizak, Sachdev, Brodaty, & Lord, 2010). Most of the participants said they were able to walk about one hour or more without fatigue: 15 (79%) in the YG and 16 (73%) in the OG, without a significant between-group difference (p = .727). No participant reported fatigue when walking less than 10 min. Older participants also reported that they spent on average 17 hours each week outside their home, with a large data dispersion for this parameter (SD = 12 hours).

As shown in Table 1, the two age groups differed when morphometric characteristics were taken into account. The younger participants were taller, and their hip-height measurements were larger. The participants' eye height was measured, without requesting them to stand fully erect, and this measure was larger in the younger participants. The younger participants had a larger shoe size, and their body mass index (BMI) was smaller.

Shorter actual steps were recorded in the OG compared to the YG for both types of steps (preferred and largest), and a significant difference was still found when the values were adjusted for either body-height or hip-height (median step lengths / (body-height or hip-height *100); ps <.001). A significant positive correlation was found between preferred and largest actual step length in both groups (OG: $r(20) = 0.86$, $p < .001$; YG: $r(17) = 0.62$, $p = .005$).

Table 1. Comparison between the younger group (YG) and the older group (OG) for morphometric and actual step characteristics (SL: Step Length). The mean values (and standard deviation), the results of the statistical analyses (Student's *t* test) and the effect sizes (Cohen's *d*) are shown.

Variables	YG	OG	*t*(39)	*p*	*d*
Full height (m)	1.66 (0.05)	1.58 (0.06)	4.60	<.001	1.49
Hip height (m)	1.01 (0.05)	0.95 (0.07)	2.71	.009	1.57
Eye height (m)	1.58 (0.04)	1.48 (0.07)	4.96	<.001	1.58
Shoe size (cm)	26.5 (1)	25.7(1)	2.48	.018	0.80
BMI	24.3 (3.99)	28.3 (5)	2.83	<.001	0.89
Actual preferred SL (cm)	58.5 (7.2)	42.5 (12.5)	4.94	<.001	1.57
Actual largest SL (cm)	90.1 (11.5)	64.6 (15)	6.03	<.001	1.91
Dominant foot	14 R/19	19 R/22	//	//	//

Step length estimation error

The equality of variances for the SLE error was in violation for the between-group comparisons (preferred step: $F(1,39) = 17.7$, $p < .001$; largest step: $F(1,39) = 8.20$, $p = .007$). The data are displayed in Table 2 and Figure 1. The difference between the older and younger participants reached significance for both types of steps: the SLE errors were larger in the OG than in the YG (see Table 2). The errors pointed to an overestimation of the step length in the OG and an underestimation in the YG. For the preferred step, the differences between the SLE errors and the "0" value were significant in both groups (OG: $t(21) = 3.29$, $p = .004$, $d = 0.70$; YG: $t(18) = 2.84$, $p = .011$, $d = 0.65$). For the largest step, significance was reached in the OG only, pointing to an overestimation ($t(21) = 2.37$; $p = .027$, $d = 0.50$; YG: $t(18) = 1.97$, $p = .064$, $d = 0.45$). The within-group comparisons showed that the older participants were less accurate when estimating their preferred steps than when estimating their largest steps ($t(21) = 2.95$, $p = .008$, $d = 0,63$; YG: $t(18) = 1.77$, $p = .094$, $d = 0,41$).

Table 2. Comparison between the younger group (YG) and older group (OG) for step length estimation errors. The mean values (and standard deviation), the results of the between-group comparison (Welch's *t* test), and the effect size (Glass's *Δ*) are shown.

Step	YG	OG	*t*(26.29)	*p*	*Δ*
Preferred (%)	-9.4 (14.4)	30.1 (42.9)	4.55	<.001	2.09
Largest (%)	-4.4 (9.8)	9.1 (18.1)	3.04	.005	0.93

Motor decline and step length estimation error in older participants

Even though the older participants were autonomous, the standardized mobility tests revealed emergent difficulties for nine of them, suggesting an increased RoF. Two participants obtained a Tinetti score equal to either 26 or 27, and four participants required more than 12 s to complete the TUG. Such lower performances in both tests were observed for three participants. Five participants reported a history of lower limb injuries that required a hip or knee prosthesis placement; two of these participants had fallen once during the previous year, and a fall was also reported by one additional participant considered at risk by the tests. By splitting the older group into two subgroups, it was possible to compare these nine participants for whom an increased RoF was suspected (OG-RoF: Older Group with increased RoF) to those who appeared at lesser risk (OG-noRoF: Older Group without increased RoF; n = 13).

