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Do older people accurately estimate the length of their first step during gait initiation?

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

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ABSTRACT

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

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

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

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

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

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

52 The hypothesis of overestimation is supported by a series of studies that have
53 compared actual motor performance with motor imagery, which consists of consciously
54 imagining oneself in action without any overt motor action. Mostly due to an overlapping of
55 the neural networks underlying imagined and actual actions (for a review, see Héту,
56 Taschereau-Dumouchel, Meziane, Jackson, & Mercier, 2016), motor imagery is used to
57 investigate the unconscious process of action representation and internal models of action
58 (Jeannerod, 1994; Jeannerod & Decety, 1995). Overestimation has been identified in
59 several tasks requiring whole body movements. Overestimation may occur when older
60 adults must estimate the maximal height they can step over (Noël, Bernard, & Luyat, 2011;
61 Lafargue et al., 2013, Sakurai, Fujiwara, Ishihara, Higuchi, Uchida, & Imanaka, 2013;
62 Sakurai et al., 2014, 2016, 2017a). Overestimation predominates when older adults must
63 estimate whether they can stand on an inclined plane (Lafargue et al., 2013) or must
64 estimate their maximal forward reach without losing balance (Liu-Ambrose, Ahamed, Graf,
65 Feldman, & Robinovitch, 2008; Okimoto, Toriyama, Deie, & Maejima, 2017; Robinovitch &
66 Cronin, 1999). There is also converging evidence for the overestimation of actions that fully
67 or partly relate to walking speed; this effect is often limited to very old adults (Beauchet et al.,
68 2010; Bridenbaugh, Beauchet, Annweiler, Allali, Herrmann, & Kressig, 2013; Fujimoto et al.,
69 2015; Naveteur, Delzenne, Sockeel, Watelain, & Dupuy, 2013; Sakamoto & Ohashi, 2016,
70 2017; Sakurai et al., 2017b; Schott, 2012; Schott & Munzert, 2007; Zivotofsky, Eldror,
71 Mandel, & Rosenbloom, 2012). Misjudgment seems to increase in older adults who have an
72 inactive life style (Sakurai et al., 2014), an increased RoF (Beauchet et al., 2010; Butler,
73 Lord, Taylor, & Fitzpatrick, 2014; Sakurai et al., 2013), or a fear of falling (Sakurai et al.,
74 2017b).

75 Concerning step length, two experiments are relevant. One is the condition called
76 “river” by Kluft, Bruijn, Weijer, van Dieën and Pijnappels (2017a). In this experiment, older
77 and younger participants walked along a tapered piece of paper, starting at the widest end.
78 They had to step across the piece of paper once they decided they could do this action. The
79 crossing position provided their perceived MSL (here, different from maximal lunge since the

80 non-dominant foot is not planted), which was compared to their actual MSL; the actual MSL
81 was separately determined by stepping inside a target. Overestimation seems to be the most
82 frequent misjudgment. No age-related effect arose, possibly due to an insufficient sample
83 size, as underlined by the authors. Additionally, the requirement to perform the task as fast
84 as possible could counteract the larger overestimation in the older participant group. This
85 study did not distinguish an imaginary-movement phase from a real action phase, as done in
86 the other experiment performed by Fujimoto et al. (2015). MSL (here, maximal lunge) was
87 recorded in two large samples of community-dwelling older adults. Those who had fallen
88 several times during the year were characterized by shorter actual MSLs compared to non-
89 fallers, and their estimated MSLs were larger than their actual MSLs. Furthermore, there was
90 a small but significant underestimation of MSL in non-fallers, and younger controls were not
91 included in this study. Hence, the question of the accuracy of step length estimation with
92 advancing age has not been fully resolved.

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

108 control group comprising younger adults. This also points to the relevance of including step
109 lengths that are considered more or less usual.

