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1 **Center-of-pressure regularity as a marker for attentional investment in postural**  
2 **control: a comparison between sitting and standing postures**

3  
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28 **Abstract**

29 Postural control is a highly automatized basic activity that requires limited attentional  
30 investments. These investments have been shown to increase from balancing experts to  
31 controls, and from controls to persons with impaired postural control. Such between-  
32 subject comparisons led to a proposed direct relation between the regularity of center-of-  
33 pressure (COP) fluctuations and the amount of attention invested in posture. This study  
34 aims to expand this relation to a within-subject comparison of conditions that differ in  
35 balance demands. Specifically, more regular COP fluctuations were expected for standing  
36 than sitting, as stimulus-response reaction-time studies showed that the required  
37 attentional demands are lower for sitting than standing. COP registrations were made for  
38 fifteen healthy adults in seated and standing postures. COP regularity was quantified with  
39 sample entropy. As expected, COP fluctuations were found to be more regular for  
40 standing than sitting, as evidenced by significantly lower sample entropy values. These  
41 findings expand the relation between COP regularity and the amount of attention invested  
42 in posture to postural tasks that vary in balance demands. An assessment of COP  
43 regularity may thus not only be instrumental in the examination of attentional investment  
44 in posture in between-subject designs, but also for different postures in within-subjects  
45 designs.

46

47 **Keywords:** postural control; attentional investment; center-of-pressure regularity; sitting;  
48 standing

49

## 50 **1. Introduction**

51 The control of everyday basic activities like sitting, standing, and walking is typically  
52 taken for granted. This is understandable from the fact that underlying control processes  
53 are largely autonomous and automatic, controlled without placing a substantial cognitive  
54 burden or attentional demand on the controller. Automaticity of control is functional as it  
55 allows for simultaneous performance and control of concurrent, commonly more  
56 attention-demanding tasks, such as talking to the phone, reading the newspaper, or  
57 holding a cup of coffee. Investigations using dual-task paradigms, however, made  
58 apparent that the control of abovementioned basic activities is not entirely automatic, but  
59 often requires attentional or cognitive resources (see Woollacott & Shumway-Cook, 2002,  
60 for a review). Several of those investigations used stimulus-response reaction times to  
61 operationalize attentional investment, which typically increased from sitting to standing  
62 to walking (e.g., Lajoie, Teasdale, Bard, & Fleury, 1993, 1996). The degree of cognitive  
63 investment also has been reported to vary with health status and expertise; attentional  
64 investment is typically greater for pathological groups than controls (e.g., Brown, Sleik,  
65 & Winder, 2002; stroke patients); Redfern, Talkowski, Jennings, & Furman, 2004;  
66 patients with unilateral vestibular loss), and smaller for experts than controls (e.g.,  
67 Vuillerme & Nougier, 2004; gymnasts). This is particularly well-documented for postural  
68 control, revealing that performing secondary tasks while sitting or standing impacts upon  
69 either postural performance, secondary task performance, or both (cf. Fraizer & Mitra,  
70 2008 for a review). Groups with impaired postural control (e.g., fall-prone elderly, stroke  
71 patients) are more affected by posture-cognition dual-tasking than controls (e.g., Brown  
72 et al., 2002; Huxhold, Li, Schmiedek, & Lindenberger, 2006; Lacour, Bernard-Demanze,

73 & Dumitrescu., 2008), whereas attentional effects in balancing experts (e.g., gymnasts,  
74 ballet dancers) have only been reported in more difficult postural configurations like  
75 standing on one leg (Stins, Michielsen, Roerdink, & Beek, 2009; Vuillerme & Nougier,  
76 2004).

77 Interestingly, the dynamical structure of center-of-pressure (COP) profiles during  
78 quiet standing, in particular its regularity, was recently found to be positively related to  
79 the amount of attention invested in postural control (e.g., Donker, Ledebt, Roerdink,  
80 Savelsbergh, & Beek, 2008; Donker, Roerdink, Greven, & Beek, 2007; Roerdink et al.,  
81 2006; Stins et al., 2009). COP regularity can for example be computed by means of  
82 sample entropy, approximate entropy, and recurrence quantification analysis, yet –largely  
83 independent of differences in methodology– posturograms were found to be more regular  
84 in pathological groups than controls (e.g., Cavanaugh et al., 2006; Donker et al., 2008;  
85 Roerdink et al., 2006; Schmit et al., 2006), less regular in balance experts than controls  
86 (Schmit, Regis, & Riley, 2005; Stins et al., 2009), and less regular when attention was  
87 experimentally withdrawn from posture using secondary tasks (Cavanaugh, Mercer, &  
88 Stergiou, 2007; Donker et al., 2007; Roerdink et al., 2006; Stins et al., 2009). Clearly, the  
89 COP regularity findings for these between-subject and within-subject comparisons are  
90 congruent with the aforementioned stimulus-response results.