The equality of variances for the SLE error was in violation for the preferred step ($F(1,20) = 8.92$, $p = .007$). The degree of misjudgment of the two groups significantly differed for the two types of steps (Table 3 and Figure 1). The SLE errors were larger in the OG-RoF than in the OG-noRoF (see Table 3). The one-sample *t*-test comparing the SLE errors to a "0" value confirmed a significant overestimation in the OG-RoF only, for both the preferred step ($t(8) = 4.67$, $p = .002$, d = 1.56 OG-noRoF: $t(12) = 0.95$, $p = .36$) and the largest step ($t(8) = 3.21$, $p = .012$, d = 1.07; OG-noRoF: $t(12) = 0.33$, $p = .75$). The within-group comparisons showed that participants in the OG-RoF were more accurate when estimating their largest steps than when estimating their preferred steps ($t(8) = 3.53$, $p = .008$, d = 1.18; OG-noRoF: $t(12) = 0.97$, $p = .349$).

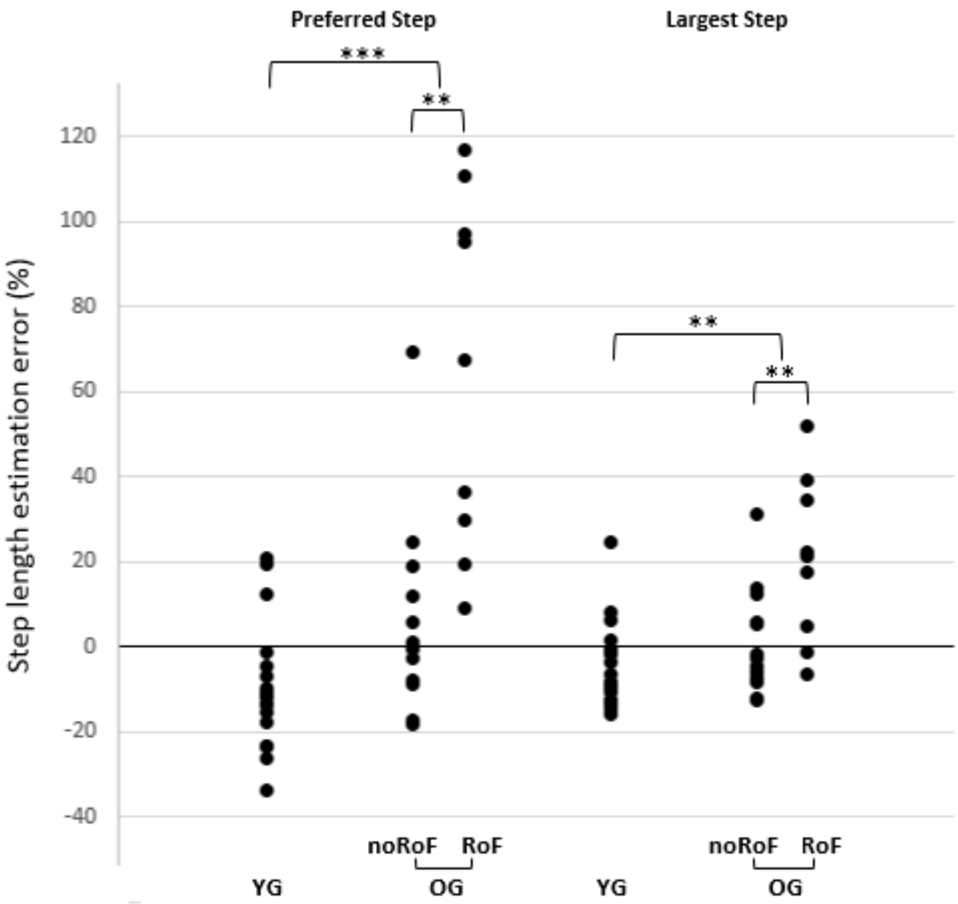

Figure 1. Step length estimation error (in percentage) in the younger group (YG) and in the older group (OG) for their preferred and largest steps. The participants in the older group were divided into two subgroups: those without an increased risk of falling (OG-noRoF) and those with an increased risk of falling (OG-RoF). [*** p <.001, ** p <.01].

