

Comparative assessment of different methods for the estimation of gait temporal parameters using a single inertial sensor: application to elderly, post-stroke, Parkinson's disease and Huntington's disease subjects

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2 **Comparative assessment of different methods for the estimation of gait temporal parameters**  
3 **using a single inertial sensor: application to elderly, hemiparetic, parkinsonian and choreic gait**

4

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16

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**34 Abstract**

35 The estimation of gait temporal parameters with inertial measurement units (IMU) is a research topic  
36 of interest in clinical gait analysis. Several methods, based on the use of a single IMU mounted at  
37 waist level, have been proposed for the estimate of these parameters showing satisfactory  
38 performance when applied to the gait of healthy subjects. However, the above mentioned methods  
39 were developed and validated on healthy subjects and their applicability in pathological gait  
40 conditions was not systematically explored. We tested the three best performing methods found in a  
41 previous comparative study on data acquired from ten older adults, ten hemiparetic, ten Parkinson's  
42 disease and ten Huntington's disease subjects. An instrumented gait mat was used as gold standard.  
43 When pathological populations were analyzed, missed or extra events were found for all methods and  
44 a global decrease of their performance was observed to different extents depending on the specific  
45 group analyzed. The results revealed that none of the tested methods outperformed the others in  
46 terms of accuracy of the gait parameters determination for all the populations except the Parkinson's  
47 disease subjects group for which one of the methods performed better than others. The hemiparetic  
48 subjects group was the most critical group to analyze (stride duration errors between 4-5 % and step  
49 duration errors between 8-13 % of the actual values across methods). Only one method provides  
50 estimates of the stance and swing durations which however should be interpreted with caution in  
51 pathological populations (stance duration errors between 6-14 %, swing duration errors between 10-  
52 32 % of the actual values across populations).

53

## 54 **1. Introduction**

55 The assessment of the temporal and spatial parameters of gait is commonly considered of primary  
56 importance in clinical gait analysis since it contributes to the quantitative characterization of many  
57 common gait abnormalities. The determination of these parameters requires the detection of the  
58 initial and final foot contacts (IC and FC), usually referred to as gait events (GEs). Inertial  
59 measurement units (IMUs), including miniature gyroscopes and accelerometers, have been  
60 increasingly employed to this purpose thanks to their high wearability, reduced cost and low power  
61 consumption. The use of IMU technology is particular promising for the evaluation of gait  
62 parameters while monitoring daily life activities [1–3]. In the latter context, the instrumental setup  
63 should be even less invasive and cumbersome than in the laboratory setting, directing researchers and  
64 developers towards the use of a single IMU. To minimally alter the subject's gait, a single IMU is  
65 often attached at the waist level so that the impact of both feet could be detected [4]. A downside of  
66 this solution is the difficulty to implement a robust and accurate method for identifying GEs, since in  
67 general, the farther from the ground the IMU location, the more difficult the parameters  
68 determination is.

69 In normal gait, some features of the lower trunk acceleration patterns (e.g., peaks, zero crossings)  
70 were consistently associated with the occurrences of ICs and FCs [4–8]. These observations have led  
71 several authors to propose methods for the detection of GEs and/or the estimate of temporal gait  
72 parameters from the acceleration signals of a single IMU mounted at the waist level [9–15]. In a  
73 previous study [16], we evaluated the performance of five selected methods employing a single IMU  
74 [17,10–13] for detecting GEs and estimating gait temporal parameters on a group of healthy young  
75 subjects. The comparison was carried out in terms of sensitivity and positive predicted values in  
76 detecting GEs, accuracy in estimating gait temporal parameters, and robustness with respect to the  
77 IMU positioning. The results reported in [16] showed an acceptable accuracy, sensitivity and  
78 robustness of all the evaluated methods in determining those gait temporal parameters based on the  
79 identification of ICs (e.g., stride duration), while a lower accuracy in determining the temporal  
80 parameters which also require the FCs identification (e.g., stance duration) was found.

