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## Effect of mental calculus on the performance of complex movements

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1 **Effect of mental calculus on the performance of complex movements.**

2

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## 36 **1. Introduction**

37 Several everyday activities require the mental computation of arithmetical calculations. For  
38 example, a subtraction may be useful for determining the exact amount of money remaining  
39 after a purchase or the remaining time before the beginning of a scheduled activity. Mental  
40 calculation is included in school curricula and as a consequence it is also a topic of interest for  
41 educational research (e.g. Fuson, 1984). Several authors have also aimed at understanding the  
42 neurofunctional mechanisms of mental arithmetic (e.g. Arsalidou & Taylor, 2011; Arsalidou,  
43 Pawliw-Levac, Sadeghi, & Pascual-Leone, 2018) and the neural bases of dyscalculia (e.g.  
44 Butterworth, 2010; Butterworth, Varma, & Laurillard, 2011).

45 These studies have suggested the possible involvement of the same cerebral mechanisms  
46 during both mental calculation and movement preparation. A possibility that is consistent  
47 with the hypothesis that any conceptual representation is grounded to sensorimotor experience  
48 (Barsalou, 2008, 2010; Wiemers, Bekkering, & Lindemann, 2014). This might explain the use  
49 of fingers to learn simple arithmetic operations, as it has been observed among children of  
50 different cultures (e.g. Previtali, Rinaldi, & Girelli, 2011). This might also explain the positive  
51 effect of training with an abacus on the performance of mental calculation (Hanakawa et al.,  
52 2002). These mechanisms learned from infancy may remain influential during calculation in  
53 adults (e.g. Moeller, Martignon, Wessolowski, Engel, & Nuerk, 2011).

54 This is supported by behavioral studies in the case of fingers where it was shown that finger  
55 gnosis (the ability to represent, differentiate and name the fingers, e.g. Ardila, Concha, &  
56 Rosselli, 2000) may predict the performance of arithmetical tasks in both children and adults  
57 (e.g. Newman, 2016; Noël, 2005; Penner-Wilger et al., 2007; Penner-Wilger, Waring, &  
58 Newton, 2014). This is consistent with neuroimaging studies that showed, in the brain cortex,  
59 a significant functional activation of finger somatosensory areas during both mental  
60 subtractions and multiplications performed without explicit movement by children (Berteletti  
61 & Booth, 2015) and adults (Andres, Michaux, & Pesenti, 2012). Berteletti and Booth (2015)  
62 also found significant functional activations of finger motor areas in children during mental  
63 subtraction. Similarly Hanakawa et al. (2002) found a significant activation of the dorsolateral  
64 Premotor Cortex in adults performing arithmetical additions (usually overlapping the Primary  
65 Motor area active during actual finger movements).

66 Spatial representations involved during mental calculation and during control of movement  
67 direction might also require similar cerebral attentional mechanisms. During mental  
68 calculation such representation of number space may lead to right- or upward and left- or

69 downward attentional shifts (e.g. Knops, Viarouge, & Dehaene, 2009). This might interfere  
70 with the attentional control of movement direction, as it is supported by the study by Wiemers  
71 et al. (2014) showing the effect of the direction of arm motion on the performance of mental  
72 calculation. These authors found that the performance of subtraction tasks was impaired by  
73 right- and upward arm movements, while mental additions were impaired by left- and  
74 downward movements. Such effects were confirmed with up- and downward passive motions  
75 of the whole body (Lugli, Baroni, Anelli, Borghi, & Nicoletti, 2013) and with right- and  
76 leftward walk (Anelli, Lugli, Baroni, Borghi, & Nicoletti, 2014), again during mental  
77 additions and subtractions.

78 Overall while both neuroimaging and behavioral studies have suggested a possible link  
79 between mental calculation and movement these studies did not consider the case of high-  
80 intensity movements and the influence of mental calculation upon the performance of a  
81 subsequent movement remained to be examined. To our knowledge only Rabahi, Fargier,  
82 Clouzeau, Rifai Sarraj and Massarelli (2013) have produced results regarding this possible  
83 influence in the case of a complex movement (see Wulf and Shea, 2002) of squat vertical  
84 jump (SVJ) with maximal intensity. Rabahi et al (2013) examined the possible effect of action  
85 verbs upon jump height in adult subjects and the results showed for example that SVJ height  
86 was higher after reading the verb « jump » than after watching a black screen (baseline).