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

Methods

Participants

124 A total of 41 female volunteers were included in this study. The older group (OG) included 22
125 participants aged 68 to 87 years ($M = 74.9$, $SD = 5.4$ years). The younger group (YG)
126 included 19 participants aged 19 to 33 years ($M = 25.2$, $SD = 3.5$ years). All the participants
127 were initially contacted through information disseminated among a number of community
128 groups, in particular clubs for the older adults and in the university or hospital for the younger
129 adults. The participants were autonomous in their everyday life, including autonomous
130 ambulation without material aids. A score of at least 6/10 at 3 m on the Monoyer scale for

131 binocular eyesight (with or without correction) was an eligibility criterion. An MMSE score
132 lower than 27 was an exclusion criterion for older participants.

Material

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

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

Procedure

149 A few days before the experimental session, people interested in taking part in the study
150 were met individually and screened for the eligibility criteria. Individuals also received more
151 information about the experiment. They were told to wear comfortable shoes for their
152 upcoming visit in the laboratory. Upon their arrival for the experimental session, the
153 participants gave their informed written consent, and they answered a few questions. They
154 assigned scores between 0 and 10 regarding both the pleasure they experience when
155 walking and their walking-related anxiety as pedestrians. They were asked about the
156 duration of walking they could perform without fatigue (i.e., less than 10 min, between 10

157 and 20 min, about half an hour, about one hour, more than one hour). They were also invited
158 to comment on any lower extremity injury that would affect their gait currently or in the past,
159 and on previous experience of falling. To determine their dominant foot, the participants
160 were asked to kick an imaginary ball. The participants were then fitted with the reflective
161 markers.

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

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

185 were conducted with the trace moving away from the participant, and the other three trials
186 were conducted with the trace moving forward. The trace moved away during the first trial,
187 and then the trials alternated between the two moving directions.

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

196 Before the end of the experiment, the older participants also completed the Falls
197 Efficacy Scale-International (FES-I), which measures fear of falling in the older population
198 (Yardley, Beyer, Hauer, Kempen, Piot-Ziegler, & Todd, 2005; French translation in Mourey,
199 Manckoundia, & Pfitzenmeyer, 2009). The participants also performed the two standardized
200 mobility tests: the TUG test, which measures the time it takes to stand from an armchair, to
201 walk a distance of 3 m, turn, and walk back to the chair, and to sit down (Podsiadlo and
202 Richardson, 1991), and the Tinetti test, which assesses mobility, balance and gait (Tinetti,
203 1986). Finally, the participants were asked to estimate the number of hours they spent
204 weekly outside their home. Before leaving the room, the participants were invited to
205 comment on the experiment. The full session lasted approximately one hour for the older
206 participants and 30 min for the younger participants. The participants received a small gift in
207 return for their participation.

Data reduction and analyses

208 The estimated step length was expressed relative to the real step length. The SLE error was
209 computed as follows: (median of estimated step lengths – median of real step
210 lengths) / median of real step lengths*100. Positive and negative SLE errors reflected step

211 length overestimation and underestimation, respectively. To sustain this conclusion, a one-
212 sample *t*-test was used to compare the SLE error in each group to a “0” value,
213 corresponding to a perfect estimation.

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

Results

Participant characteristics

223 All the participants reported experiencing pleasure when walking ($M = 8.12 / 10$; $SD = 1.77$).
224 Walking-related anxiety as a pedestrian was seldom reported, but a between-group
225 difference arose, with a higher score for the older participants (YG: $Mdn = 0 / 10$, $IQR = 1$;
226 OG: $Mdn = 2 / 10$, $IQR = 8$, $U = 121$, $Z = 2.30$, $p = .011$, $r = .36$). For fear of falling measured
227 in the OG, the mean FES-I score was 26.09 ($SD = 8.68$, range: 17-56 / 64, with low,
228 moderate and high concern for 6, 8, and 8 participants, respectively, according to the
229 classification proposed by Delbaere, Close, Mikolaizak, Sachdev, Brodaty, & Lord, 2010).
230 Most of the participants said they were able to walk about one hour or more without fatigue:
231 15 (79%) in the YG and 16 (73%) in the OG, without a significant between-group difference
232 ($p = .727$). No participant reported fatigue when walking less than 10 min. Older participants
233 also reported that they spent on average 17 hours each week outside their home, with a
234 large data dispersion for this parameter ($SD = 12$ hours).

