Effect of mental calculus on the performance of complex movements

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1. Introduction

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

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

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

Spatial representations involved during mental calculation and during control of movement direction might also require similar cerebral attentional mechanisms. During mental calculation such representation of number space may lead to right- or upward and left- or downward attentional shifts (e.g. Knops, Viarouge, & Dehaene, 2009). This might interfere with the attentional control of movement direction, as it is supported by the study by Wiemers et al. (2014) showing the effect of the direction of arm motion on the performance of mental calculation. These authors found that the performance of subtraction tasks was impaired by right- and upward arm movements, while mental additions were impaired by left- and downward movements. Such effects were confirmed with up- and downward passive motions of the whole body (Lugli, Baroni, Anelli, Borghi, & Nicoletti, 2013) and with right- and leftward walk (Anelli, Lugli, Baroni, Borghi, & Nicoletti, 2014), again during mental additions and subtractions.

Overall while both neuroimaging and behavioral studies have suggested a possible link between mental calculation and movement these studies did not consider the case of high-intensity movements and the influence of mental calculation upon the performance of a subsequent movement remained to be examined. To our knowledge only Rabahi, Fargier, Clouzeau, Rifai Sarraj and Massarelli (2013) have produced results regarding this possible influence in the case of a complex movement (see Wulf and Shea, 2002) of squat vertical jump (SVJ) with maximal intensity. Rabahi et al (2013) examined the possible effect of action verbs upon jump height in adult subjects and the results showed for example that SVJ height was higher after reading the verb « jump » than after watching a black screen (baseline). Different words were used as controls and mental subtraction as a control of attentional task. It was interestingly found that mental subtraction increased SVJ height almost as much as the verb "jump", a result that required both confirmation and further examination.

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

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

2. Materials and Methods

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

2.1. Experimental design

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

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

Insert Fig. 1. Here

2.2. Series SVJ

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

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

2.2.1. Experimental procedure

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

2.2.2. Squat vertical jump

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

2.3. Series MPT

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

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

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

2.3.1. Manual-pointing task

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

2.3.2. Performance measurement

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

2.5. Statistical analysis

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

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

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

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

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

3. Results

3.1. Series SVJ

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

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

Insert Fig. 2 here

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

Insert Table 1 here

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

3.2. Series MPT

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

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

Insert Fig. 3 here

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

Insert Table 2. here

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

4. Discussion

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

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

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

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

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

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

In the case of the more usual operation with Arabic digits the mental subtraction might instead have directed the subjects' attention on the optimal path of movement in SVJ and MPT as the operation may involve a spatial representation of numbers oriented vertically (as in SVJ; e.g. Wiemers et al., 2014) or horizontally (as in MPT; e.g. Anelli et al., 2014). However previous studies have suggested that the performance of a mental subtraction may be either impaired by upward movements (Lugli et al., 2013; Wiemers et al., 2014) or forward ones (Anelli et al., 2014), but only when they were performed concomitantly to the calculation. In the present study the subjects were initially aware of the movement that they would have to perform. They were also required to execute it with maximal intensity after mental calculation [contrary to the studies of Anelli et al. (2014), Lugli et al. (2013), and Wiemers et al. (2014)]. This might have favored, during calculation, a mental representation of numbers (see § 1.) in a spatial a plane congruent with the plane in which the subsequent movement would be optimally executed (i.e. vertical plane in SVJ and horizontal plane in MPT).
Concerning the presentation of the operation with numbers written as Arabic digits or as words McCloskey and colleagues (e.g. McCloskey, 1992) have proposed a model in which numbers, regardless the numerical modality used to present them, are encoded into a unique abstract format to allow the mental calculation. Conversely Campbell and colleagues (e.g. Clark & Campbell, 1991) have proposed a model composed of a network of mechanisms specific to different modalities of number presentation each of them supporting number comprehension and calculation.
The results observed in the present study in this respect with Arabic and written numbers might only be explained, if interpreted with the McCloskey's model, by the influence of distinct encoding mechanisms of Arabic and of written numbers before calculation (see also Dehaene, 1992). Interpreted with the Campbell's model instead the present results might also be explained by the involvement of a memory specific for Arabic digits during calculation (see also Myers & Szücs, 2015), differently located from the language areas of the brain.