81 The above mentioned methods were developed and validated on healthy young or elderly subjects  
82 and their applicability in pathological gait conditions was not systematically explored. The only  
83 exception is the method proposed by [9] which was later applied to pathological groups, such as  
84 amputees [18], various neurological patients [19], or patients with Parkinson's disease [20]. In most  
85 cases, only average values of the gait parameters were analyzed and caution in interpreting gait  
86 parameters was often recommended [18,19]. It seems that these methods cannot simply be extended  
87 to the analysis of pathological gaits.

88 Indeed, in some gait pathologies, deviations of the acceleration patterns (e.g., smaller amplitudes,  
89 higher variability) from those typically observed in normal gait are not negligible [21,22]. Such  
90 deviations are often due to impairments and consequent compensatory strategies. For example,  
91 hemiparetic gait is often characterized by an increased lateral displacement of the foot during swing  
92 in the paretic limb, consistently with limb vaulting to further assist limb clearance [23]. Other gait  
93 abnormalities, such as choreiform gait, also known as "drunken gait", are characterized by staggering  
94 from side to side, with lateral swaying, and stride-by-stride lateral deviations from forward direction  
95 during walking [24], while parkinsonian gait is generally characterized by small shuffling steps and a  
96 stooped posture [25].

97 The gait abnormalities described above reflect in changes of the trunk acceleration waveforms  
98 which can potentially affect the performances of the single IMU based methods, thus limiting their  
99 applicability in the clinical setting. The aim of this work was to propose a comparative analysis of  
100 selected single IMU based methods for estimating gait temporal parameters in different pathological  
101 gait conditions. To this purpose, based on the findings reported in [16], the three best performing  
102 previously tested methods [9,11,12] were applied to the gait data of ten patients with hemiparesis, ten  
103 patients with Parkinson's disease, ten patients with Huntington's disease, and ten healthy elderly.

104 For each method, we evaluated the number of missed and extra GEs, along with the total number  
105 of GEs as detected by an instrumented gait mat, used here as a gold standard. The accuracy,  
106 associated with the GEs and temporal gait parameters determination, was evaluated against reference  
107 data provided by the instrumented mat. Comparative evaluations across methods within populations  
108 (Which is best performing algorithm for a given population?) and within methods for the different  
109 populations (Does a specific algorithm perform better for a given population?) were also performed.

110

## 111 **2. Materials and Methods**

### 112 ***2.1 Tested methods***

113 Schematic descriptions of the Z-method [9], S-method [11] and M-method [12] are reported in  
114 Table 1; additional details can be found in the literature.

115

**TABLE 1 ABOUT HERE**

### 116 ***2.2. Data collection protocol***

#### 117 *Instrumentation*

118 A single IMU (Opal™, APDM) featuring a 3-axis accelerometer and 3-axis gyroscope (unit weight  
119 22 g, unit size 48.5×36.5×13.5 mm) was positioned over the subject's lumbar spine, between L4 and  
120 S2, using a semi-elastic waist belt. For the selected methods, the robustness to the IMU positioning  
121 along the lower trunk was found not to be a critical factor [16]. Sampling frequency was set at 128  
122 Hz and accelerometer range at ±6 g. A spot check of the MIMU performance was performed  
123 according to the guidelines proposed by [26]. An instrumented gait pressure mat (GAITRite™  
124 Electronic Walkway, CIR System Inc) acquiring at 120 Hz (spatial resolution accuracy: ±12.7 mm;  
125 time accuracy: ±1 sample) was used to acquire reference data. The instrumented mat returned all GEs  
126 and temporal parameters analyzed. The IMU and the instrumented mat were synchronized (±1  
127 sample).