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

240 Shorter actual steps were recorded in the OG compared to the YG for both types of
 241 steps (preferred and largest), and a significant difference was still found when the values
 242 were adjusted for either body-height or hip-height (median step lengths / (body-height or hip-
 243 height *100); p s <.001). A significant positive correlation was found between preferred and
 244 largest actual step length in both groups (OG: $r(20) = 0.86$, $p <.001$; YG: $r(17) = 0.62$, $p =$
 245 .005).

246 **Table 1.** Comparison between the younger group (YG) and the older
 247 group (OG) for morphometric and actual step characteristics (SL: Step
 248 Length). The mean values (and standard deviation), the results of the
 249 statistical analyses (Student's t test) and the effect sizes (Cohen's d) are
 250 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	//	//	//

251

Step length estimation error

252 The equality of variances for the SLE error was in violation for the between-group
253 comparisons (preferred step: $F(1,39) = 17.7, p < .001$; largest step: $F(1,39) = 8.20, p = .007$).
254 The data are displayed in Table 2 and Figure 1. The difference between the older and
255 younger participants reached significance for both types of steps: the SLE errors were larger
256 in the OG than in the YG (see Table 2). The errors pointed to an overestimation of the step
257 length in the OG and an underestimation in the YG. For the preferred step, the differences
258 between the SLE errors and the “0” value were significant in both groups (OG: $t(21) = 3.29,$
259 $p = .004, d = 0.70$; YG: $t(18) = 2.84, p = .011, d = 0.65$). For the largest step, significance
260 was reached in the OG only, pointing to an overestimation ($t(21) = 2.37; p = .027, d = 0.50$;
261 YG: $t(18) = 1.97, p = .064, d = 0.45$). The within-group comparisons showed that the older
262 participants were less accurate when estimating their preferred steps than when estimating
263 their largest steps ($t(21) = 2.95, p = .008, d = 0,63$; YG: $t(18) = 1.77, p = .094, d = 0,41$).

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

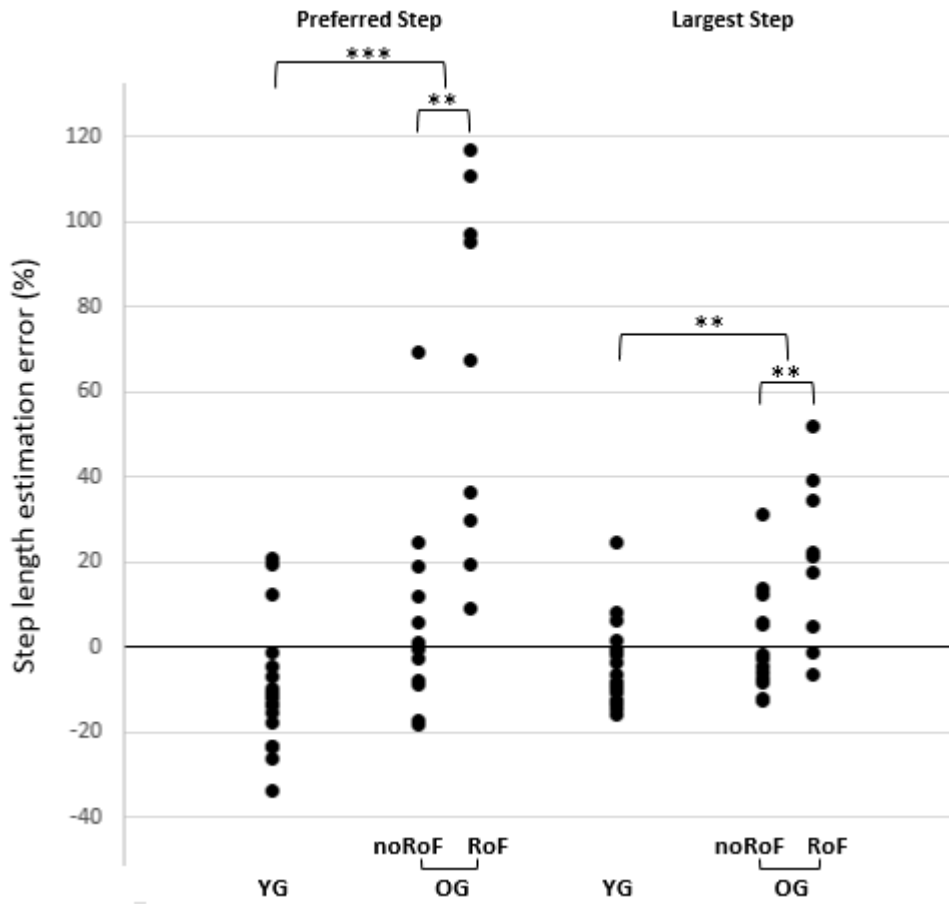
Step	YG	OG	$t(26.29)$	p	Δ
Preferred (%)	-9.4 (14.4)	30.1 (42.9)	4.55	<.001	2.09
Largest (%)	-4.4 (9.8)	9.1 (18.1)	3.04	.005	0.93