87 Different words were used as controls and mental subtraction as a control of attentional task.  
88 It was interestingly found that mental subtraction increased SVJ height almost as much as the  
89 verb “jump”, a result that required both confirmation and further examination.

90 The present study thus aimed at examining the respective influence, upon SVJ performance,  
91 of number processing (e.g. number viewing) and the application of operation rules (Arsalidou  
92 et al., 2018) as both are involved during mental subtraction. The present study also examined  
93 whether the effect of mental subtraction on SVJ performance is affected by the numerical  
94 format (i.e. numbers written in Arabic digits or numbers written as words) as Rabahi et al.  
95 (2013) considered the case of Arabic digits only. The possible influence of the numerical  
96 format was tested in the present study as studies on numerical cognition (e.g. Dehaene, 1992)  
97 have suggested that cerebral mechanisms involved in number processing and/or calculation  
98 may partly differ depending on the used numerical format.

99 In addition the investigation was extended to a simpler movement than SVJ, i.e. an upper limb  
100 motion (manual-pointing task, MPT), in accordance with previous studies suggesting a link  
101 between cognitive stimuli and motor performance (e.g. Boulenger et al., 2006, 2008; Nazir et  
102 al., 2008).

103

## 104 **2. Materials and Methods**

105 The study was approved by the ethical committee of the AZM Center for Research in  
106 Biotechnology and its Application (Tripoli, Lebanon). The total number of subjects was of  
107 161 undergraduate male students, from the Faculty of Public Health of the Lebanese  
108 University (Beyrouth, Lebanon). They further gave their written and informed consent. All  
109 subjects were healthy, had normal or corrected-to-normal vision and were English-speaking.

110

### 111 ***2.1. Experimental design***

112 The possible effect of mental subtraction upon motor performance was studied in two  
113 separate series of experiments respectively concerning the performance of SVJ and MPT  
114 (named Series SVJ and Series MPT). Before each experiment the subjects were informed of  
115 the scope of the study and of the experimental tasks, but they were left unaware of possible  
116 effects of any stimulus used in the experimental protocol. In each experiment the subjects  
117 realized some warm-up trials and particularly of the movement performed during the  
118 experiment to obtain a correct performance of this movement. All of them were  
119 systematically asked to achieve the highest possible SVJ and to realize the MPT reaching  
120 movement as fast as possible.

121 After warm-up each subject performed three series of either six SVJs (Series SVJ), or six  
122 MPTs (Series MPT), each series of six being thereafter called a block (Fig. 1). Between two  
123 consecutive blocks there was a 3 mn rest. In each block the first three movements were  
124 performed without any previous cognitive task (subjects in front of a black screen during 10  
125 sec). The measured performance of the movements constituted a baseline. The three ensuing  
126 movements were performed after a cognitive task, i.e. each of them was performed after a  
127 mental subtraction or after reading loudly a number (during 10 sec) or an action verb (specific  
128 to the movement realized in the experiment, i.e. “jump” in Series SVJ and “reach” in Series  
129 MPT; performed during 10 sec). The latter was taken as control (see Rabahi et al, 2013). The  
130 blocks and the numerical stimuli inside a block were randomly assigned.

131

132

*Insert Fig. 1. Here*

133

### 134 ***2.2. Series SVJ***

135 The 101 subjects participating to this series of experiments were randomly distributed into  
136 three groups of 21, 40 and 40, forming respectively a control group and experimental groups

137 1 and 2. The mean age (years  $\pm$  SD) of the participants was respectively of  $20.1 \pm 1.7$ ,  $20.1 \pm$   
138  $1.5$  and  $20.3 \pm 1.5$  and the mean body-mass index (BMI  $\pm$  SD in  $\text{kg}/\text{m}^2$ ) was respectively  $24 \pm$   
139  $1.0$ ,  $24 \pm 1.2$  and  $23.5 \pm 1.0$  (considered to be the normal BMI; e.g. Garrouste-Orgeas et al.,  
140 2004; Zhao, Li, Yang, Wang, & Xi, 2018).