### 128 *Subjects*

129 Ten hemiparetic subjects (HE) (two females, eight males; mean (*sd*) age: 58.6 (12.1) y.o., height:  
130 1.72 (0.06) m, mass: 82.5 (15.9) kg), ten subjects with Parkinson's disease (PD) (five females, five  
131 males; mean (*sd*) age: 73.8 (5.7) y.o., height: 1.66 (0.10) m, mass: 67.7 (9.3) kg), ten subjects with  
132 Huntington's disease (HD) (five females, five males; mean (*sd*) age: 50.3 (13.3) y.o., height: 1.63  
133 (0.05) m, mass: 60.6 (12.2) kg), and ten healthy elderly (EL) (six females, four males; mean (*sd*)  
134 age: 69.7 (5.8) y.o., height: 1.62 (0.08) m, mass: 63.6 (5.7) kg) were enrolled from the out-patient  
135 Movement Disorders Clinic of the University of Genoa. Disease severity was determined by means  
136 of the Functional Ambulatory Category (FAC) [27] for the HE subjects (3.3±1.5), the Unified  
137 Huntington's Disease Rating Scale (UHDRS) [28] for the HD subjects (62.7±19.1) and the Unified  
138 Parkinson's Disease Rating Scale (UPDRS) [29] for the PD subjects (34.9±16.9). The Declaration of  
139 Helsinki was respected, all subjects provided informed written consent, and local ethic committee  
140 approval was obtained.

### 141 *Acquisition protocol*

142 Subjects were asked to walk back and forth for about one minute along a 12-meter walkway with  
143 the instrumented mat placed two meters from the starting line where they stood with their feet  
144 together for a few seconds after the beginning of the IMU acquisition. Subjects walked at self-  
145 selected, comfortable speed, wearing their own shoes. Walking aids such as canes or tripods were  
146 allowed if used in daily life. A single trial including several gait cycles was recorded for each subject.

### 147 **2.3 Data analysis**

148 All the methods analyzed provided an estimate of the stride and step durations. In particular, the  
149 Z-method and M-method define the gait cycle from the IC timing, conversely, the S-method

150 identifies the zero-crossing instants of the acceleration norm (these instants occur in the proximity of  
 151 the IC). Since only M-method provides FC timing estimates, stance and swing duration were  
 152 estimated only for this method.

### 153 *Number of missed and extra GEs*

154 The number of actual GEs (*act-GE*) were provided by the gold standard ( $N_{act-GE}$ ). They could  
 155 either be detected (*det-GE*) or missed (*mis-GE*) by each of the methods ( $N_{det-GE}$ ,  $N_{mis-GE}$ ). The GEs  
 156 estimated (*est-GE*) by each method ( $N_{est-GE}$ ) could be either detected or extra GEs (*ext-GE*) ( $N_{ext-GE}$ ).  
 157 The following relationships exist:

$$\begin{aligned}
 158 \quad & 0 \leq N_{det-GE} \leq N_{act-GE}; \\
 159 \quad & 0 \leq N_{mis-GE} \leq N_{act-GE}; \\
 160 \quad & N_{est-GE} = N_{det-GE} + N_{ext-GE};
 \end{aligned}
 \tag{1}$$

161 When neither mis-GEs nor ext-GE are present, the estimated GEs coincide with the act-GEs.

### 162 *Accuracy of the temporal parameters estimates*

163 For each method, the differences between the IC timing, stride and step duration estimates (plus  
 164 FC timing, stance and swing duration for M-method) and the relevant gold standard values were  
 165 calculated. In the EL, HD and PD subjects left and right sides were not differentiated, conversely for  
 166 the HE subjects, the results relative to the affected and non-affected sides were considered separately.  
 167 For each subject and each tested method, the errors ( $e$ ) of the estimated GEs and gait temporal  
 168 parameters were computed as the averages of the above mentioned differences over the recorded gait  
 169 cycles. Their group mean ( $\mu$ ), standard deviation ( $sd$ ), mean absolute error ( $mae$ ) and the relevant  
 170 percent error ( $mae\%$ ) were then computed.