268 **Motor decline and step length estimation error in older participants**

269 Even though the older participants were autonomous, the standardized mobility tests
270 revealed emergent difficulties for nine of them, suggesting an increased RoF. Two
271 participants obtained a Tinetti score equal to either 26 or 27, and four participants required
272 more than 12 s to complete the TUG. Such lower performances in both tests were observed

273 for three participants. Five participants reported a history of lower limb injuries that required
274 a hip or knee prosthesis placement; two of these participants had fallen once during the
275 previous year, and a fall was also reported by one additional participant considered at risk by
276 the tests. By splitting the older group into two subgroups, it was possible to compare these
277 nine participants for whom an increased RoF was suspected (OG-RoF: Older Group with
278 increased RoF) to those who appeared at lesser risk (OG-noRoF: Older Group without
279 increased RoF; $n = 13$).

280 The equality of variances for the SLE error was in violation for the preferred step
281 ($F(1,20) = 8.92, p = .007$). The degree of misjudgment of the two groups significantly differed
282 for the two types of steps (Table 3 and Figure 1). The SLE errors were larger in the OG-RoF
283 than in the OG-noRoF (see Table 3). The one-sample t -test comparing the SLE errors to a
284 “0” value confirmed a significant overestimation in the OG-RoF only, for both the preferred
285 step ($t(8) = 4.67, p = .002, d = 1.56$ OG-noRoF: $t(12) = 0.95, p = .36$) and the largest step
286 ($t(8) = 3.21, p = .012, d = 1.07$; OG-noRoF: $t(12) = 0.33, p = .75$). The within-group
287 comparisons showed that participants in the OG-RoF were more accurate when estimating
288 their largest steps than when estimating their preferred steps ($t(8) = 3.53, p = .008, d = 1.18$;
289 OG-noRoF: $t(12) = 0.97, p = .349$).



290

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

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

Step	OG-noRoF	OG-RoF	<i>t value*</i>	<i>p</i>	<i>Effect size*</i>
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