91 The purpose of the present experiment was to extend this line of research by  
92 comparing COP regularity between sitting and standing postures. To this end, we  
93 operationalized COP regularity in terms of sample entropy (see Methods for more details),  
94 a measure of time-series regularity developed by Richman and Moorman (2000). The  
95 balance demands required for sitting and standing postures differ considerably in

96 mechanical terms, mainly because the center of mass is positioned closer to the base of  
97 support when seated (cf. Genthon & Rougier, 2006). As a consequence, adverse effects  
98 of internal or external perturbations are less pronounced in a seated position. Interestingly,  
99 numerous stimulus-response reaction-time studies showed that the attentional demand  
100 required for controlling a sitting posture is lower than that required for controlling a  
101 standing posture (Lajoie et al., 1993, 1996; Teasdale, Bard, LaRue, & Fleury, 1993;  
102 Vuillerme & Nougier, 2004; Vuillerme, Forestier, & Nougier, 2002; Vuillerme, Isableu,  
103 & Nougier 2006), which is at least to some extent related to the aforementioned  
104 mechanical difference in imposed balance demands between the two postures. Thus, in  
105 line with the proposed relation between COP regularity and the amount of attention  
106 invested in posture (Donker et al., 2007, 2008; Roerdink et al., 2006; Stins et al., 2009),  
107 we hypothesized that COP trajectories were more regular (lower sample entropy) for the  
108 standing than for the sitting posture, as the former posture is associated with a greater  
109 attentional investment (e.g., Lajoie et al., 1993, 1996; Teasdale et al., 1993; Vuillerme &  
110 Nougier, 2004; Vuillerme et al., 2002, 2006).

111

## 112 **2. Methods**

113 *Participants.* Fifteen healthy young male adults participated in the study (age (mean  $\pm$   
114 *SD*):  $22 \pm 1$  years; body weight:  $77 \pm 5$  kg; height:  $178 \pm 5$  cm). They were naïve as to the  
115 purpose of the study. They gave their written informed consent to the experimental  
116 procedure as required by the Helsinki declaration and the local Ethics Committee. None  
117 of the subjects presented a history of motor problems, neurological disease, or visual or  
118 vestibular impairments.



119

120 *Experimental procedure.* Participants were asked to complete two postural conditions:  
121 sitting and standing. For the sitting task, participants were seated on a force platform  
122 (Equi+, PF01, Aix les Bains, France) positioned on a rigid table border 1 m above the  
123 floor with their back unsupported and the arms crossed over the abdomen. The proximal  
124 part of the thighs was supported by the force platform (i.e., distance between border of  
125 the force platform and the popliteus hollows corresponded to one-third of the thigh length)  
126 while the shanks and feet dangled unsupported (cf., Genthon & Rougier, 2006; Genthon,  
127 Vuillerme, Monnet, Petit, & Rougier, 2007). In the standing task, participants stood  
128 barefoot on the same force platform (now situated on the ground) in a natural position  
129 (feet abducted at 20°, heels 3 cm apart) with the arms hanging loosely at the sides. In  
130 both postural conditions, the healthy young participants had their eyes closed to reduce  
131 the likelihood of potential ceiling effects in attentional investments and/or COP regularity.  
132 Participants were instructed to minimize trunk and body motion for sitting and standing  
133 tasks, respectively. Trial duration was 32 s and anterior-posterior (AP) and medio-lateral  
134 (ML) COP trajectories were registered at a sampling rate of 64 Hz. The order of sitting  
135 and standing conditions was randomized over participants.

136

137 *Data analysis.* The AP and ML COP time series were linearly detrended and centered on  
138 zero mean prior in order to construct the resultant distance (RD) COP time series.  
139 Specifically, RD is the vector distance from the center of the posturogram to each pair of  
140 points in the AP and ML time series and is hence not sensitive to the orientation of the  
141 base of support with respect to force platform (Prieto, Myklebust, Hoffmann, Lovett, &

142 Myklebust, 1996). The “amount of sway” was quantified by means of two conventional,  
143 scale-dependent measures (see Prieto et al., 1996). First, the average COP distance to the  
144 origin of the mean-centered posturogram was determined by taking the mean of the RD  
145 time series (i.e., mean amplitude in mm). Second, path length (mm) was determined by  
146 taking the sum of the distances between consecutive points in the conventional  
147 posturogram (Prieto et al., 1996).