### 171 *Statistical analysis*

172

#### 173 Comparative evaluations across methods within populations

174 To verify if differences among methods were present, the following statistical tests were  
 175 performed (affected and non-affected side for the HE group were dealt with separately).

176 A Wilcoxon signed-rank test was used to compare the  $mae$  values of the IC timings obtained with  
 177 Z-method and M-method. Differences were considered significant if the p-value was less than 0.05.  
 178 A Friedman test for non-normal distribution was used to compare the  $mae$  values obtained for the  
 179 stride and step duration estimates across all methods for each subject group. A post-hoc analysis  
 180 (Wilcoxon signed-rank test) was then performed. A Bonferroni Holm's correction for multiple  
 181 comparisons was also applied.

182

183 Comparative evaluations within methods for the different populations

184 To verify if errors obtained for each of the pathological groups were larger than those obtained for  
185 the EL group, for each method a Wilcoxon rank sum test was performed on the *mae* values found for  
186 the GEs and the gait temporal parameters. A Wilcoxon signed rank test was also performed to reveal  
187 differences between the *mae* values obtained for the affected and unaffected side in the HE subjects.  
188 Differences were considered significant if the p-value was less than 0.05.

189

190 **3. Results**

191 Over 2,253 gait cycles were obtained with the instrumented mat and used for the comparative  
192 analysis. The total number of gait cycles analyzed for each subject group along with the descriptive  
193 statistics ( $\mu$  and *sd*) values of the temporal parameters (gait velocity, stride time, step time, stance  
194 time, swing time) as determined by the instrumented mat are reported in Table 2.

195 **TABLE 2 ABOUT HERE**

196 *Number of missed and extra GEs*

197 In Table 3 the number of mis-GEs and ext-GEs along with their percentage with respect to *act*-  
198 GEs and *est*-GEs for each subjects group and each method has been reported.

199 **TABLE 3 ABOUT HERE**

200 *Accuracy of the temporal parameters estimates*

201 Descriptive statistics ( $\mu$  and *sd*) of *e* and *mae* for IC timings, stride duration and step duration (for  
202 all methods) and FC timings, stance and swing time (for M-method) for all the subjects groups are  
203 reported in Table 4. The *mae%* values for stride and step durations are also reported for all the  
204 methods while *mae%* values for stance and swing durations are reported only for M-method. In Fig.1  
205 a five number summary statistics was used to represent the *mae* values in estimating stride and step  
206 durations for each subjects group and each method.

207 **TABLE 4 ABOUT HERE**

208 **FIGURE 1 ABOUT HERE**



## 209 *Statistical analysis*

210

### 211 Comparative evaluations across methods within populations

212 No significant differences were found in the *mae* values obtained for all the gait parameters  
213 between the tested methods for all the subject groups ( $p > 0.017$ ) except for the PD group for which  
214 (a) IC timing errors for the Z-method were smaller than the M-methods; (b) stride time errors for the  
215 M-method were smaller than the S-method; and (c) step time errors for the Z-method were smaller  
216 than the S-method.

217

### 218 Comparative evaluations within methods for the different populations

219 For the Z-method, the IC timing errors, the stride time and step time errors for the HD group  
220 resulted significantly larger than those obtained for the EL group.

221 For the S-method, the stride time and step time errors for the HE (both affected and non affected  
222 side) and PD groups resulted significantly larger than those obtained for the EL group.

223 For the M-method, the IC timing errors, the stride time and step time errors for all the pathological  
224 groups (HE, PD and HD) were significantly larger than those obtained for the EL group. In addition,  
225 both stance and swing duration errors were significantly larger for the pathological groups.