Table 3. Comparison between the participants in the older group (OG) with and without an increased risk of falling (RoF vs noRoF) for step length estimation errors. The mean values (and standard deviation), the results of the between-group comparison, and the effect size are shown.

Step	OG-noRoF	OG-RoF	*t value**	*p*	*Effect size**
Preferred (%)	6.0 (22.9)	65.0 (41.7)	3.85	.002	2.58
Largest (%)	1.1 (12.4)	20.7 (19.3)	29.04	.009	1.21

* Preferred: Welch's t test and Glass's Δ; Largest: Student's *t* test and Cohen's *d*

Given the significant difference in the SLE error between the older participants with and without an increased RoF, further analyses were tentatively performed to identify other possible differences between the two groups. Table 4 summarizes the results of the between-group comparisons for the available data (only eye height was included as representative of the size parameter, given its strong correlation within this morphometric data set: $r(20) > .70$). The results showed that participants in the OG-RoF performed smaller actual steps when compared to those in the OG-noRoF, the between-group difference being significant for both preferred and largest steps. The differences in step length between the OG-noRoF and the YG were still significant (preferred step: $t(30) = 3.03$, $p < .001$, $d = 1.05$; largest step: $t(30) = 4.52$, $p < .001$, $d = 1.63$). The participants who said they could walk about one hour or more without fatigue totaled five (56%) in the OG-RoF and 11 (85%) in the OG-noRoF, respectively, but the difference was not significant ($p = 0.178$). Table 4 also shows that the MMSE score was significantly lower in the OG-RoF than in the OG-noRoF, and participants in the former were older than in the latter. However, the correlations between the SLE errors and age in the whole OG did not reach significance (preferred step: $r(20) = .374$, $p = .086$; largest step: $r(20) = .11$, $p = .626$), with several of the oldest participants providing good estimates. In contrast, the results showed significant correlations between the SLE errors and the actual step length (preferred step: $r(20) = -.82$, $p < .001$, FDR $p = .008$; largest step: $r(20) = -.72$, $p = .0001$, FDR $p = .016$) as well as between the SLE errors and the MMSE score (preferred step: $r(20) = -.61$, $p = .003$, FDR $p = .025$; largest step: $r(20) = -.54$, $p = .009$, FDR $p = .033$. Figure 2 depicts links for the estimates of the preferred step in the whole sample of older participants, distinguishing between those with and without an increased RoF.

Table 4. Complementary comparisons between older participants without an increased risk of falling (OG-noRoF; n = 13) and those with an increased risk of falling (OG-RoF; n = 9). The mean values (and standard deviation), the results of the statistical analyses with a control for false discovery rate (FDR), and the effect sizes Cohen's *d)* are shown.

Variables	OG-noRoF	OG-RoF	*t* value	*p*	*FDR-p*	*d*
Actual preferred SL (cm)	49.2 (10.2)	32.9 (8.8)	3.890	.001	.005	1.71
Actual largest SL (cm)	71.7 (11.0)	54.4 (14.3)	3.215	.004	.010	1.36
MMSE	29.2 (0.7)	28.1 (1.1)	2.816	.011	.015	1.19
Age (years)	72.8 (5.5)	78.4 (3.8)	-2.647	.015	.020	1.18
Time outdoors (h/w)	*22.0 (13.0)*	*10.8 (7.3)*	*2.337*	*.030*	*.025*	*1.06*
Eye height (m)	*1.50 (0.06)*	*1.45 (0.07)*	*1.951*	*.065*	*.030*	*0.77*
FES-I	*23.8 (6.2)*	*29.4 (10.9)*	*-1.558*	*.135*	*.035*	
Walking anxiety (/10)	*2.69 (3.47)*	*5.11 (4.11)*	*-1.492*	*.151*	*.040*	
BMI	*27.3 (5.9)*	*29.9 (3.2)*	*-1.248*	*.228*	*.045*	
Walking pleasure (/10)	*8 (2.2)*	*8 (2.0)*	*0.000*	*1.00*	*.050*	

