Size coding of alternative responses is sufficient to induce a potentiation effect with manipulable objects

Loïc P. Heurley, Thibaut Brouillet, Alexandre Coutté, Nicolas Morgado

SIZE CODING OF ALTERNATIVE RESPONSES IS SUFFICIENT TO INDUCE A POTENTIATION EFFECT WITH MANIPULABLE OBJECTS

HEURLEY Loïc P. (corresponding author: heurleyloic@yahoo.fr)
BROUILLET Thibaut
COUTTÉ Alexandre
MORGADO Nicolas

Laboratoire sur les Interactions Cognition, Action, Émotion (LICAE) – Université Paris Nanterre, 200 avenue de La République, 92001 Nanterre Cedex, France.

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Abstract

The mere perception of manipulable objects usually grasped with a power-grip (e.g., an apple) or a precision-grip (e.g., a cherry) potentiate power-grip- and precision-grip-responses, respectively. This effect is seen as to be driven by automatic access of the representation of manipulable objects that includes a motor representation of usually performed grasping behaviors (i.e., the embodied view). Nevertheless, a competing account argues that this effect could be due to an overlapping of size codes used to represent both manipulable objects and response options. Indeed, objects usually grasped with a power- and a precision-grip (e.g., an apple *vs*. a cherry) could be coded as large- and small-objects, respectively; and power- and precision-grip responses as large- and small-responses, respectively. We conducted 4 experiments to test this hypothesis. In Experiment 1, the response device usually used in studies reporting a potentiation effect is fixed horizontally (the grasping component of responses was removed). We instructed participants to press the small-switch with their index-digit and the large-switch with their palm-hand. In line with the size-coding-hypothesis, responses on the small-switch performed with the index-digit led to shorter RTs when objects usually associated with a precision-grip (e.g., a cherry) were presented compared to objects usually associated with a power-grip (e.g., an apple). A reverse pattern was obtained for responses on the large-switch performed with the palm-hand. In Experiments 2, 3 and 4, we went further by investigating which factors of Experiment 1 allow the size coding of responses: the size of switch and/or the size of the effector part used. Data confirmed the critical involvement of the size of switches and the possible involvement of the size of the effector part used. Thus, data support the possibility that the potentiation of grasping is due to a compatibility/incompatibility between size codes rather than involving motor representations of usually performed grasping behaviors as advocated in several embodied views. Moreover, data support the possibility that responses are coded thanks to a size code that extends the Theory of Event Coding.

Keywords

Motor representations; Embodied Cognition; Potentiation Effect; Size; Manipulable Objects; Stimulus-Response Compatibility

Supplementary material

The raw data, the analyses performed, and the stimuli used can be found at osf.io/c6tva.

Highlights

- Large and small manipulable objects can potentiate large and small responses, respectively
- The size coding of responses can depend on the switch size and the effector size
- The size is a relevant dimension to code responses options
- The usual potentiation of power- and precision-grip could be due to a size coding of responses

1. Introduction

Understanding how visual and motor processes are linked is of a primary interest in cognitive sciences. Researchers have often used potentiation effects induced by objects to investigate this link. The possibility that the mere perception of manipulable objects automatically potentiate compatible manual behaviors was first reported by Tucker and Ellis (1998). They observed that manipulable objects with a handle oriented toward the left or right (e.g., a fork) facilitate a manual response located in the same side. It is usually argued that manipulable objects allow an automatic access to an object representation that includes motor components resulting in a covert motor preparation. Such a view is especially assumed by proponents of various embodied views of object representation (Barsalou, 2008; Borghi & Riggio, 2015; see Matheson, White & McCullen, 2015 for a review). Nevertheless, other authors have questioned this interpretation and have developed an alternative explanation (Anderson, Yamagishi & Karavia, 2002; Matheson, White & McCullen, 2014; Phillips & Ward, 2002; Roest, Pecher, Naeije & Zeelenberg, 2016; see Proctor & Miles, 2014 for a review). They particularly argue that some features of manipulable objects (e.g., the object handle) automatically grabs attention to a specific side of the object. This lateralized attention would potentiate in turn actions on the same side as in the more classical Simon effect (Simon, 1969). This hypothesis is supported by various researches that showed the potentiation effect of lateralized responses while stimuli presented were no longer manipulable objects (e.g., animals with their head turned toward the left or right; Matheson et al., 2014; Pellicano, Iani, et al., 2018; Pellicano, Luigi, et al., 2018; Xiong, Proctor & Zelaznik, 2019).

Although the embodied explanation is undermined by these data, there is another well-established and well-replicated potentiation effect that is still used as a possible evidence of the embodied view of objects perception. This effect was first reported by Ellis and Tucker (2000). The mere perception of manipulable objects usually grasped with a power-grip (e.g., an apple) and a precision-grip (e.g., a cherry) induces shorter response times (RTs) when participants had to perform a compatible rather than an incompatible grip on an appropriate device (e.g., Ellis & Tucker, 2000; Girardi, Lindemann & Bekkering, 2010; Makris, Hadar & Yarrow, 2011; Tucker & Ellis, 2004). The proponents of several embodied views (e.g., Barsalou, 2008; Borghi & Riggio, 2015) argued that the perception of an object strongly associated with a particular grip (e.g., an apple) leads to the automatic access to its associated mental representations including a motor component. The automatic access to this motor component would result in a motor preparation of the usual grip facilitating the execution of a compatible grip and/or impairing the execution of an incompatible grip.

