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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);  $p < .001$ ). 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	<i>t</i> (39)	<i>p</i>	<i>d</i>
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

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  $\Delta$ ) are shown.

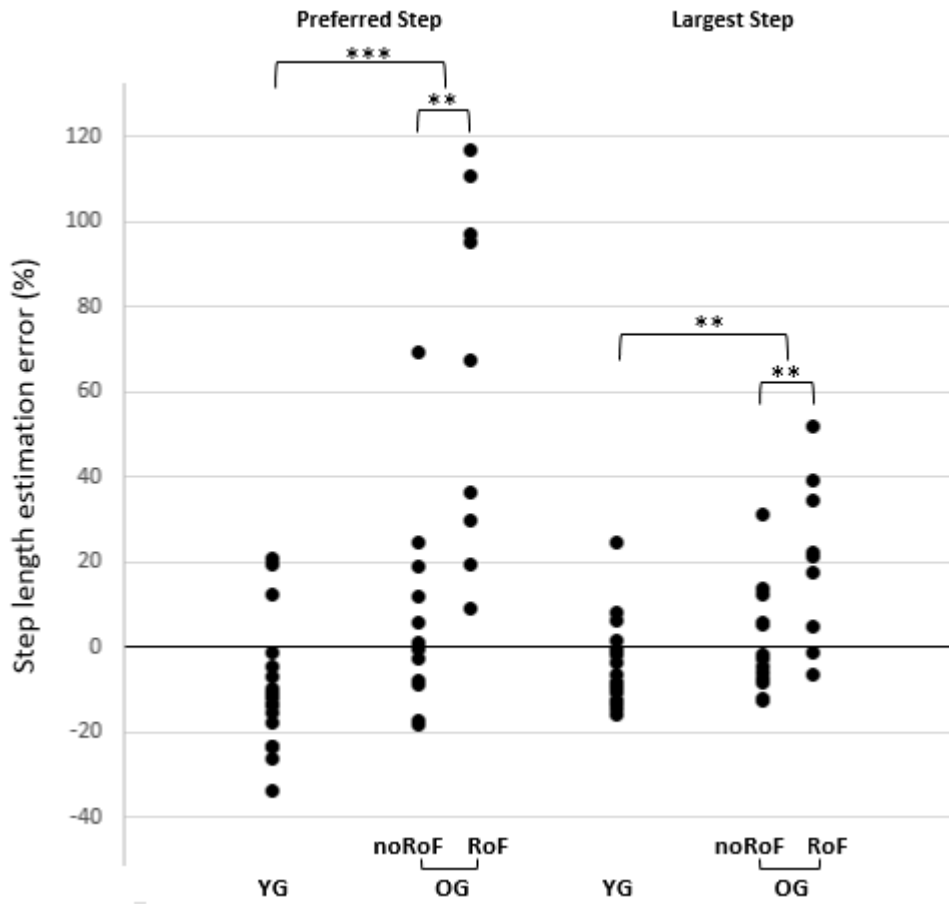
Step	YG	OG	$t(26.29)$	$p$	$\Delta$
Preferred (%)	-9.4 (14.4)	30.1 (42.9)	4.55	<.001	2.09
Largest (%)	-4.4 (9.8)	9.1 (18.1)	3.04	.005	0.93