226

## 227 **4. Discussion**

228 In the healthy elderly group, no missed or extra events were found for any of the tested methods,  
229 confirming previous results in healthy young adults [16]. It should be noticed that in the present  
230 study, the acceleration signals were filtered before processed using the Z-method (high pass filter,  
231 cut-off frequency 1 Hz [30]). This simple solution is extremely helpful when using the Z-method  
232 since it prevents from extra events detection associated to erroneous zero-crossing values due to the  
233 signal offset. In healthy elderly, no significant differences were found for IC timings estimate errors  
234 across methods. All methods showed a good accuracy level when estimating the stride duration  
235 (*mae%* values  $< 2\%$ ) and an acceptable accuracy level for the step duration (*mae%* values  $< 4\%$ ).  
236 Slightly larger errors were observed for the swing duration estimates provided by the M-method  
237 (*mae%* values  $< 5\%$ ).

238 Conversely, when pathological populations were analyzed, missed or extra events were found and  
239 a global decrease of performance was observed to different extents depending on the specific group  
240 analyzed. The results revealed that the hemiparetic subjects group is the most critical group to  
241 analyze. In particular, the hemiparetic subjects group showed a moderate number of missed ICs when

242 the Z- and M- methods were applied (respectively 6% and 5% of the act-ICs), and a high number of  
243 extra ICs when the S- and M methods was applied (30% and 11% of the est-ICs). The M-method also  
244 returned a high number of extra FCs (13% of the det-FCs). Conversely, all methods perform very  
245 well in terms of ICs detection when applied to the Parkinson's disease and Huntington's disease  
246 subjects groups with the only exception of the S-method which found a moderate number of extra  
247 ICs (respectively 6% and 8% of the Est-ICs). The presence of the significantly high number of  
248 missed and extra events in the hemiparetic subjects can be explained by trunk acceleration patterns  
249 that are much more irregular compared to normal gait also due to the use of walking aids and by the  
250 lowest gait speed which causes a signal attenuation (mean gait speed of 0.6 m/s). On the contrary,  
251 Parkinson's disease subjects group showed the most similar performances for all the tested methods  
252 with respect to the healthy elderly group. It is worth to notice that the presence of missed or extra  
253 GEs could greatly affect the validity of the gait temporal parameters estimates. In fact, since the gait  
254 cycle and each sub-phase (i.e. step, stance and swing durations) are identified starting from the IC  
255 and FC timings, if any missed or extra event is present in the data, the gait parameters estimation will  
256 be incorrect (i.e., longer or shorter stride/step/stance/swing time or higher or smaller number of gait  
257 cycles). This would potentially weaken the clinical applicability. Furthermore, the presence of extra  
258 or missed events can be especially critical when functional electrical stimulation is adopted for a  
259 proper and timely dispensing of the electrical stimuli during walking, for example [6,31].

260 None of the tested methods outperformed the others in terms of accuracy of the gait parameters  
261 determination for all the populations except the Parkinson's disease subjects group. A general  
262 decrease of the methods accuracy was observed when they were applied to pathological groups with  
263 respect to healthy elderly. The accuracy analysis confirmed that the hemiparetic subjects group was  
264 the most critical one for all methods and the largest errors were found for the affected side (mae%  
265 between 4% and 5% for the stride time and between 8% and 13 % for the step time). The errors were  
266 even larger for the estimates of the stance and swing durations provided by the M-method (mae%  
267 between 10% and 32%).

268 For the Parkinson's disease subjects group, the Z-method performed relatively better than the other  
269 methods, reporting absolute errors comparable with those obtained in the healthy elderly group. No  
270 clear trends emerged for the Huntington's disease subjects group. The errors, affecting the estimates  
271 of the stance and swing durations provided by the M-method, were found to be significantly larger in  
272 the pathological groups with respect to the healthy elderly group.

273 In summary, on the basis of the results of this study, the following remarks can be drawn:

274 1) The analysis of the gait of hemiparetic subjects using a single inertial unit worn on the lower  
275 back can be critical both in terms of missed/extra gait events and temporal parameters accuracy  
276 irrespective of the method employed.