148 To examine the structure of COP trajectories in more detail, independent of its  
149 size or scale, two scale-independent COP measures were quantified. To this end, AP and  
150 ML time series were normalized to unit variance by dividing those time series by their  
151 respective standard deviations, resulting in a normalized posturogram. Subsequently, the  
152 path length of the normalized posturogram was determined in a similar manner as  
153 described above for the conventional posturogram. Since posturograms were normalized  
154 to unit variance, differences in path length could only be the result of changes in the  
155 structure of the posturogram, with a longer path in the normalized posturogram indicating  
156 a larger amount of “twisting and turning” or “curviness” in the COP trajectory (cf.,  
157 Donker et al., 2007, 2008).

158 Second, sample entropy was quantified for RD distance time series and, in view  
159 of the potential non-stationary nature of COP trajectories (Ramdani, Seigle, Lagarde,  
160 Bouchara, & Bernard, 2009), also for RD increment time series. Both RD distance and  
161 increment time series were normalized to unit variance and algorithms of Lake and  
162 colleagues (Lake, Richman, Griffin, & Moorman, 2002; Richman, Lake, & Moorman,  
163 2004) were used to estimate corresponding sample entropy values. Specifically, sample  
164 entropy is quantified as the negative natural logarithm of the conditional probability (CP

165 =  $A/B$ ) that a dataset of length  $N$ , having repeated itself within a tolerance  $r$  for  $m$  points,  
166 will also repeat itself for  $m + 1$  points, without allowing self-matches (see also Lake et al.,  
167 2002; Richman & Moorman, 2000). Accordingly,  $B$  represents the total number of  
168 matches of length  $m$  while  $A$  represents the subset of  $B$  that also matches for  $m + 1$ .  
169 Sample entropy thus follows from  $-\log(A/B)$ , with a low sample entropy value arising  
170 from a high probability of repeated template sequences in the data. In this context,  
171 entropy is the rate of generation of new information and the lower the entropy the greater  
172 the regularity of the time series in question.

173         Parameter choice of  $m$  and  $r$  was optimized to ensure that the number of matches  
174 remains large enough for reliable sample entropy estimation. Increased number of  
175 matches of length  $m$  and  $m + 1$  (i.e., large  $B$  and  $A$  values) improve the accuracy and  
176 confidence of CP estimates, however, when  $m$  decreases and  $r$  increases (i.e., with  
177 relaxed criteria), the probability of matches tends toward 1 and sample entropy tends to 0,  
178 thereby losing discriminative power. Thus, sample entropy is best estimated with  $m$  as  
179 large and  $r$  as small as possible. Lake and colleagues (2002) introduced a statistical  
180 criterion to optimize the parameter choice, which is based on the maximum of the relative  
181 error of sample entropy and CP estimates. This metric simultaneously penalizes CP near  
182 0 and near 1 (Lake et al., 2002) and represents the tradeoff between accuracy and  
183 discriminative capability. The criterion was set to be no higher than .05, implying that the  
184 95% confidence interval of the sample entropy estimate is maximally 10% of its value  
185 (Lake et al., 2002; see also Ramdani et al., 2009; Roerdink et al., 2006).

186

187 *Statistics.* To evaluate the effect of sitting and standing postures, the two conventional  
188 (i.e., mean amplitude and path length) and the two scale-independent (i.e., normalized  
189 path length and sample entropy) posturographic measures were subjected to separate two-  
190 tailed paired-samples *t*-tests. Sample entropy for both RD distance and increment time  
191 series were independently subjected to these *t*-tests. Bonferroni correction was applied in  
192 view of the number of comparisons (i.e., *p*-value of .05/5). Values are reported as mean  $\pm$   
193 *SD*.

194

### 195 **3. Results**

196 Fig. 1 depicts conventional and normalized posturograms (upper panels) and  
197 corresponding RD distance time series (lower panels) for sitting and standing postures of  
198 a single representative participant. As can be appreciated from this figure, the size of  
199 conventional posturograms differs markedly between sitting and standing postures (cf.  
200 two upper left panels), as evidenced by considerably smaller RD amplitudes for sitting  
201 than standing (lower left panel). As a consequence of this amplitude discrepancy, path  
202 length of the conventional posturogram is much shorter for sitting than standing postures.  
203 These typical findings are supported by groups statistics: 1) mean RD amplitude is  
204 significantly smaller for sitting than standing postures ( $0.57 \pm 0.19$  vs.  $4.52 \pm 1.29$  mm,  
205  $t(14) = 12.37$ ,  $p < .0001$ ) and, 2) path length of the conventional posturogram is  
206 significantly shorter for sitting than standing postures ( $159 \pm 14$  vs.  $413 \pm 62$  mm,  $t(14) =$   
207  $16.67$ ,  $p < .0001$ ).