#### 141 *2.2.1. Experimental procedure*

142 The control experiment was done to check a possible effect of movement repetition on SVJ  
143 performance. This was performed according to the experimental protocol described in Fig. 1  
144 (§ 2.1.) with the exception that no cognitive stimulus was given (subjects simply stood in  
145 front of a black screen). Experiments 1 and 2 were done also as described in Fig. 1 (§ 2.1.). In  
146 experiment 1, each number was written as word. The numbers to be read and the subtractions  
147 were respectively: (a) “four”, “seven” and “seventeen” and (b) “seventeen - eight”, “sixteen -  
148 nine” and “twelve - four” (only number notation differed between experiments 1 and 2 to  
149 verify the possible influence of the numerical format on motor performance). In experiment 2,  
150 the same numbers and mental subtractions as in experiment 1 were written in Arabic digits.  
151 Each stimulus was written in white (Times New Roman, font size 96) and it was projected on  
152 a black wall. The image was 1.3 m in diagonal and the subjects stood at 3.5 m from the wall,  
153 in accordance with the specifications of the manufacturer (Optoma<sup>®</sup>/ThemeSceneH projector,  
154 92100 Boulogne-Billancourt, France).

#### 155 *2.2.2. Squat vertical jump*

156 The jumps realized in Series SVJ were performed as described and analyzed by Fargier,  
157 Massarelli, Rabahi, Gemignani & Fargier (2016). Jump height was determined by measuring  
158 the time of flight by an Optojump Next<sup>®</sup> apparatus (Microgate France, 38330 St-Ismier)  
159 connected to a laptop.

160

### 161 **2.3. Series MPT**

162 The participants (a total number of 60 other subjects participated to these experiments of the  
163 MPT Series) were randomly distributed in three groups of 20 subjects, respectively forming a  
164 control group and experimental groups 3 and 4 similarly to Series SVJ.

165 The mean age (years  $\pm$  SD) of the participants to the control experiment and to the  
166 experiments 3 and 4 was respectively  $20.1 \pm 2.0$ ,  $20.8 \pm 1.8$  and  $20.2 \pm 1.8$ . The subjects were  
167 right handed as it was assessed by using the Edinburgh Inventory (Oldfield, 1971). The mean  
168 scores obtained with the Edinburgh Inventory (number of points  $\pm$  SD) of the participants to  
169 the control experiment and to experiments 3 and 4 were respectively of  $78.1 \pm 10.0$ ,  $78.2 \pm$

170 9.8 and  $72.9 \pm 9.6$ . All subjects declared a preference for the right handiness and performed  
171 MPT accordingly. The MPT measurement system was home-made and will be described in  
172 the following.

### 173 *2.3.1. Manual-pointing task*

174 Each subject sat on a chair behind a desk. In front of the subject two wooden parallelepipeds  
175 (5 cm in height each) were fixed one following the other upon the desk top board. The first  
176 parallelepiped was at a distance of 25 cm from the chest of the subject. At the center of the  
177 superior face of each parallelepiped a circular button was fixed. The distance between the  
178 centers of the two buttons was of 25 cm. During each cognitive task (Fig. 1, § 2.1.) the  
179 subjects were asked to touch the button fixed on the first parallelepiped with the index finger,  
180 the middle finger and the ring finger of the right hand. At the end of each cognitive task the  
181 subjects were required to press the button of the second parallelepiped as fast as possible.

### 182 *2.3.2. Performance measurement*

183 The beginning of the movement was determined by a three-axis accelerometer (Vernier®;  
184 13979 SW Millikan Way, Beaverton, OR 97005, USA) fixed on a mitten that each subject  
185 wore on the right hand. The Response Time (RT) was determined when the button on the  
186 distal parallelepiped was pressed. The acquisition and the analysis of the measures were made  
187 with a data acquisition card (DAQ®; data acquisition, National Instruments, 11500 Mopac  
188 Expwy, Austin, Texas) connected to Labview® software [Laboratory Virtual Instrument  
189 Engineering Workbench 2009 (32-bit), National Instruments, Austin, Texas] and Matlab®  
190 script (Matlab R2016a, MathWorks incorporation, Natick, Massachusetts).