299

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

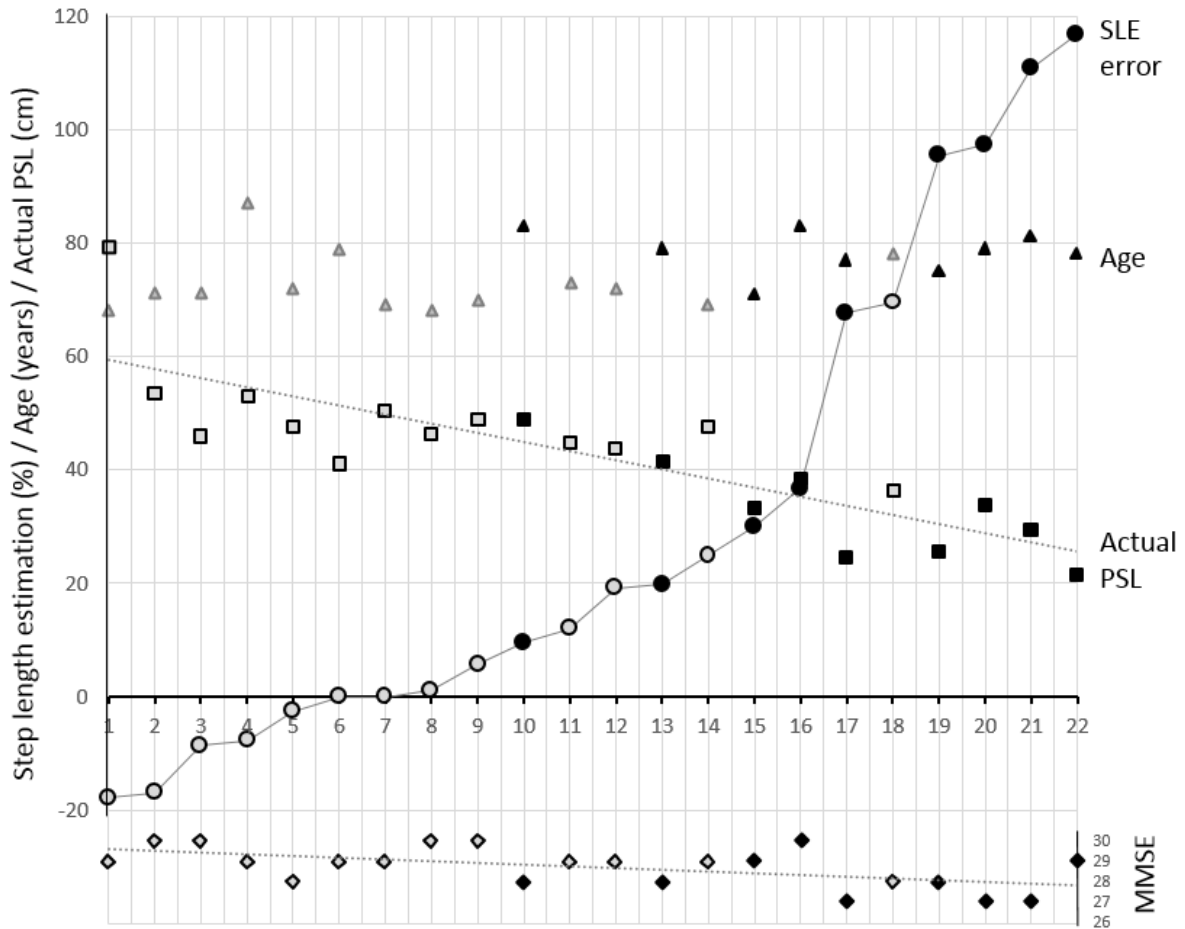
300 Given the significant difference in the SLE error between the older participants with
301 and without an increased RoF, further analyses were tentatively performed to identify other
302 possible differences between the two groups. Table 4 summarizes the results of the
303 between-group comparisons for the available data (only eye height was included as
304 representative of the size parameter, given its strong correlation within this morphometric
305 data set: $r(20) > .70$). The results showed that participants in the OG-RoF performed smaller
306 actual steps when compared to those in the OG-noRoF, the between-group difference being
307 significant for both preferred and largest steps. The differences in step length between the
308 OG-noRoF and the YG were still significant (preferred step: $t(30) = 3.03, p < .001, d = 1.05$;
309 largest step: $t(30) = 4.52, p < .001, d = 1.63$). The participants who said they could walk
310 about one hour or more without fatigue totaled five (56%) in the OG-RoF and 11 (85%) in the
311 OG-noRoF, respectively, but the difference was not significant ($p = 0.178$). Table 4 also
312 shows that the MMSE score was significantly lower in the OG-RoF than in the OG-noRoF,
313 and participants in the former were older than in the latter. However, the correlations
314 between the SLE errors and age in the whole OG did not reach significance (preferred step:
315 $r(20) = .374, p = .086$; largest step: $r(20) = .11, p = .626$), with several of the oldest
316 participants providing good estimates. In contrast, the results showed significant correlations
317 between the SLE errors and the actual step length (preferred step: $r(20) = -.82, p < .001$,
318 FDR $p = .008$; largest step: $r(20) = -.72, p = .0001$, FDR $p = .016$) as well as between the
319 SLE errors and the MMSE score (preferred step: $r(20) = -.61, p = .003$, FDR $p = .025$; largest
320 step: $r(20) = -.54, p = .009$, FDR $p = .033$). Figure 2 depicts links for the estimates of the
321 preferred step in the whole sample of older participants, distinguishing between those with
322 and without an increased RoF.