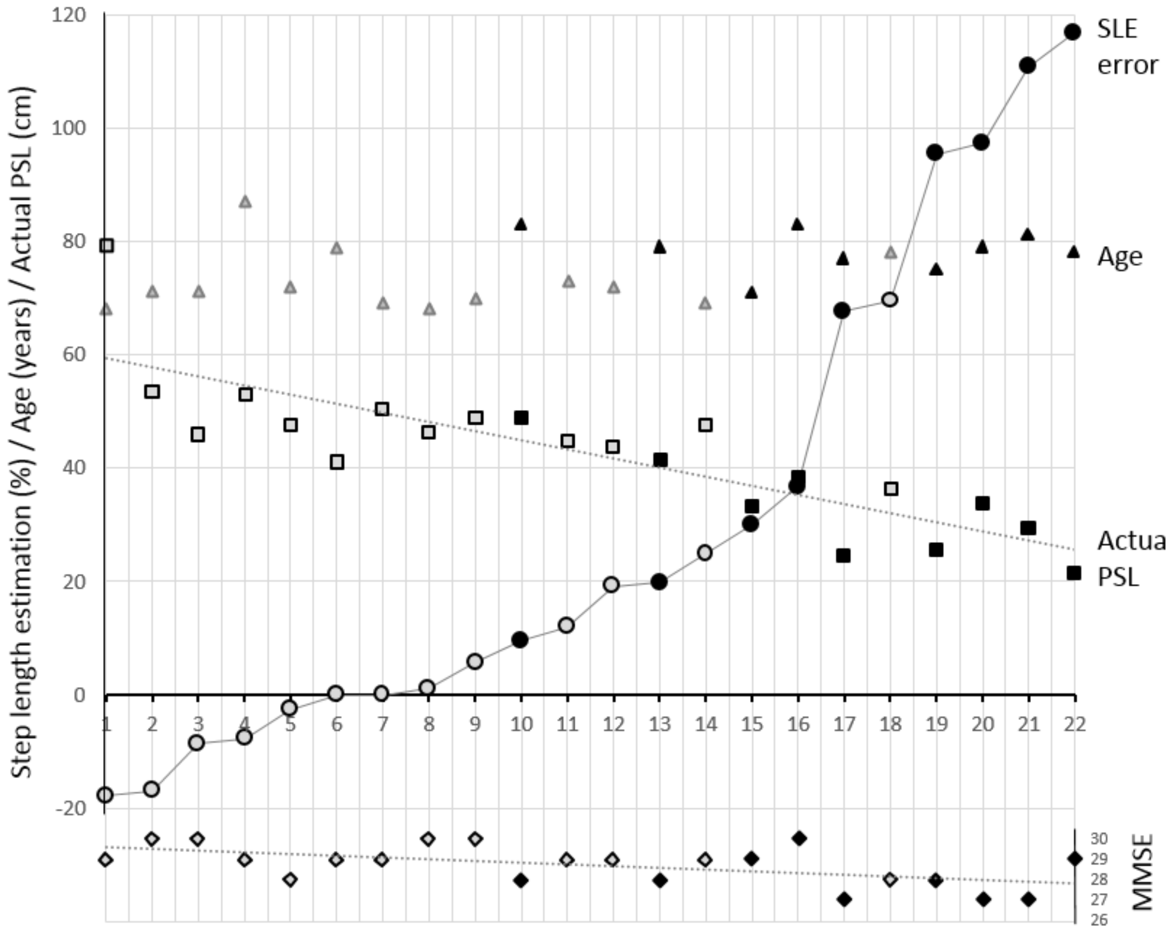

Figure 2. Older participants ranked in ascending order in abscissa as a function of their step length estimation (SLE) error for their preferred step; the individual data represented by black markers were those of participants with an increased RoF. The figure shows that the SLE error was significantly and negatively related to both the actual step length (SL) and MMSE score.

Discussion

The present study showed that when older participants must estimate the length of their first step during gait initiation, they judge it to be larger than it actually is. However, a conclusion in terms of overall self-overestimation in older people would be unsupported. Although the older participants had autonomous ambulation, some of them presented with slight motor decline, as suggested by their poorer performance on the TUG and/or Tinetti test. These participants were among those who performed the shortest steps, which is characteristic of age-related decline (Aboutorabi et al., 2016; Mbourou et al., 2003). A fine-grained analysis also revealed that these particular participants were those who overestimated their step length, the effect sizes being large and very large according to Sawilowsky (2009). Therefore, we postulate that there is an increased RoF in this sub-group. An increased RoF has previously been associated with overestimation of MSL (Fujimoto et al., 2015). Moreover, compatible findings have emerged in other procedures, such as mental chronometry (TUG: Beauchet et al., 2010; Fujimoto et al., 2015), the Standardized Walking Obstacle Course (Sakamoto & Ohashi, 2016), or the Step-over test (Sakurai et al., 2013). Therefore, our results corroborate previous assumptions about the key role of metacognition, especially regarding the overestimation of one's own physical capabilities, in the propensity to fall.