277 2) The Z-method, including a preliminary filtering of the acceleration signals, should be preferred  
278 when analyzing Parkinson's disease population.

279 3) The estimate of the stride duration is more reliable and valid than the step duration.

280 4) The estimates of the stance and swing durations in pathological population are not be reliable.

281 It is important to note that the results reported in the present study are referred to a straight level  
282 walking. During daily life when the subject varies the direction of progression and keeps stopping  
283 and starting, the methods performance are expected to decrease.

284 In conclusion, when highly impaired gait is analyzed (e.g. hemiparetic subjects), methods  
285 employing two inertial units on each leg should be preferred, at least for those gait parameters related  
286 to the accurate detection of both the ICs and FCs (e.g. stance time). In this regard, it has been recently  
287 shown [32] on similar pathological populations, that by exploiting some lower limb invariant  
288 kinematic characteristics, both missed and extra events can be avoided and that the errors can be  
289 reduced to 1% for the stride duration, 2-3 % for the step and stance durations and 6-7% for the swing.

290

#### 291 **Conflict of interests**

292 The authors declare that they have no conflict of interests.

293

294

295 **References**

296

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383

Table 1: Description of the tested gait event detection methods

	<b>sensor type</b>	<b>sampling rate [Hz]</b>	<b>sensor position</b>	<b>estimated GEs</b>	<b>evaluated signals</b>	<b>alghoritm features</b>	<b>estimated parameters</b>
Z-method* [9]	3-axis acc	100	S2	IC	antero-posterior acceleration	zero crossing, peak detection	GEs detection; mean step length estimate
S-method [11]	3-axis acc	50	waist	IC	acceleration norm	sliding window summation, zero crossing	step length estimate
M-method [12]	IMU	100	L5	IC; FC	vertical acceleration	Gaussian CWT, minima and maxima	GEs detection

(\*) The acceleration signals were filtered before processed (high pass filter, cut-off frequency 1 Hz [30]).

Table 2: Number of gait cycles and mean (*sd*) of gait velocities, stride time, step time, stance time and swing time for all groups (healthy elderly – EL, hemiparetic – HE, Parkinson's disease – PD and Huntington's disease – HD).

Group	gait cycles	gait velocity [m/s]	Stride time [s]	Step time [s]	Stance time [s]	Swing time [s]
<b>EL</b>	574	1.17 (0.16)	1.05 (0.10)	0.53 (0.05)	0.68 (0.07)	0.38 (0.03)
<b>HE *</b>	576	0.61 (0.24)	1.35 (0.24)	0.67 (0.12)	0.94 (0.17)	0.41 (0.10)
<b>PD</b>	532	0.85 (0.14)	1.14 (0.09)	0.57 (0.05)	0.76 (0.07)	0.38 (0.03)
<b>HD</b>	567	1.08 (0.30)	1.11 (0.14)	0.56 (0.07)	0.71 (0.10)	0.40 (0.05)

(\*) Six hemiparetic subjects used a walking aid during the data acquisition sessions



384 Table 3: Missed and extra GEs for all methods and their percentage (light gray: 1-3%; medium  
 385 gray: 4-8%; dark gray: >9%) with respect to the number of actual and estimated GEs  
 386 obtained for all groups (healthy elderly - EL, hemiparetic - HE, Parkinson's disease - PD  
 387 and Huntington's disease - HD).  
 388

Method/GE	% of		% of		
	mis-GE	act-GE	ext-GE	est-GE	
Z-method/IC	EL	0	0.0%	0	0.0%
	HE	37	6.4%	5	0.9%
	PD	0	0.0%	1	0.2%
	HD	5	0.9%	5	0.9%
S-method/IC	EL	0	0.0%	0	0.0%
	HE	3	0.5%	250	30.4%
	PD	2	0.4%	36	6.4%
	HD	1	0.2%	50	8.1%
M-method/IC	EL	0	0.0%	0	0.0%
	HE	27	4.7%	13	2.3%
	PD	6	1.1%	0	0.0%
	HD	4	0.7%	3	0.5%
M-method/FC	EL	0	0.0%	0	0.0%
	HE	0	0.0%	73	11.2%
	PD	0	0.0%	0	0.0%
	HD	1	0.2%	5	0.9%