323

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

Variables	OG-noRoF	OG-RoF	<i>t</i> value	<i>p</i>	<i>FDR-p</i>	<i>d</i>
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
<i>Time outdoors (h/w)</i>	22.0 (13.0)	10.8 (7.3)	2.337	.030	.025	1.06
<i>Eye height (m)</i>	1.50 (0.06)	1.45 (0.07)	1.951	.065	.030	0.77
<i>FES-I</i>	23.8 (6.2)	29.4 (10.9)	-1.558	.135	.035	
<i>Walking anxiety (/10)</i>	2.69 (3.47)	5.11 (4.11)	-1.492	.151	.040	
<i>BMI</i>	27.3 (5.9)	29.9 (3.2)	-1.248	.228	.045	
<i>Walking pleasure (/10)</i>	8 (2.2)	8 (2.0)	0.000	1.00	.050	

328



329

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

Discussion

335 The present study showed that when older participants must estimate the length of their first
 336 step during gait initiation, they judge it to be larger than it actually is. However, a conclusion
 337 in terms of overall self-overestimation in older people would be unsupported. Although the
 338 older participants had autonomous ambulation, some of them presented with slight motor
 339 decline, as suggested by their poorer performance on the TUG and/or Tinetti test. These

340 participants were among those who performed the shortest steps, which is characteristic of
341 age-related decline (Aboutorabi et al., 2016; Mbourou et al., 2003). A fine-grained analysis
342 also revealed that these particular participants were those who overestimated their step
343 length, the effect sizes being large and very large according to Sawilowsky (2009).
344 Therefore, we postulate that there is an increased RoF in this sub-group. An increased RoF
345 has previously been associated with overestimation of MSL (Fujimoto et al., 2015).
346 Moreover, compatible findings have emerged in other procedures, such as mental
347 chronometry (TUG: Beauchet et al., 2010; Fujimoto et al., 2015), the Standardized Walking
348 Obstacle Course (Sakamoto & Ohashi, 2016), or the Step-over test (Sakurai et al., 2013).
349 Therefore, our results corroborate previous assumptions about the key role of metacognition,
350 especially regarding the overestimation of one's own physical capabilities, in the propensity
351 to fall.

352 As in the present study, overestimation is the most frequent result in the literature,
353 and more attention is placed on overestimation when there are mixed findings due to
354 potentially greater negative consequences concerning balance. However, the
355 underestimation of motor capabilities also arose in older people. Therefore, the failure to
356 update the internal model of action seems to be an insufficient explanation for the entire set
357 of findings. Task difficulty has been proposed to explain the discrepancy (Sakamoto &
358 Ohashi, 2016), but a possible link to internal models of action must be strengthened. The
359 transactional model of coping (Lazarus, 1991) seems powerful on that point, assuming its
360 relevance in motor imagery. Put simply, primary appraisal identifies a task as more or less
361 challenging (complex and/or physically demanding) based on both external and internal
362 factors, among which are probably the internal models for the required action. If the task
363 seems challenging with reference to self-estimated capabilities, the subsequent step of
364 appraisal ("How do I address the challenge?") could dictate caution. The idea is that
365 participants could behave more carefully in the motor imagery than when actually performing
366 the action. Real action indeed provides online feedback, most likely reassuring, given both
367 the repetition of trials and ethical limitations associated with endangerment. This feedback is

368 not available in motor imagery, which usually occurs before the actual task in studies
369 comparing imagined and actual actions. Ultimately, the resulting difference between
370 imagined and real actions could point to an underestimation of performance. Alternatively,
371 any challenge could be identified in the task, a conclusion sometimes drawn without an in-
372 depth primary appraisal. Hence, the more a task appears easy and usual, the less hesitation
373 or slowdown in the imagined action. This leads to overestimation if the internal models of
374 action are not updated, as is assumed in fallers. Counterintuitively, easy tasks could
375 therefore be favorable to highlight overestimation by those who do not fully acknowledge
376 their age-related limitations, as is the case when merely having to walk a few steps forward.