As in the present study, overestimation is the most frequent result in the literature, and more attention is placed on overestimation when there are mixed findings due to potentially greater negative consequences concerning balance. However, the underestimation of motor capabilities also arose in older people. Therefore, the failure to update the internal model of action seems to be an insufficient explanation for the entire set of findings. Task difficulty has been proposed to explain the discrepancy (Sakamoto & Ohashi, 2016), but a possible link to internal models of action must be strengthened. The transactional model of coping (Lazarus, 1991) seems powerful on that point, assuming its relevance in motor imagery. Put simply, primary appraisal identifies a task as more or less challenging (complex and/or physically demanding) based on both external and internal factors, among which are probably the internal models for the required action. If the task seems challenging with reference to self-estimated capabilities, the subsequent step of appraisal ("How do I address the challenge?") could dictate caution. The idea is that participants could behave more carefully in the motor imagery than when actually performing the action. Real action indeed provides online feedback, most likely reassuring, given both the repetition of trials and ethical limitations associated with endangerment. This feedback is not available in motor imagery, which usually occurs before the actual task in studies comparing imagined and actual actions. Ultimately, the resulting difference between imagined and real actions could point to an underestimation of performance. Alternatively, any challenge could be identified in the task, a conclusion sometimes drawn without an in-depth primary appraisal. Hence, the more a task appears easy and usual, the less hesitation or slowdown in the imagined action. This leads to overestimation if the internal models of action are not updated, as is assumed in fallers. Counterintuitively, easy tasks could therefore be favorable to highlight overestimation by those who do not fully acknowledge their age-related limitations, as is the case when merely having to walk a few steps forward.

For the older participants with an increased RoF, the preferred steps were less accurately estimated than the largest steps. This effect underscores the aforementioned explanation referring to Lazarus (1991): the outcome of the primary appraisal could be comparatively less reassuring for the largest steps; cautiousness in the SLE task could then partly compensate for the insufficient updating of the internal model of action. The reason for underestimation in the younger group is less clear. Given the inherent relationship between step length and body size, one explanation could still be inaccurate motor models of action, if not yet fully adjusted to body growth. Compatibly, the underestimation of eye height has been incidentally observed by Marcilly and Luyat (2008) in a sample of participants in their early twenties. Good SLE performance in more advanced ages without motor decline could also sustain this view.

The MMSE scores of our participants were within the normal range. Nevertheless, the MMSE score was negatively related to the degree of misjudgment of step length, and it is lower in overestimators who were also characterized by an increased RoF. Even if caution is required due to poor predictive value of the highest MMSE scores (cf. Spencer et al., 2013; Jensen, Nyberg, Gustafson, & Lundin-Olsson, 2003), this incidental effect can gain meaning by association with previous findings considering poorer cognitive functioning and motor imagery disturbances (Beauchet et al., 2010; Bridenbaugh et al., 2013, Schott 2012). Thus, future studies should cover a wider range of MMSE scores, as long as the instructions remain understandable. In the present sample, no problems were identified at this level, and the SLE task was well accepted; several participants even described it as a “funny”.

The present study has some limitations. The first is the small sample size. However, given that the main effects emerged with effect sizes ranging from large to huge and given the coherent pattern of results, one might consider SLE as a powerful procedure for establishing meaningful misjudgment. However, since only 3 participants designated at increased risk actually experienced a fall in the past year, one cannot negate the need for a larger sample, with both retrospective and prospective surveys of falls. A large sample would also provide the opportunity to further study people in their eighties who are still accurate in estimating their step length. This positive approach is motivated by the fact that age per se did not appear a significant predictor of misjudgment, despite those who overestimated their step length being among the older participants. Still in line with the sample size, insufficient power may be suspected for the link between misjudgment and both fear of falls and level of activity. Actually, there was a non-significant finding for the FES-I, while a positive link was reported by Sakurai et al. (2017b). Moreover, there was only a trend toward more overestimation in those who spend more time outdoors, while overestimators were described by Sakurai et al. (2014) as more numerous among those with a decreased frequency of going outdoors. Second, only female participants were included. In line with the overall higher ratio of women in the older population, they are often more numerous in this literature, and gender-related effects are seldom reported. In contrast, Bridenbaugh et al. (2013) has found that female participants were more likely to misjudge in a timed TUG. A generalization of our findings to males should thus be verified. Third, even though the younger participants were taller than the older participants, confounding effects are unlikely, given that the analyses were performed on relative error and conclusions provided by this intuitive parameter were corroborated by analyses of data expressed as visual angles (not reported for brevity).