191

## 192 *2.5. Statistical analysis*

193 The data collected from each experiment were analyzed by using a multilevel linear mixed-  
194 effect model (Pinheiro & Bates, 2000; Finch, Bolin, & Kelley, 2014). The response variables  
195 in Series SVJ and MPT were respectively the height of jump (cm) and the RT (ms).

196 In each case three levels of variability were considered and represented by three nested  
197 random effects in the statistical model. The effect at the first level was the subject effect. The  
198 effect at the second level considered the performance of each series of three consecutive  
199 movements in the same experimental condition (see Fig. 1, § 2.1.). At the third level the effect  
200 was a residual effect, considering the individual performance in the same experimental  
201 condition. All nested random effects followed non-correlated normal distributions with zero  
202 expectation.

203 The data obtained from the control experiment of each Series were analyzed by considering  
204 two fixed-effect and the corresponding interaction. A block fixed-effect was examined to  
205 control a possible effect of block repetition (i.e. effect of fatigue or of training) during the  
206 experiments. An intra-block fixed-effect was also examined to allow a comparison of the two  
207 successive series of three movements (black wall) in the same block. Finally the interaction  
208 effect between block and intra-block was considered.

209 The absence of statistically significant intra-block and interaction effects would show the  
210 stability of the baseline. A statistically significant block effect would lead to check such  
211 possible effect during experiments 1 to 4. In any case the statistical analysis of the data of  
212 each of the experiments 1 to 4 aimed at examining a fixed-effect regarding the experimental  
213 conditions (see Fig. 1, § 2.1.), i.e. black screen (baseline), action verb reading, number  
214 reading and mental subtraction.

215 All multilevel linear mixed-effect models were fitted by using restricted maximum likelihood  
216 estimation (Pinheiro & Bates, 2000, p. 75). Fixed-effects were tested by using conditional F-  
217 tests (Pinheiro & Bates, 2000, p. 90) at the 5% level. The method of Bretz, Hothorn, &  
218 Westfall (2010) was used to carry out post-hoc tests (single-step method; family-wise error  
219 rate set at 5%). All computations were performed by using the R statistical software 3.4.3 (R  
220 Core Team, 2017) and the packages nlme, lme4, multcomp and effects.

221

### 222 **3. Results**

223

#### 224 **3.1. Series SVJ**

225 In the SVJ control experiment the test of the block fixed-effect reached statistical significance  
226 ( $F(2,100) = 3.61, p < .05$ ) suggesting that the repetition of three blocks of SVJs (see Fig. 1, §  
227 2.1.) may influence jump height. From the first block to the third one SVJ heights in cm  
228 (mean  $\pm$  SD) were respectively:  $28.97 \pm 2.04$ ,  $29.42 \pm 1.85$  and  $29.31 \pm 1.97$ . All-pairwise  
229 comparisons showed that only the difference between the first and the second blocks was  
230 significant. Although this difference was only 0.45 cm, its statistical significance imposed to  
231 control a possible effect of blocks repetition in experiments 1 and 2. No intra-block fixed-  
232 effect (controlling a possible order effect of the two series of three jumps in the same block)  
233 and no interaction between block and intra-block were found with respectively:  $F(1,100) =$   
234  $2.06, p > .05$  and  $F(2,100) = 1.00, p > .05$ . As a consequence the mean baseline of each block  
235 of both experiments 1 and 2 was used as reference.



236 In both experiments 1 (numbers written as words) and 2 (numbers written in Arabic digits) no  
237 influence of block repetition (block fixed-effect) was found with respectively:  $F(2,195) =$   
238  $0.29, p > .05$  and  $F(2,195) = 0.65, p > .05$ . The condition (cognitive tasks) effect reached  
239 statistical significance with respectively:  $F(3,195) = 24.51, p < .001$  and  $F(3,195) = 23.22, p <$   
240  $.001$  (see Fig. 2).