In conclusion the present study showed that mental subtraction, rather than number reading, may influence SVJ and MPT performance when numbers are written in Arabic digits (and not when numbers are written as words). Mental subtractions of moderate difficulty presented in a usual format (i.e. Arabic digits) possibly led subjects to an emotional state favoring attention to elements relevant to perform SVJ and MPT. Among such elements attention to the optimal path of movement might have been favored by the spatial representation of numbers used to calculate. The influence of mental subtraction with Arabic digits on motor performance might also be linked to mechanisms of encoding and/or memorization specific to this numerical format. The results of the present study are in any case in accordance with neuroimaging studies showing an increased functional activation of the Premotor Cortex during calculation with Arabic digits (e.g. Hanakawa et al., 2002). Whether attention, numbers encoding and/or memorization might contribute to such activation remains an opened question.

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Figure captions

Fig. 1. Experimental protocol.

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

Fig. 2. Effect of cognitive tasks on SVJ height

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

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

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

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

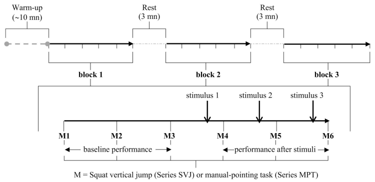
	a. Experiment 1 (numbers as words)				**b. Experiment 2 (Arabic numerals)**			
Differences	**Estim. (cm)**	**SE**	**z-score**		**Estim. (cm)**	**SE**	**z-score**	
Jump - Base	1.57	0.19	8.36	***	1.06	0.18	5.98	***
N - Base	0.53	0.19	2.84	*	0.25	0.18	1.41	
S - Base	0.10	0.19	0.55		1.26	0.18	7.02	***
N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

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

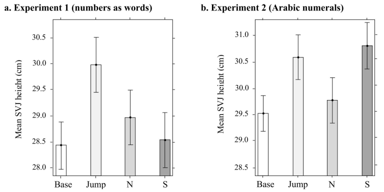
Table 2 – All-pairwise comparisons in experiments 3 and 4

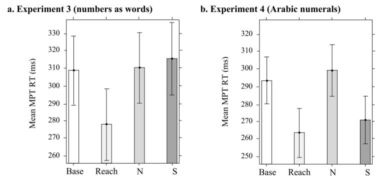
	a. Experiment 3 (numbers as words)				b. Experiment 4 (Arabic numerals)			
Differences	**Estim. (ms)**	**SE**	**z-score**		**Estim. (ms)**	**SE**	**z-score**	
Reach - Base	-30.92	3.06	-10.09	***	-30.26	3.06	-9.88	***
N - Base	1.43	3.06	0.47		5.21	3.06	1.70	
S - Base	6.97	3.08	2.26		-22.91	3.06	-7.49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

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



Warm-up
(~10 mn)
Rest
(3 mn)
Rest
(3 mn)
block 1
block 2
block 3
stimulus 1
stimulus 2
stimulus 3
M1
M2
M3
M4
M5
M6
baseline performance
performance after stimuli
M = Squat vertical jump (Series SVJ) or manual-pointing task (Series MPT)


a. Experiment 1 (numbers as words)
Mean SVJ height (cm)
30.5
30.0
29.5
29.0
28.5
28.0
Base
Jump
N
S
b. Experiment 2 (Arabic numerals)
Mean SVJ height (cm)
31.0
30.5
30.0
29.5
29.0
28.5
Base
Jump
N
S


a. Experiment 3 (numbers as words)
b. Experiment 4 (Arabic numerals)
Mean MPT RT (ms)
330
320
310
300
290
280
270
260
250
Base
Reach
N
S