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

388 The MMSE scores of our participants were within the normal range. Nevertheless,
389 the MMSE score was negatively related to the degree of misjudgment of step length, and it
390 is lower in overestimators who were also characterized by an increased RoF. Even if caution
391 is required due to poor predictive value of the highest MMSE scores (cf. Spencer et al.,
392 2013; Jensen, Nyberg, Gustafson, & Lundin-Olsson, 2003), this incidental effect can gain
393 meaning by association with previous findings considering poorer cognitive functioning and
394 motor imagery disturbances (Beauchet et al., 2010; Bridenbaugh et al., 2013, Schott 2012).
395 Thus, future studies should cover a wider range of MMSE scores, as long as the instructions

396 remain understandable. In the present sample, no problems were identified at this level, and
397 the SLE task was well accepted; several participants even described it as a “funny”.

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

422 In summary, this experiment implemented a step length estimation procedure. This
423 experiment revealed an underestimation of preferred step length by younger adults, an

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

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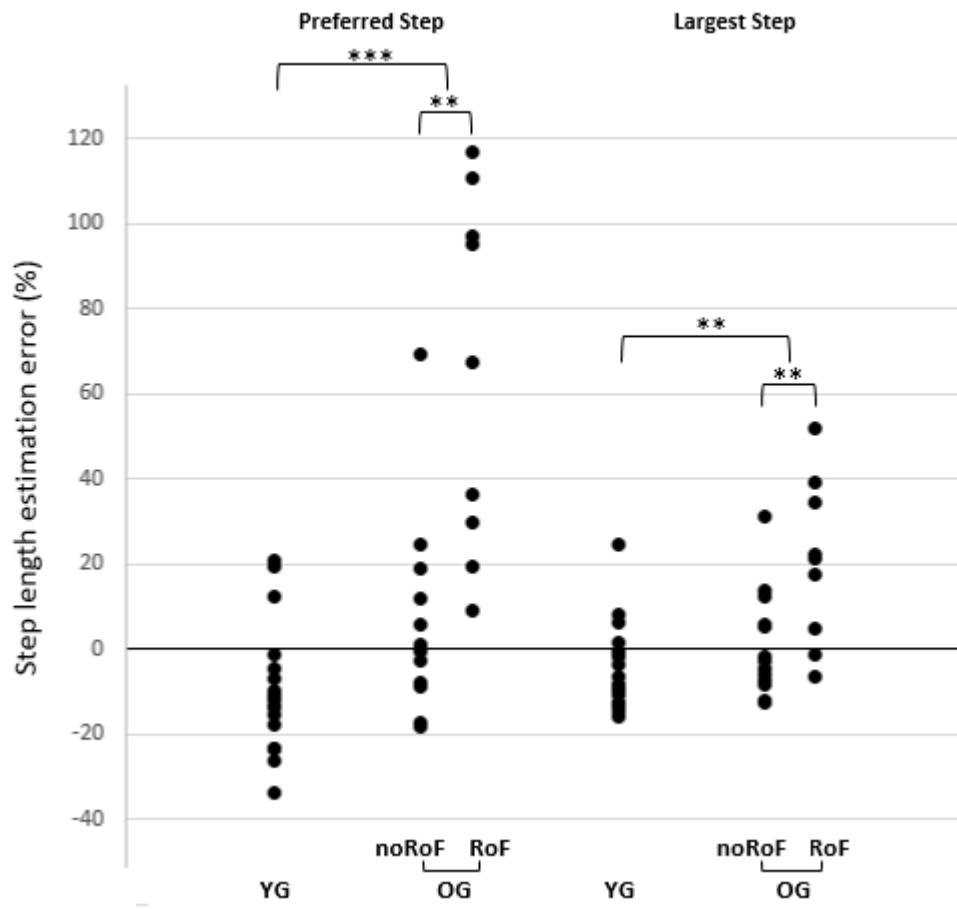
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585 Figure 1