241 *Insert Fig. 2 here*

242  
243 Regarding experiment 1 (numbers written as words; Fig. 2. a.) all-pairwise comparisons  
244 (Table 1. a.) showed that SVJ height was significantly higher (1.57 cm) after reading “jump”  
245 than in the baseline condition,  $p < .001$ . SVJ height was also significantly higher after reading  
246 a number written as word than in the baseline condition,  $p < .05$ . This difference was of 0.53  
247 cm only and SVJ height after reading “jump” was significantly higher than SVJ height after  
248 numbers read as words,  $p < .001$ . In addition SVJ height after mental subtraction of numbers  
249 written as words was not significantly different than in the baseline condition,  $p > .05$ .

250  
251 *Insert Table 1 here*

252  
253 In experiment 2 (numbers written in Arabic digits; Fig. 2. b.) all-pairwise comparisons (Table  
254 1. b.) showed again that SVJ height was higher after reading “jump” than in the baseline  
255 condition,  $p < .001$ . In contrast with experiment 1 (numbers written as words), in this  
256 experiment 2 it was found that SVJ height after reading a number written in Arabic digits was  
257 not significantly different than in the baseline condition,  $p > .05$ . It was also found that mental  
258 subtraction with numbers written in Arabic digits was higher than in the baseline condition,  $p$   
259  $< .001$  and after the reading of a number written in Arabic digits,  $p < .001$ .

### 260 261 **3.2. Series MPT**

262 In the control experiment no statistically significant effect of block repetition (block effect)  
263 was found,  $F(2,59) = 1.19, p > .05$ . However considering that a significant block effect was  
264 found in the control experiment of Series SVJ it was decided to check again such possible  
265 effect in the experiments 3 and 4 of Series MPT. Similarly to the control experiment of Series  
266 SVJ the control experiment of Series MPT showed no statistically significant intra-block  
267 effect and interaction effect between block and intra-block. As a consequence the mean  
268 baseline of each block of both experiments 3 and 4 was used as reference.

269 In both experiments 3 (numbers written as words) and 4 (numbers written in Arabic digits) no  
270 influence of block repetition (block fixed-effect) was found with respectively:  $F(2,59) = 2.56$ ,  
271  $p > .05$  and  $F(2,59) = 0.41$ ,  $p > .05$ , while the condition (cognitive tasks) effect was  
272 significant with respectively:  $F(3,59) = 43.34$ ,  $p < .001$  and  $F(3,59) = 51.24$ ,  $p < .001$  (see  
273 Fig. 3).

274  
275 *Insert Fig. 3 here*  
276

277 In experiment 3 (numbers written as words; Fig. 3. a.) all-pairwise comparisons (Table 2. a.)  
278 showed only the influence of reading the word “reach” upon MPT performance (RT) when  
279 compared to the baseline,  $p < .001$ . In addition the RT observed after reading “reach” was  
280 significantly faster than the RT measured after reading a number written as word and after  
281 mental subtraction with numbers written as words (Table 2.a).

282  
283 *Insert Table 2. here*  
284

285 In experiment 4 (numbers written in Arabic digits; Fig. 3. a.) all-pairwise comparisons (Table  
286 2. b.) showed again that MPT RT was faster after reading “reach” than in the baseline  
287 condition,  $p < .001$ . Interestingly RT after reading a number written in Arabic digits was not  
288 significantly different than in the baseline while RT after mental subtraction with numbers  
289 written in Arabic digits was significantly faster than the baseline RT,  $p < .001$ . In addition the  
290 RTs after reading “reach” and after mental subtraction with numbers written in Arabic digits  
291 were significantly faster than the baseline RT and the RT after reading a number written in  
292 Arabic digits (Table 2. b.).

#### 293 294 **4. Discussion**

295 The aim of the present study was to examine the possible effect of mental subtraction on the  
296 performance of a complex movement of squat vertical jump with maximal intensity (SVJ) and  
297 of a manual-pointing task with maximal velocity (MPT). Two series of experiments,  
298 respectively including SVJ (Series SVJ) and MPT (Series MPT), examined this possible  
299 effect when numbers were written as words or in Arabic digits. Each experiment allowed  
300 comparisons among motor performance after viewing a black screen (baseline), reading a  
301 specific action verb (control), reading a number and after mental subtraction.