208

209

-Fig. 1-

210

211 After normalization to unit variance, the size of the posturograms does not differ  
212 between sitting and standing postures (two upper right panels of Fig. 1); hence, mean RD  
213 amplitudes are comparable for normalized posturograms (lower right panel). Interestingly,  
214 in contrast to conventional posturograms, path length of normalized posturograms is  
215 considerably larger for sitting than standing postures, indicative of more “twisting and  
216 turning” or “curviness” in the posturograms. This was supported statistically as the path  
217 of normalized posturograms was found to be significantly longer for sitting than standing  
218 postures ( $428 \pm 171$  vs.  $122 \pm 31$  a.u.,  $t(14) = 6.90$ ,  $p < .0001$ ).

219

220

-Fig. 2-

221

222 Fig. 2 depicts the outcome of the parameter optimization procedure. As can be  
223 appreciated from this figure, the maximum template length for which the median of the  
224 relative error meets the 0.05 criterion is  $m = 3$ , irrespective of whether RD distance or RD  
225 increment time series are used. Corresponding optimal tolerance range values are 0.06  
226 and 0.29, respectively (viz. minima in the  $m = 3$  curves). Sample entropy was thus  
227 determined using  $m = 3$  and  $r = 0.06$  for RD distance time series and  $m = 3$  and  $r = 0.29$   
228 for RD increment time series. As depicted in Fig. 3, sample entropy was larger for the  
229 sitting than for the standing posture for both RD distance (upper panels;  $1.61 \pm 0.22$  vs.  
230  $0.62 \pm 0.12$ ;  $t(14) = 20.39$ ,  $p < .0001$ ) and RD increment (lower panels;  $1.55 \pm 0.07$  vs.  
231  $1.17 \pm 0.15$ ;  $t(14) = 8.29$ ,  $p < .0001$ ) time series.

232

233 -Fig. 3-

234

#### 235 **4. Discussion**

236 The aim of this study was to examine COP regularity in sitting and standing postures in a  
237 group of young healthy participants. In doing so, we attempted to expand the relation  
238 between COP regularity and the amount of attention invested in posture for conditions  
239 that differ in balance demands. Numerous stimulus-response reaction time studies  
240 disclosed greater attentional investments for standing than sitting postures, as evidenced  
241 by increased reaction times in the former posture (e.g., Lajoie et al., 1993, 1996; Teasdale  
242 et al., 1993; Vuillerme & Nougier, 2004; Vuillerme et al., 2002, 2006). Considering the  
243 proposed direct relation between COP regularity and the amount of attention invested in  
244 posture (Donker et al., 2007, 2008; Roerdink et al., 2006; Stins et al., 2009), and in line  
245 with abovementioned results, we expected more regular COP fluctuations for the  
246 standing than for the sitting posture. COP regularity was quantified by means of sample  
247 entropy and the results were fully in line with the expectations. Indeed, sample entropy  
248 was significantly lower (indexing more regular COP fluctuations) for the standing than  
249 for the sitting posture, independent of whether RD distance or RD increment time series  
250 were used (the latter was included in view of the potential non-stationarity of COP time  
251 series during standing, cf. Ramdani et al., 2009). Moreover, conventional posturographic  
252 measures showed greater COP displacements for standing than sitting postures, as  
253 evidenced by significantly larger RD amplitude and path length. These conventional COP  
254 measures were complemented by the path length of the normalized posturogram (cf.  
255 Donker et al., 2007, 2008) to index the amount of “twisting and turning” or “curviness”

256 in the posturogram, independent of its size. The results were opposite to path lengths for  
257 conventional posturograms; the path of the normalized posturogram was longer for sitting  
258 than standing postures (Fig. 1), symptomatic of more “complex” posturograms in the  
259 former postural configuration. This observation is clearly in line with the more irregular  
260 posturograms for sitting than standing postures, as evidenced by higher sample entropy  
261 (Fig. 3), which is also a scale-independent measure.