## 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  $\Delta$ ; Largest: Student's *t* test and Cohen's *d*



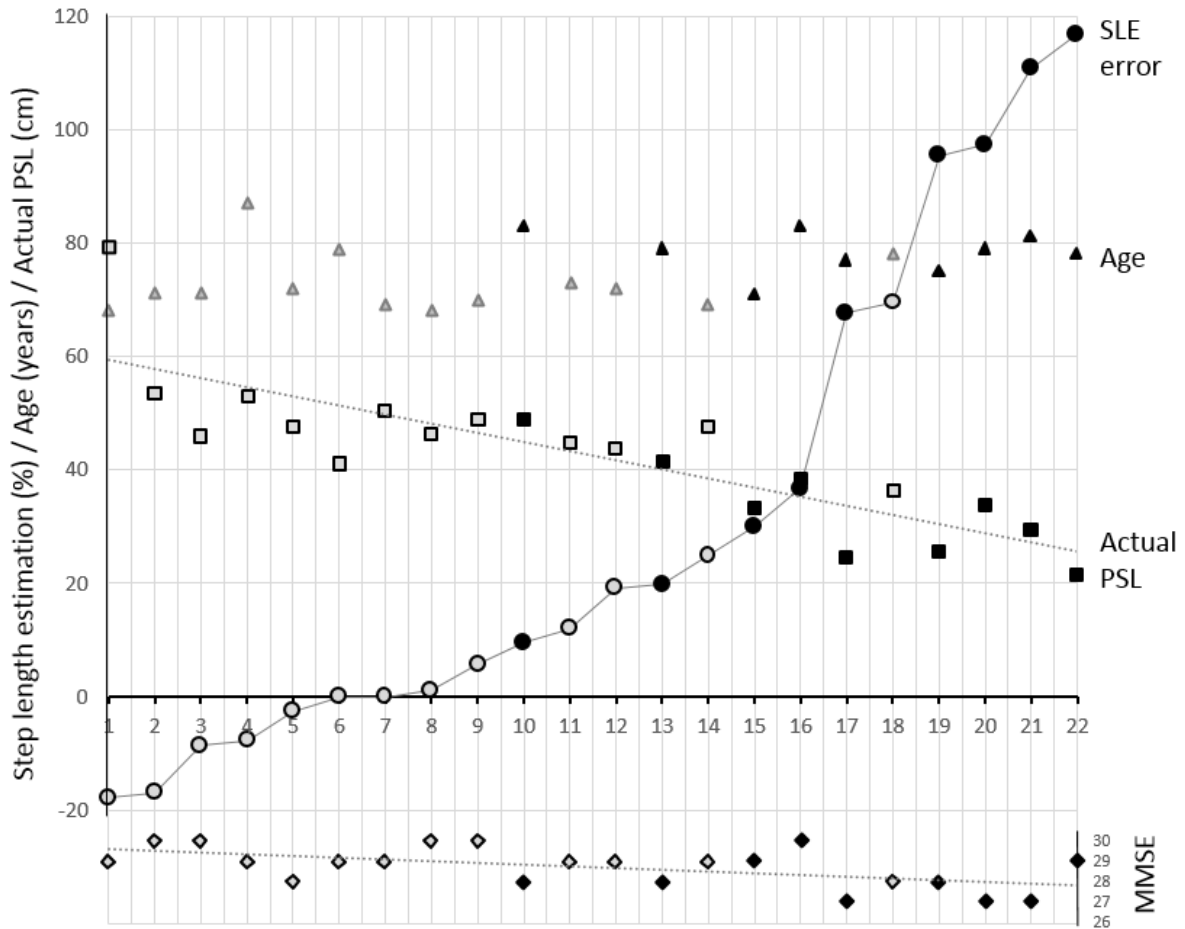
300           Given the significant difference in the SLE error between the older participants with  
301 and without an increased RoF, further analyses were tentatively performed to identify other  
302 possible differences between the two groups. Table 4 summarizes the results of the  
303 between-group 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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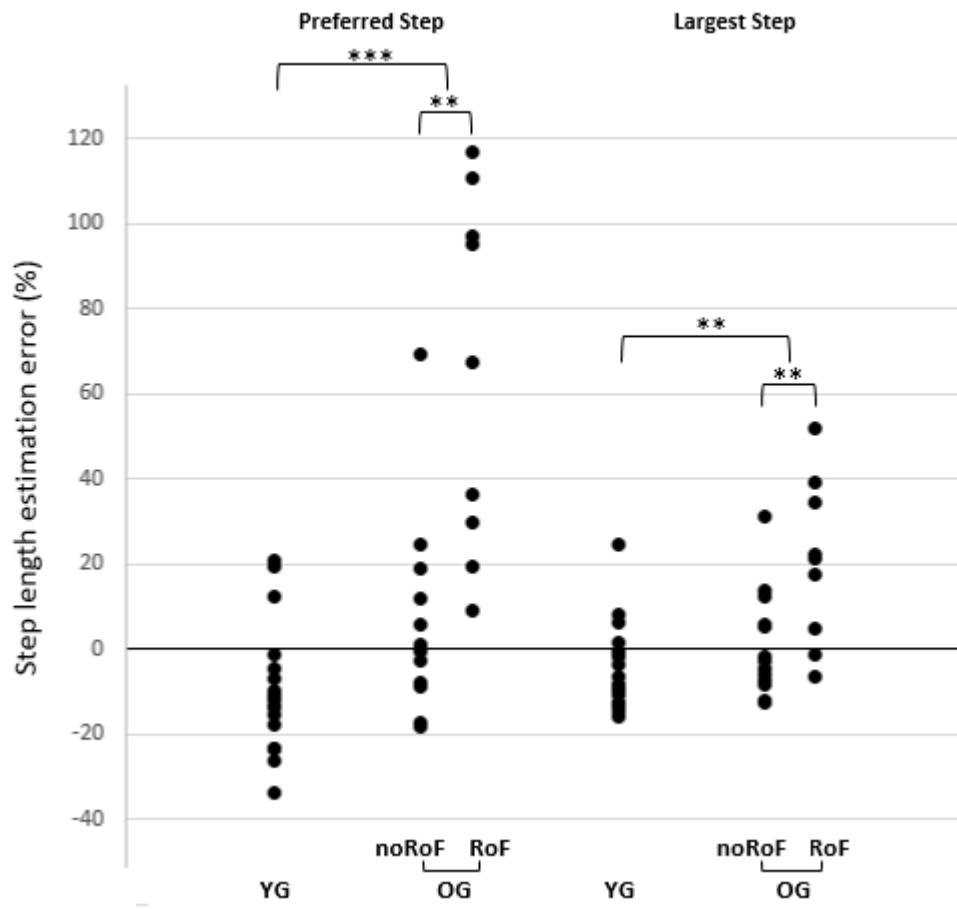
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585 Figure 1