302 In each experiment of Series SVJ (experiments 1 and 2) the subjects performed higher SVJs  
303 after reading the word “jump” than in the baseline condition (see Fig. 2 and Table 1, § 3.1.) as  
304 it has been previously shown (Rabahi et al., 2013). In each experiment of Series MPT  
305 (experiments 3 and 4) the subjects also performed faster RTs after reading “reach” than in the  
306 baseline condition (see Fig. 3 and Table 2, § 3.2.). The present results thus confirmed the  
307 influence of reading a specific action verb on motor performance.

308 A statistically significant influence of number reading upon motor performance was in  
309 addition found in experiment 1 but not in experiments 2, 3 and 4. This influence, found in the  
310 case of SVJ and when numbers were written as words, was rather small as the performance of  
311 SVJ after number reading was only 0.53 cm higher than the baseline,  $p < .05$  (see Table 1. a.,  
312 § 3.1.). Especially so when considering that SVJ performance after reading the word “jump”  
313 was: 1.57 cm higher than the baseline,  $p < .001$ , and 1.04 cm higher than after reading a  
314 number written as word,  $p < .001$  (see Table 1. a., § 3.1.). The present study thus shows that  
315 simple number reading may have either no effect, or a weak effect, on motor performance. It  
316 should be mentioned that previous results have shown indirectly that a link might exist  
317 between number processing and lateral and/or vertical movement, but a real motor  
318 performance was not actually measured (e.g. Loetscher, Schwarz, Schubiger, & Brugger,  
319 2008; Winter & Matlock, 2013).

320 The main finding of the present study was that mental subtraction with numbers written in  
321 Arabic digits influenced both SVJ and MPT performance while mental subtraction with  
322 numbers written as words did not (see Table 1, § 3.1., and Table 2, § 3.2.). After mental  
323 subtraction with Arabic digits the subjects performed SVJ 1.06 cm higher than the baseline,  $p$   
324  $< .001$ , and MPT RTs 30.26 ms faster than the baseline,  $p < .001$ .

325 The positive effect of mental subtraction with numbers written in Arabic digits upon SVJ  
326 performance confirmed the findings of Rabahi et al. (2013) and showed that such an effect on  
327 motor performance was not limited to a complex movement of SVJ as it also influenced the  
328 simpler MPT performance.

329 This effect might be linked to the difficulty level of the calculations to be done that were  
330 presented in a classical form (e.g. 12 - 4) and were of medium difficulty level according to  
331 Thevenot, Castel, Fanget, & Fayol (2010). The calculations may thus have fostered a feeling  
332 of accomplishment in the experimental undergraduate subjects possibly favoring their  
333 attentional control (Derakshan & Eysenck, 2009). On the other hand mental subtractions with  
334 numbers written as words were certainly unusual to the subjects increasing thus a state of  
335 anxiety that might hamper the stimulation effect of the subtractions on performance.

336 In the case of the more usual operation with Arabic digits the mental subtraction might  
337 instead have directed the subjects' attention on the optimal path of movement in SVJ and  
338 MPT as the operation may involve a spatial representation of numbers oriented vertically (as  
339 in SVJ; e.g. Wiemers et al., 2014) or horizontally (as in MPT; e.g. Anelli et al., 2014).  
340 However previous studies have suggested that the performance of a mental subtraction may  
341 be either impaired by upward movements (Lugli et al., 2013; Wiemers et al., 2014) or forward  
342 ones (Anelli et al., 2014), but only when they were performed concomitantly to the  
343 calculation. In the present study the subjects were initially aware of the movement that they  
344 would have to perform. They were also required to execute it with maximal intensity after  
345 mental calculation [contrary to the studies of Anelli et al. (2014), Lugli et al. (2013), and  
346 Wiemers et al. (2014)]. This might have favored, during calculation, a mental representation  
347 of numbers (see § 1.) in a spatial a plane congruent with the plane in which the subsequent  
348 movement would be optimally executed (i.e. vertical plane in SVJ and horizontal plane in  
349 MPT).