262 On the whole, these results support the proposed relation between COP regularity  
263 and the amount of attention invested in posture (cf. Donker et al., 2007, 2008; Roerdink  
264 et al., 2006; Stins et al., 2009). Moreover, the results expand this relation to postural tasks  
265 that vary in balance demands. To date, evidence in favor of the COP-regularity /  
266 attentional-investment relation stemmed primarily from between-subject comparisons, in  
267 which COP regularity was compared between controls and experts (e.g., ballet dancers;  
268 Schmit et al., 2005; Stins et al., 2009), or between controls and patients (e.g., stroke  
269 patients, children with cerebral palsy, Parkinson’s patients, athletes with cerebral  
270 concussion; Cavanaugh et al., 2006; Donker et al., 2008; Roerdink et al., 2006; Roerdink,  
271 Geurts, de Haart, & Beek, 2009; Schmit et al., 2006). Recently, the relation was further  
272 validated by studies adopting a within-subject design with and without diverting attention  
273 experimentally from posture by means of a dual task (Cavanaugh et al., 2007; Donker et  
274 al., 2007; Roerdink et al., 2006; Stins et al., 2009). Moreover, a few longitudinal studies  
275 on clinical posturography showed that COP fluctuations become increasingly more  
276 irregular in the course of rehabilitation after stroke (Roerdink et al., 2006) or cerebral  
277 concussion (Cavanaugh et al., 2006), which is in line with the clinical observation that

278 with recovery the control of posture becomes less attention demanding (cf. Geurts, de  
279 Haart, van Nes, & Duysens, 2005, for a review on the recovery of posture after stroke).

280 With the present study, the relation between COP regularity and the amount of  
281 attention invested in posture was further corroborated by results arising from a within-  
282 subject design with different imposed balance demands acting on the postural task  
283 (control of sitting vs. standing postures). Hence, COP regularity may tentatively not only  
284 be employed as a measure to index differences in the amount of attention invested in  
285 posture between different groups of participants or with recovery during rehabilitation,  
286 but also between different postures within a group of participants. This expansion of the  
287 relation between COP regularity and the amount of attention invested in posture could  
288 have potential relevance for clinical posturography. That is, in rehabilitation settings the  
289 amount of attention invested in the control of upright quiet stance under different base of  
290 support configurations (i.e., standing with the feet apart, with the feet together, or in  
291 tandem stance) may possibly be evaluated simply by examining COP regularity.  
292 Nevertheless, future studies are first required to validate the use of sample entropy as a  
293 marker of the amount of attention invested in posture against a gold standard stemming  
294 from stimulus-response reaction time tasks. In addition, the question which marker (i.e.,  
295 sample entropy vs. stimulus-response reaction time) is most sensitive and reliable in the  
296 evaluation of the amount of attention invested in posture needs to be addressed prior to  
297 widespread application of sample entropy in clinical posturography.

298 Ramdani and colleagues (2009) recently proposed to apply sample entropy  
299 analyses to COP increment time series rather than the raw position time series in view of  
300 the possible non-stationary nature of the latter due to long-range correlations. Indeed,



301 Govindan, Wilson, Eswaran, Lowery, and Preißl (2007) showed that such correlations  
302 may lead to difficulties in the correct quantification of the underlying complexity of the  
303 system. Such difficulties can be circumvented by taking the first difference of COP time  
304 series, as temporal correlations are minimized in increment time series of long-range  
305 correlated processes (Govindan et al., 2007; Ramdani et al., 2009). In the present study,  
306 sample entropy was therefore determined for both RD distance and RD increment time  
307 series, with qualitatively similar results; in both cases sample entropy was significantly  
308 larger for sitting than standing posture (Fig. 3). In contrast, Ramdani et al. (2009)  
309 reported a significant difference in sample entropy between conditions of standing with  
310 eyes open and standing with eyes closed for the COP increment time series only. The  
311 insignificant result for original COP time series may well be due to the fact that the  
312 parameter optimization procedure was applied only for the increment data (resulting in  $m$   
313  $= 3$  and  $r = 0.30$ , which is comparable to our optimal values distilled from Fig. 2). For  
314 original COP time series, Ramdani and colleagues determined sample entropy with  
315 “classical parameters  $m = 2, 3$  and  $r = 0.20$ ”, which, as can be appreciated from Fig. 2,  
316 are far from suitable. In fact, parameter optimization as applied in our study (cf. Fig. 2)  
317 and in previous studies consistently led to  $r$  values ranging between 0.035 and 0.06  
318 (Donker et al., 2007, 2008; Roerdink et al., 2006, 2009; Stins et al., 2009). The liberal  
319 choice of  $r = 0.20$  may thus have reduced the discriminative power of sample entropy  
320 estimates considerably, as confirmed by the fairly low sample entropy values of about  
321 0.15 (cf. Table B1 in Ramdani et al., 2009, p. 1030), implying that the conditional  
322 probability of finding matches progresses towards 1.