389

Table 4: Mean ( $\mu$ ) and standard deviation ( $sd$ ) of the error and mean absolute error (MAE) in estimating IC timing, stride and step duration with all the methods (Z-Method, S-Method, M-Method) and FC timing, stance and swing duration with M-Method for all groups (healthy elderly - EL, hemiparetic - HE, Parkinson's disease - PD and Huntington's disease - HD). The percent mean absolute error MAE% values for stride, step, stance and swing duration estimates are also reported (light gray: 1-3%; medium gray: 4-8%; dark gray: >9%). Affected (bold) and non affected side estimate errors obtained for the H group are reported separately. Quantities are in milliseconds.

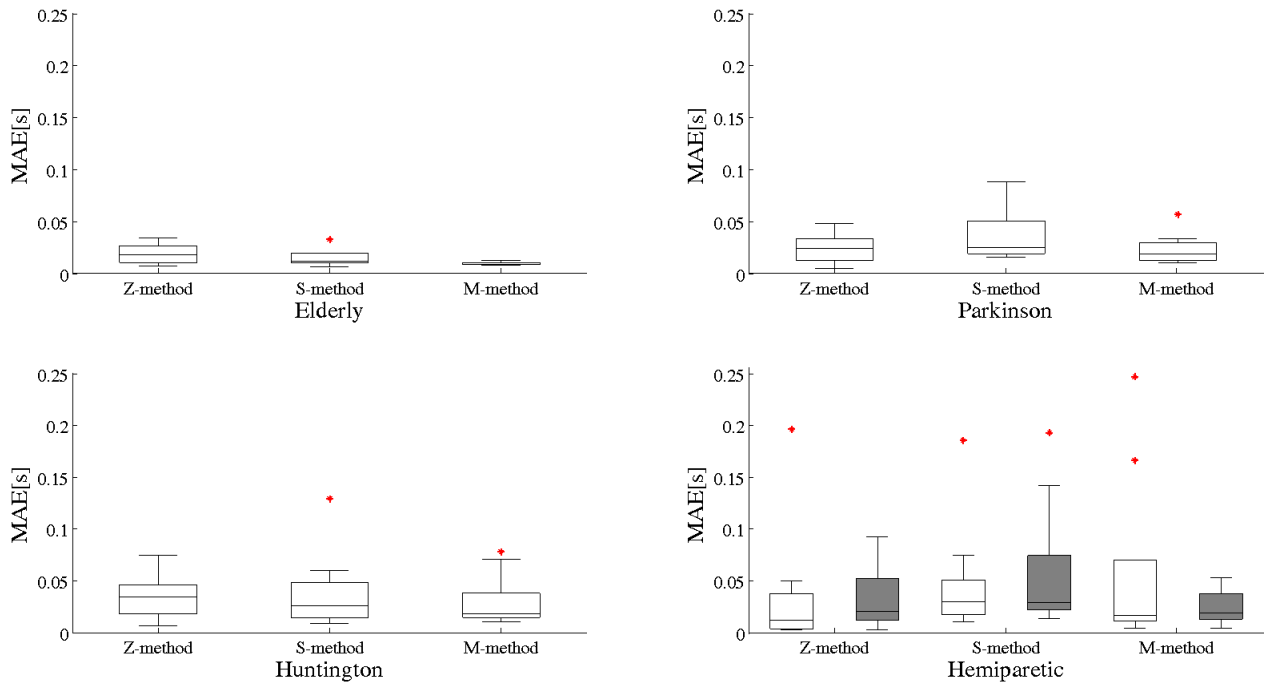
390

Method		IC		stride time			step time			FC		stance time			swing time		
		$\mu$ (sd)	MAE	$\mu$ (sd)	MAE	MAE%	$\mu$ (sd)	MAE	MAE%	$\mu$ (sd)	MAE	$\mu$ (sd)	MAE	MAE%	$\mu$ (sd)	MAE	MAE%
Z-method	EL	-7 (30)	21	0 (33)	20	2%	0 (36)	23	4%	-	-	-	-	-	-	-	-
	HE	-11 (47)	33	1 (50)	22	2%	29 (138)	59	9%	-	-	-	-	-	-	-	-
		<b>-84 (177)</b>	<b>100</b>	<b>2 (121)</b>	<b>52</b>	<b>4%</b>	<b>-29 (135)</b>	<b>57</b>	<b>8%</b>	-	-	-	-	-	-	-	-
	PD	-7 (33)	25	0 (38)	24	2%	0 (38)	25	4%	-	-	-	-	-	-	-	-
HD	-40 (60)	47	1 (68)	37	3%	0 (74)	46	8%	-	-	-	-	-	-	-	-	
S-method	EL	137 (51)	137	0 (23)	14	1%	0 (25)	17	3%	-	-	-	-	-	-	-	-
	HE	157 (86)	162	-4 (100)	42	3%	21 (121)	80	12%	-	-	-	-	-	-	-	-
		<b>131 (114)</b>	<b>155</b>	<b>-1 (140)</b>	<b>73</b>	<b>5%</b>	<b>-26 (139)</b>	<b>84</b>	<b>12%</b>	-	-	-	-	-	-	-	-