350 Concerning the presentation of the operation with numbers written as Arabic digits or as  
351 words McCloskey and colleagues (e.g. McCloskey, 1992) have proposed a model in which  
352 numbers, regardless the numerical modality used to present them, are encoded into a unique  
353 abstract format to allow the mental calculation. Conversely Campbell and colleagues (e.g.  
354 Clark & Campbell, 1991) have proposed a model composed of a network of mechanisms  
355 specific to different modalities of number presentation each of them supporting number  
356 comprehension and calculation.

357 The results observed in the present study in this respect with Arabic and written numbers  
358 might only be explained, if interpreted with the McCloskey's model, by the influence of  
359 distinct encoding mechanisms of Arabic and of written numbers before calculation (see also  
360 Dehaene, 1992). Interpreted with the Campbell's model instead the present results might also  
361 be explained by the involvement of a memory specific for Arabic digits during calculation  
362 (see also Myers & Szűcs, 2015), differently located from the language areas of the brain.

363

364 In conclusion the present study showed that mental subtraction, rather than number reading,  
365 may influence SVJ and MPT performance when numbers are written in Arabic digits (and not  
366 when numbers are written as words). Mental subtractions of moderate difficulty presented in a  
367 usual format (i.e. Arabic digits) possibly led subjects to an emotional state favoring attention  
368 to elements relevant to perform SVJ and MPT. Among such elements attention to the optimal  
369 path of movement might have been favored by the spatial representation of numbers used to

370 calculate. The influence of mental subtraction with Arabic digits on motor performance might  
371 also be linked to mechanisms of encoding and/or memorization specific to this numerical  
372 format. The results of the present study are in any case in accordance with neuroimaging  
373 studies showing an increased functional activation of the Premotor Cortex during calculation  
374 with Arabic digits (e.g. Hanakawa et al., 2002). Whether attention, numbers encoding and/or  
375 memorization might contribute to such activation remains an opened question.

376

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378 The authors express their grateful thanks to Emeritus Professor Raphaël Massarelli for his key  
379 support in this study.

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599 **Figure captions**

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601 **Fig. 1.** Experimental protocol.

602 Before the start of the experiment the subjects were requested to realize a warm-up during ~10 mn.  
603 They further performed three series of six movements (M = SVJ in Series SVJ and MPT in Series  
604 MPT), i.e. three blocks of movements separated by 3 mn rest. Each block began by the realization of  
605 three movements (M1 to M3) without any previous cognitive task (subjects in front of a black screen  
606 during 10 sec). The performance of these movements constituted a baseline. Each of the ensuing three  
607 movements was realized after a cognitive task, i.e. for each of M4 to M6: either after a mental  
608 subtraction, or after reading loudly a number during 10 sec, or after reading loudly an action verb  
609 during 10 sec (“jump” in Series SVJ, “reach” in Series MPT).

610

611 **Fig. 2.** Effect of cognitive tasks on SVJ height

612 The graphical display, called “effect plot” by Fox and Hong (2009), shows the adjusted mean  
613 heights of jump in SVJ after: watching a black screen (Base: baseline performance), reading  
614 the verb “jump” (Jump), reading a number (N) and mental subtraction (S). In experiments 1  
615 (Fig. 2. a) and 2 (Fig. 2. b) the numbers were respectively written as words and in Arabic  
616 digits. The vertical bars indicate  $\pm 0.95$  confidence interval.

617

618 **Fig. 3.** Effect of cognitive tasks on MPT response time

619 The graphical display, called “effect plot” by Fox and Hong (2009), shows the mean response  
620 time (RT) in MPT after: watching a black screen (Base, baseline performance), reading the  
621 verb “reach” (Reach), reading a number (N) and mental subtraction (S). In experiments 3  
622 (Fig. 3. a.) and 4 (Fig. 3. b.) the numbers were respectively written as words and in Arabic  
623 digits. The vertical bars indicate  $\pm 0.95$  confidence interval.