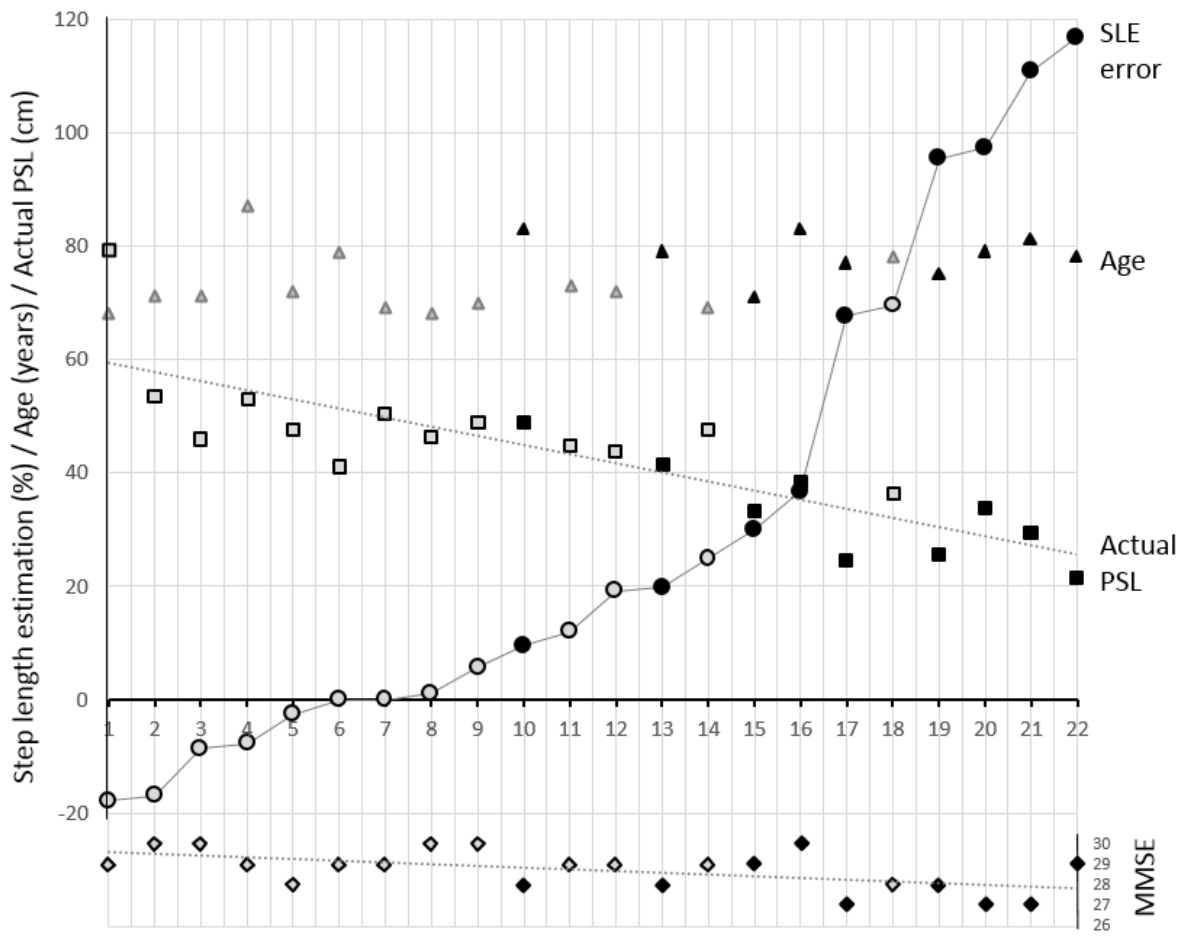


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589 Figure 2



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