323 This faux pas notwithstanding, Ramdani and colleagues (2009) are consistent  
324 with other studies demonstrating the potential of sample entropy, or regularity statistics in  
325 general, to characterize complexity features in posturograms, by concluding that, with  
326 appropriate  $m$  and  $r$  parameters, “sample entropy could be a good dynamical signature to  
327 characterize the postural effects of aging and diseases” (p. 1029). We fully endorse this  
328 conclusion and would like to add that COP regularity, so-defined, may represent a marker  
329 of the amount of attention invested in the control of posture, between groups that differ in  
330 age, health status, or expertise, as well as within groups, under changing postural  
331 demands, as outlined in Fig. 4. In this figure, the relation between COP regularity and the  
332 amount of attention invested in posture is summarized using a COP-regularity continuum  
333 in parallel to an automaticity-of-control continuum (Panel A). That is, based on regularity  
334 characteristics of posturograms, the former continuum ranges from fairly regular (left  
335 side) to fairly irregular posturograms (right side). Based on reaction times found in  
336 stimulus-response paradigms during postural control, the latter continuum ranges from  
337 low automaticity of control (large reaction times, left side) to highly automatized control  
338 (short reaction times, right side). As is often the case with a continuum, controls are  
339 situated somewhere in the centre, whereas “pathology” and “expertise” are located at left  
340 and right sides, respectively (Panel B). There are several within-subject factors  
341 influencing the relative position in the parallel continua (Panel C). That is, with recovery  
342 from pathology, the position in the continuum progressively shifts towards the right. If  
343 attention is experimentally withdrawn from posture, the position in the continuum shifts  
344 towards the right as well. As demonstrated in the present study, the position in the  
345 parallel continua depends on the imposed balance demands (towards the right side with

346 less challenging demands, e.g., sitting instead of standing). The same holds for imposed  
347 postural threats (towards the left side when standing at the edge of a cliff, cf. Huffman,  
348 Horslen, Carpenter, & Adkin, 2009; Stins et al., 2010) and imposed sensory deprivation  
349 (towards the left side when standing with eyes closed vs. standing with eyes open;  
350 Donker et al., 2007; Ramdani et al., 2009).

351

352 -Fig. 4-

353

354 There are several unexplored paths in the parallel continua to further verify or  
355 falsify the proposed relation between COP regularity and the automaticity of control.  
356 Examples are adopting an internal vs. external attentional focus (e.g., McNevin & Wulf,  
357 2002; Vuillerme & Nafati, 2007), gradually diverting larger amounts of attention from  
358 posture (e.g., Pellecchia, 2003; Riley, Baker, & Schmit, 2003; Swan, Otani, & Loubert,  
359 2007; Vuillerme et al., 2000, 2006), healthy ageing (e.g., Huxhold et al., 2006; Lacour et  
360 al., 2008), a comparison between normal and fatigued standing (e.g., Vuillerme et al.,  
361 2002), et cetera. Ideally, future studies in this direction should adopt a complementary  
362 approach by studying both COP regularity from posturograms and the attentional  
363 investment in posture from stimulus-response reaction-time paradigms. The limitation of  
364 the proposed relation between COP regularity and the amount of attention invested in  
365 posture currently resides in the question *why* the regularity of COP trajectories would  
366 change with changes in the degree of automaticity of postural control, in other words,  
367 what are the mechanisms underlying the existing link between COP regularity and  
368 attentional investment in posture? Future efforts are required to uncover underlying

369 control processes responsible for the proposed relation. This limitation notwithstanding,  
370 based on the present set of converging findings, as summarized in Fig. 4, and pending  
371 consistent findings of recommended future studies for the unexplored paths in the parallel  
372 continua, we feel confident by stating that regularity of COP fluctuations may be  
373 considered as a marker for the amount of attention invested in posture.