In summary, this experiment implemented a step length estimation procedure. This experiment revealed an underestimation of preferred step length by younger adults, an accurate estimation by older people without a RoF, and an overestimation by older adults with motor decline, suggesting an increased RoF. When the largest steps were tested, an overestimation by those with an increased RoF was the sole error that arose. The evidence of misjudgment in the older population is in line with the growing interest in cognitive factors, as included in the etiology of the RoF. Overestimation is thought to result from erroneous primary appraisal, based on the insufficient actualization of motor models of action. Both the results of the experiment and the participants' eagerness to complete the task suggest that this step length assessment could become a clinical laboratory tool to assess the RoF, but validation is required including a prospective investigation of the link between misjudgment and actual falls. The methodological options must also be carefully considered beforehand to optimize the benefit/cost ratio. For instance, the greater sensitivity concerning preferred steps has potential pragmatic advantages since only this easiest condition could be included. Accordingly, the direction for future studies should concern test-retest reliability, cross-validation as well as, the link between misjudgment and performance at interoception, motor imagery and memory tests. Finally, the potential task applicability for improving the awareness of misjudgment in people at risk should be investigated.

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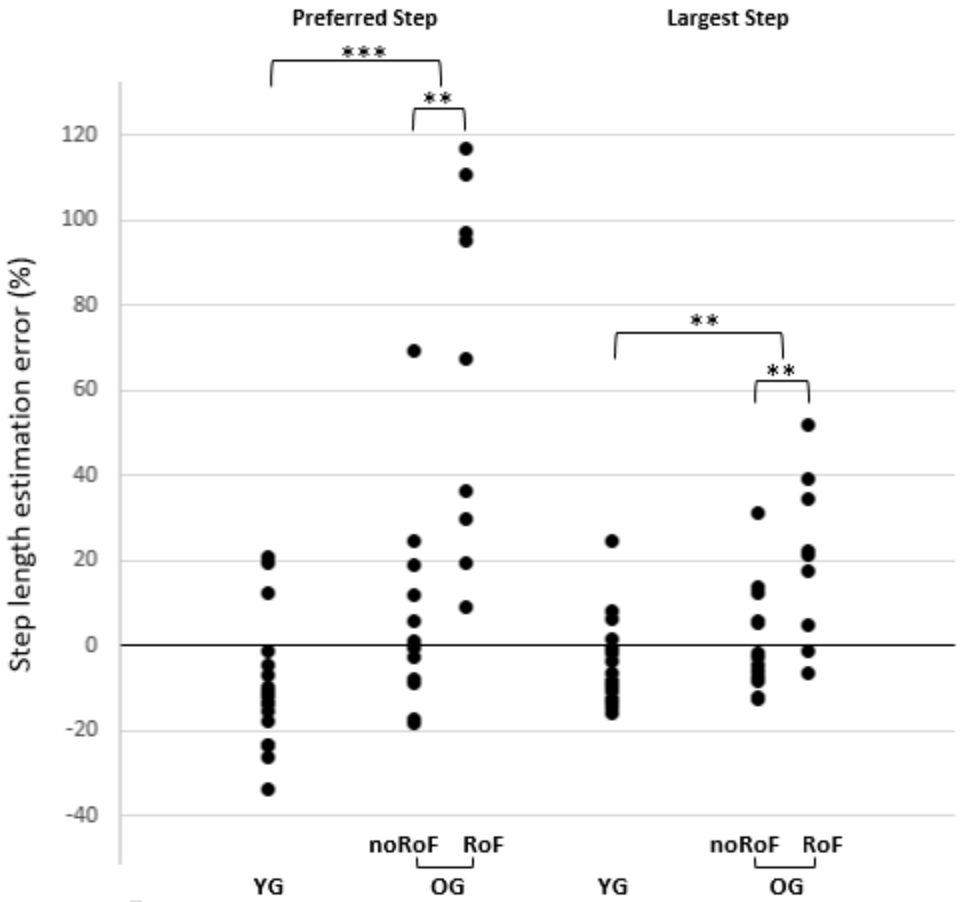
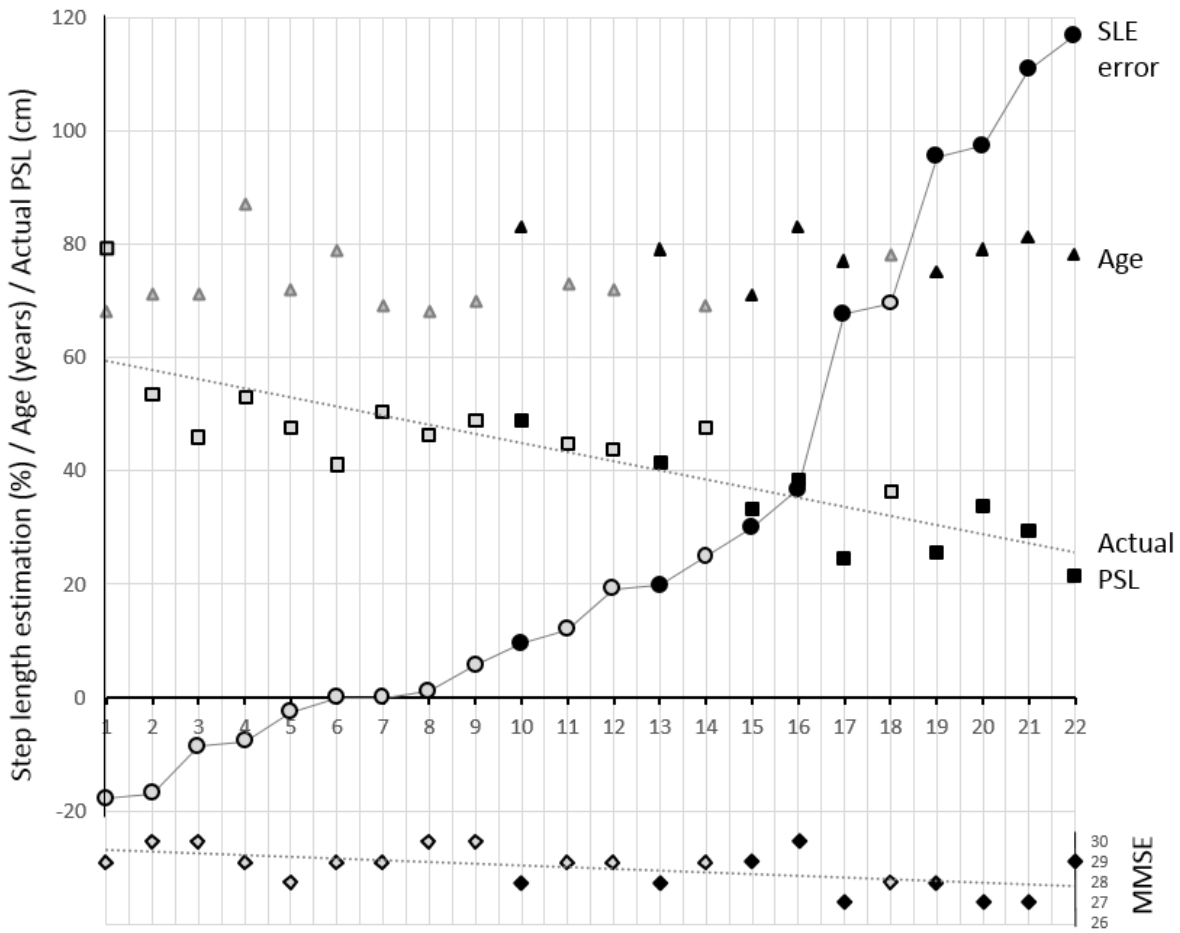
Figure 1



Preferred Step
Largest Step
***
**
**
**
Step length estimation error (%)
120
100
80
60
40
20
0
-20
-40
noRoF
RoF
noRoF
RoF
YG
OG
YG
OG

Figure 2


Step length estimation (%) / Age (years) / Actual PSL (cm)
120
100
80
60
40
20
0
-20
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
SLE error
Age
Actual PSL
30 29 28 27 26
MMSE