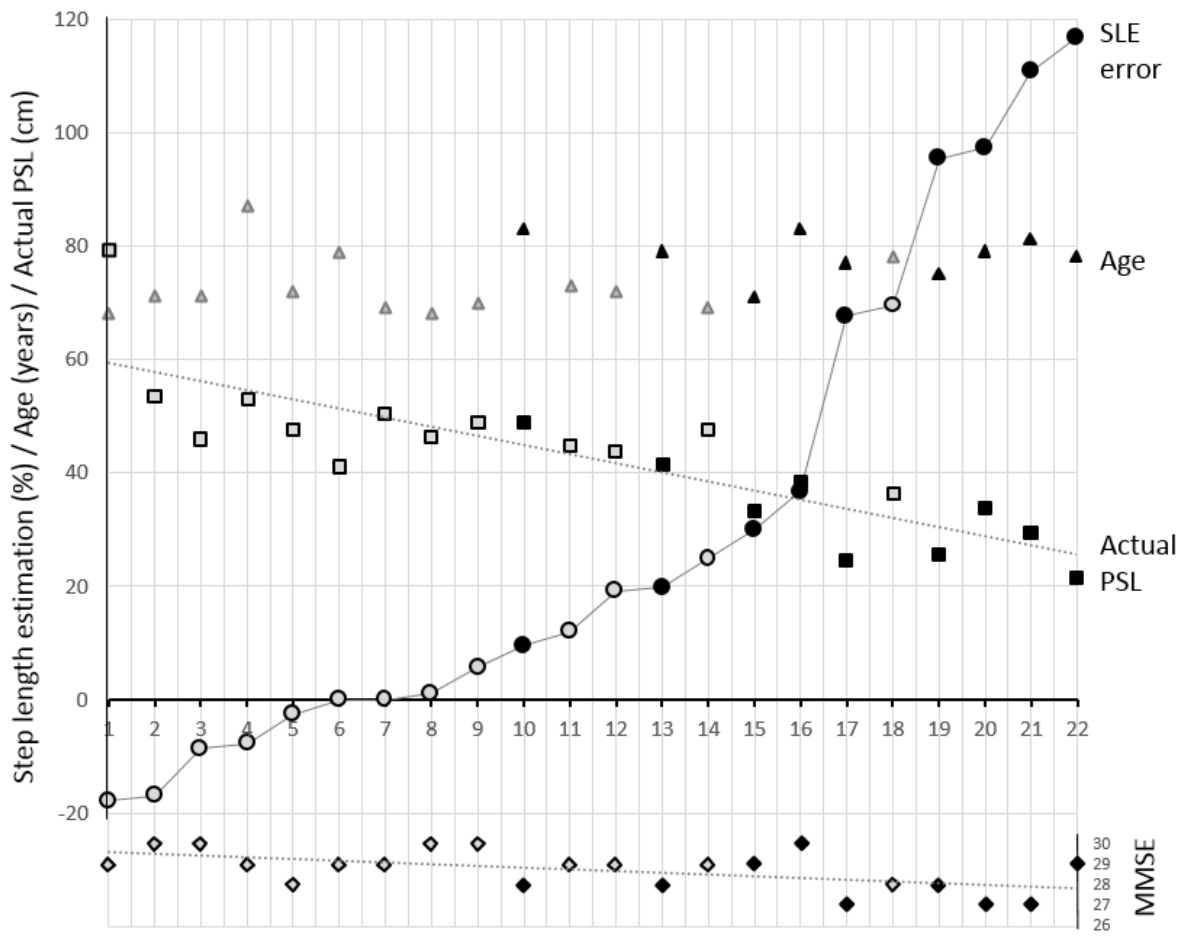


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589 Figure 2



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