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633 **Table 1.** All-pairwise comparisons in experiments 1 and 2

Differences	a. Experiment 1 (numbers as words)			b. Experiment 2 (Arabic numerals)		
	Estim. (cm)	SE	z-score	Estim. (cm)	SE	z-score
<b>Jump - Base</b>	1.57	0.19	8.36 ***	1.06	0.18	5.98 ***
<b>N - Base</b>	0.53	0.19	2.84 *	0.25	0.18	1.41
<b>S - Base</b>	0.10	0.19	0.55	1.26	0.18	7.02 ***
<b>N - Jump</b>	-1.04	0.23	-4.51 ***	-0.81	0.22	-3.66 **
<b>S - Jump</b>	-1.47	0.23	-6.35 ***	0.20	0.22	0.91
<b>S - N</b>	-0.43	0.23	-1.86	1.01	0.22	4.48 ***

634

635 The results of the multiple comparisons (pairwise comparisons) of SVJ heights among Base  
 636 (baseline performance), Jump (jump height after reading the word “jump”), N (jump height  
 637 after reading a number) and S (jump height after mental subtraction) are shown. The multiple  
 638 comparisons were carried out using the method of Bretz et al. (2010) and the family-wise  
 639 error rate was set at 5%. Regarding Estim. (Estimate, differences in cm) differences between  
 640 two SE (standard error) may occur after the second decimal (for example in experiment 1 the  
 641 SE for Jump - Base and N - Base are respectively 0.1877 and 0.1874). Regarding z-scores the  
 642 adjusted p-values [single-step method;  $p (> |z|)$ ] of the statistically significant differences are  
 643 indicated by \* =  $p < .05$ , \*\* =  $p < .01$  and \*\*\* =  $p < .001$ .

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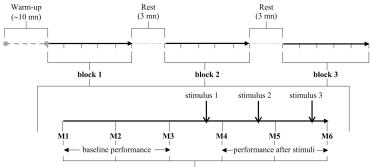
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660 **Table 2 – All-pairwise comparisons in experiments 3 and 4**

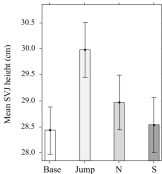
Differences	a. Experiment 3 (numbers as words)			b. Experiment 4 (Arabic numerals)		
	Estim. (ms)	SE	z-score	Estim. (ms)	SE	z-score
<b>Reach - Base</b>	-30.92	3.06	-10.09 ***	-30.26	3.06	-9.88 ***
<b>N - Base</b>	1.43	3.06	0.47	5.21	3.06	1.70
<b>S - Base</b>	6.97	3.08	2.26	-22.91	3.06	-7.49 ***
<b>N - Reach</b>	32.35	3.75	8.63 ***	35.47	3.76	9.42 ***
<b>S - Reach</b>	37.89	3.79	10.00 ***	7.35	3.75	1.96
<b>S - N</b>	5.55	3.79	1.46	-28.12	3.75	-7.50 ***

661  
 662 The results of the multiple comparisons of MPT response times (RTs) among Base (baseline  
 663 performance), Reach (RT after reading the word “reach”), N (RT after reading a number) and  
 664 S (RT after mental subtraction) are shown. The multiple comparisons were carried out using  
 665 the method of Bretz et al. (2010) and the family-wise error rate was set at 5%. Regarding  
 666 Estim. (Estimate, differences in ms) differences between two SE (standard error) may occur  
 667 after the second decimal. Regarding z-scores the adjusted p-values [single-step method;  $p (>$   
 668  $|z|)$ ] of the statistically significant differences are indicated by \*\*\* =  $p < .001$ .

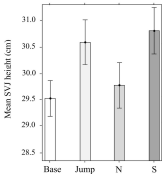


M = Squat vertical jump (Series SVJ) or manual-pointing task (Series MPT)

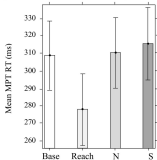
**a. Experiment 1 (numbers as words)**



**b. Experiment 2 (Arabic numerals)**



**a. Experiment 3 (numbers as words)**



**b. Experiment 4 (Arabic numerals)**