374

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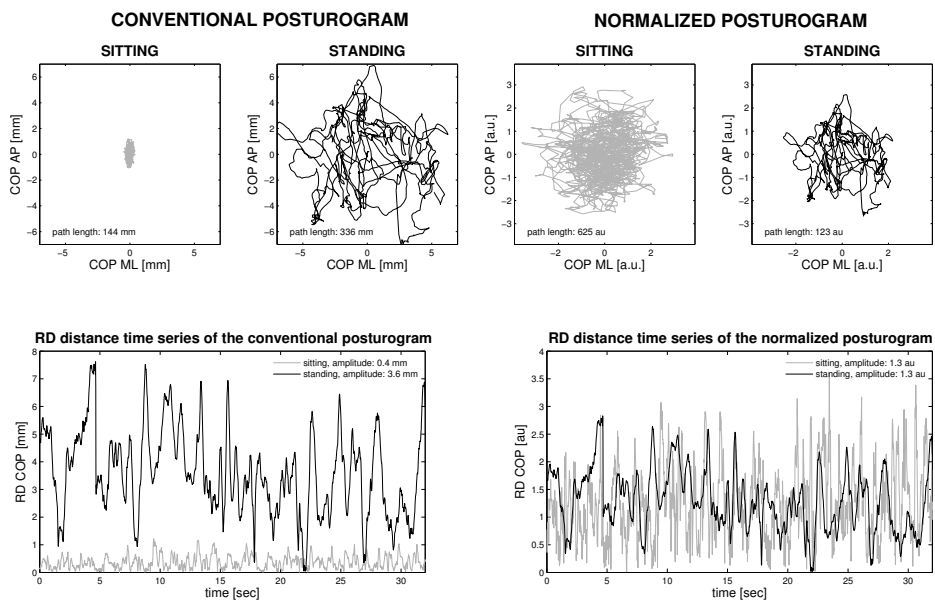
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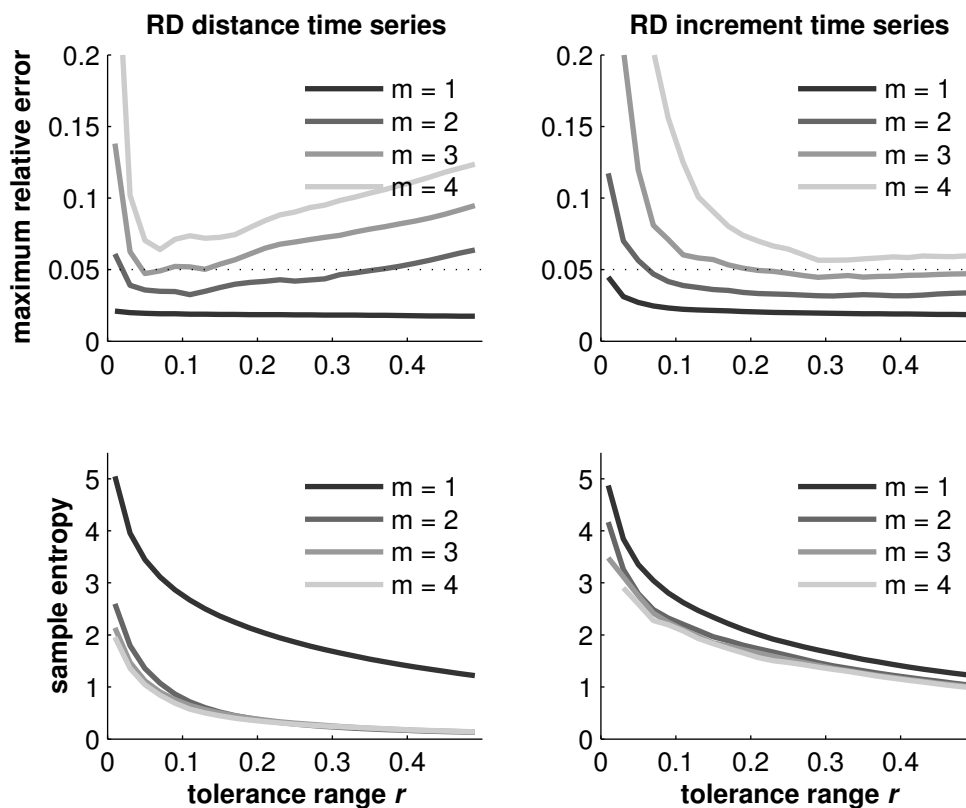
479 **Fig. 1.** Conventional and normalized posturograms of a single participant for sitting and  
 480 standing postures (upper panels), as well as corresponding RD distance time series (lower  
 481 panels). Respective path lengths and RD amplitudes are indicated as well; see text for  
 482 further details.  
 483