	PD	183 (65)	186	1 (69)	36	3%	1 (83)	49	9%	-	-	-	-	-	-	-	-
HD	138 (75)	146	0 (80)	37	3%	1 (109)	57	10%	-	-	-	-	-	-	-	-	
M-method	EL	42 (23)	43	0 (13)	10	1%	0 (16)	13	2%	36 (29)	42	-6 (29)	21	3%	7 (28)	20	5%
	HE	72 (62)	81	4 (78)	26	2%	66 (170)	89	13%	-4 (78)	58	-75 (103)	94	10%	79 (99)	94	23%
		<b>-5 (177)</b>	<b>112</b>	<b>1 (185)</b>	<b>69</b>	<b>5%</b>	<b>-62 (175)</b>	<b>90</b>	<b>13%</b>	<b>-32 (107)</b>	<b>68</b>	<b>-27 (189)</b>	<b>133</b>	<b>14%</b>	<b>28 (190)</b>	<b>132</b>	<b>32%</b>
	PD	65 (68)	75	1 (69)	24	2%	0 (91)	34	6%	34 (33)	40	-31 (70)	47	6%	32 (68)	46	12%
HD	57 (62)	68	0 (73)	29	3%	-2 (66)	31	5%	50 (40)	56	-10 (68)	39	6%	10 (68)	38	10%	

Figure 1: Minimum, first quartile ( $q_1$ ), median, third quartile ( $q_3$ ) and maximum values of: (a) stride time estimate mean absolute errors ( $MAE$ ) as obtained from each of the tested methods for each subjects group (Elderly, Parkinson, Huntington, Hemiparetic); (b) step time estimate mean absolute errors ( $MAE$ ) as obtained from each of the tested methods for each subjects group (Elderly, Parkinson, Huntington, Hemiparetic). Errors larger than  $q_1+1.5(q_3+q_1)$  or smaller than  $q_1-1.5(q_3-q_1)$  are considered outliers and represented with stars. Methods are listed in the x-axis of the plots and represented by the relevant initial. Affected (gray box) and non affected side estimate errors obtained for the hemiparetic group are reported separately.

Figure 1

(a)



(b)