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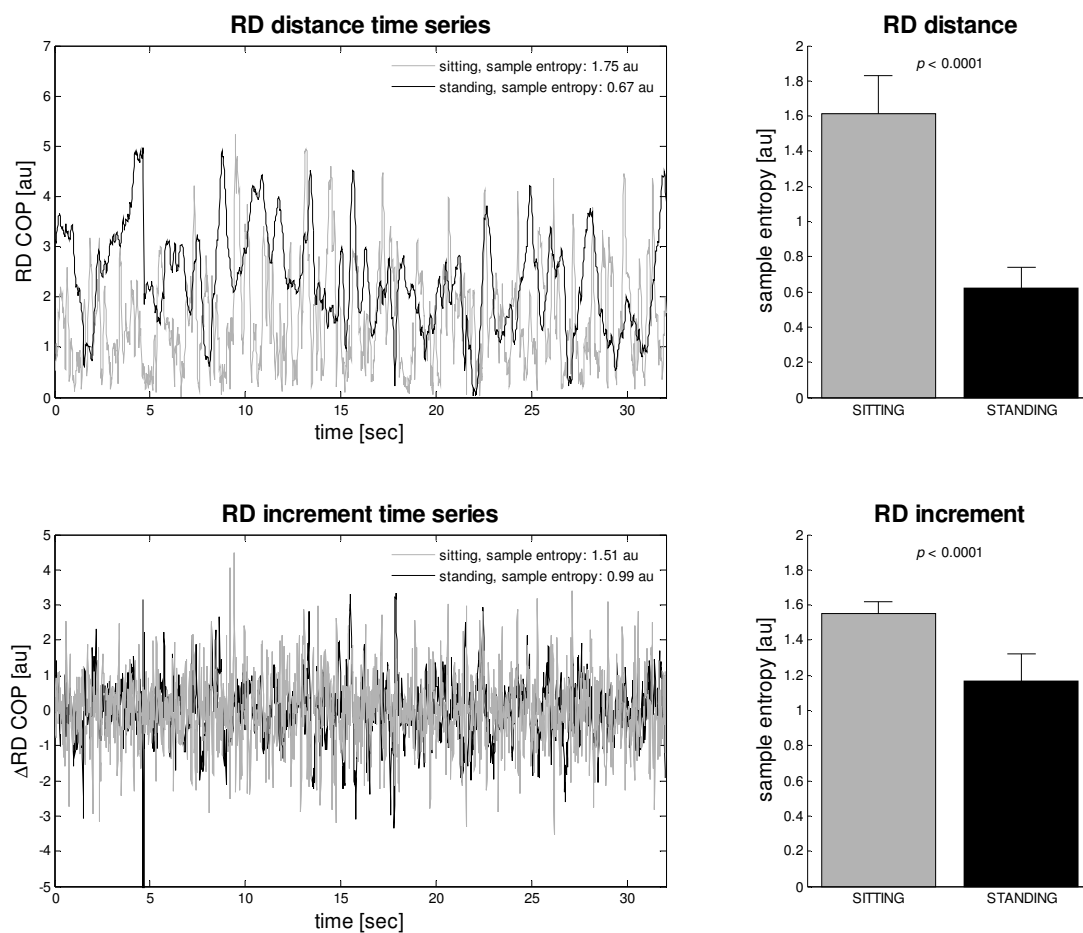
485

486 **Fig. 2.** A visual guide to optimal selection of template length  $m$  and tolerance range  $r$  for  
 487 sample entropy estimation of RD distance and RD increment time series, using a criterion  
 488 value of 0.05 for the median of the maximal relative in CP and sample entropy estimates  
 489 (upper panels). The lower panels depict corresponding sample entropy values for various  
 490 combinations of  $m$  and  $r$ , showing convergence for  $m$  is 2 to 4. Note that the depicted  
 491 maximum relative error (upper panels) and sample entropy (lower panels) plots for the  
 492 various parameter combinations represent median curves for all trials of all participants.



493

494 **Fig. 3.** Typical sitting (gray) and standing (black) RD distance (upper left panel) and RD  
495 increment (lower left panel) time series, with associated sample entropy values indicated  
496 in the legend. Average sample entropy values for these conditions collapsed over all  
497 participants are depicted in the panels on the right.



498

499 **Fig. 4.** Schematic overview of the relation between COP regularity and automaticity of  
 500 control, represented as parallel continua with relatively regular posturograms and lower  
 501 automaticity of postural control on the left, and relatively irregular posturograms and  
 502 higher automaticity of control on the right hand side of the figure (A). Between-subject  
 503 and within-subject factors influencing the relative position within the continua are  
 504 indicated in panels B and C, respectively (see text for details).