Even if this interpretation is shared by several researchers, some authors have developed an alternative view. Proctor and Miles (2014) argued for instance, that this effect could be due to an overlap of more abstract codes used to represent manipulable objects and response options. They particularly argued that power- and precision-grip responses could be coded as large- and small-responses, respectively. Such motor size codes would overlap the perceptual size codes of the target/object. Indeed, objects usually grasped with a power-grip are also larger than objects usually grasped with a precision-grip (e.g., an apple *vs.* a cherry). In the same vein, Masson (2015) argued that “a more abstract type of compatibility (i.e., size)” explains this potentiation effect rather than the activation of grasping motor representations when perceiving the object. This interpretation is closed to that of the Theory of Event Coding (TEC; Hommel et al., 2001; Hommel, 2013). In this view, Stimulus-Response-Compatibility effects would be due to a match (or a mismatch) between spatial features used to code both stimuli and responses. For instance, the Simon effect would be due to the use of the left/right dimension to indifferently codes stimuli (i.e., located on the left or right side of the screen) and responses (i.e., left or right hand; see Hommel, 2011 for a review). In the case of the potentiation of grasping behaviors, the relevant spatial dimension would be the size (i.e., large *vs*. small) instead of the left/right location.

Accordingly, this size-coding-hypothesis first requires that objects usually grasped with a power- *vs*. precision-grip are automatically coded as large and small objects, respectively. Some elements partially support this hypothesis. First, in most of the studies on the potentiation effect of grasping behaviors, objects were presented in a visual size matching their real size (e.g., Flumini, Barca, Borghi & Pezzulo, 2015; Kalénine, Shapiro, Flumini, Borghi, & Buxbaum, 2014; Makris, Grant, Hadar & Yarrow, 2013; Makris, Hadar & Yarrow, 2011, 2013). Insofar as power-grip-related objects are generally larger than precision-grip-related objects (e.g., an apple *vs*. a cherry), the firsts are thus visually larger than the seconds. Such a visual difference could favor their relative coding as large and small objects. Second, some studies suggested that the familiar size of objects can be automatically retrieved from memory. For instance, Ferrier, Staudt, Reilhac, Jiménez and Brouillet (2007) reported that objects associated with a large or small familiar size prime categorical judgments of objects with a close familiar size compared to objects with an important size difference. It is noteworthy that in this experiment, objects were presented with a constant visual size supporting the critical involvement of the familiar size rather than the visual one (see also Long, Konkle, Cohen & Alvarez, 2016; Long & Konkle, 2017 for converging evidences). In sum, because power- and precision-grip-related objects both differed at the level of visual and familiar (or semantic) size, both factors could favor the automatic size coding of both objects categories.

Another critical requirement of the size-coding-hypothesis is that power- and precision-grips are coded as large and small responses, respectively. According to the TEC (Hommel et al., 2001; Hommel, 2013), alternative responses in a two alternative-forced-choice task are coded thanks to spatial features allowing participants to distinguish between them. For instance, evidence supports that responses could be coded along the left/right, far/near and even up/down dimensions (see Hommel & Elsner, 2009 for a review). In accordance, it is likely that the size could be another spatial feature used to code alternative responses. In the particular case of power- *vs*. precision-grip, at least two components could favor this size coding. First, in all previous experiments, researchers usually used two kinds of device allowing participants to perform both grips. The most usual device is the one originally introduced by Ellis and Tucker (2000). Interestingly, it is composed by a large switch pressed thanks to a power-grip and a small switch pressed thanks to a precision grip (see Figure 1 of Ellis & Tucker, 2000, p. 455). The other frequently used device is a wooden block made of a large and a small part, and participants are usually instructed to grasp the large part with a power-grip and the small part with a precision-grip (e.g., Girardi et al., 2010). For both response devices, actual response alternatives differ according to the size of the targeted part of the device. Second, it is also noteworthy that both grips differed thanks to the size of the effectors part used. Indeed, when participants carry out a power-grip, they use their whole hand (i.e., the large part) while when they carry out a precision-grip, they only used two fingers (i.e., a smaller part). In sum, size coding of responses could occur because of the size of switches and/or the size of the used parts of the effector, especially considering that in experiments usually reporting a potentiation of grasping behaviors, a two alternative-forced-choice task is always used.

To directly test the size-coding-hypothesis, we conducted four experiments. Our goal was to experimentally induce a size coding of two non-grasping responses and to test if manipulable objects (usually associated with a power- or precision-grip) would potentiate them. More specifically, we used an experimental protocol known to induce a potentiation effect of grasping behaviors (Heurley, Morgado, Brouillet & Coutté, submitted) but in which participants had no longer to carry out a power- and a precision-grip. Instead, the device was fixed horizontally on the table and participants had solely to press each of its switches as if they were keys on a keyboard (i.e., the grasping component was removed). In Experiment 1, participants had to press the small-switch with their index-digit and the large-switch with their palm-hand. We selected these particular responses to maximize the possibility that participants coded each response as large and small, respectively. Indeed, we manipulated simultaneously two factors: the switch size (large *vs*. small) and the size of the effector part used to press each switch (i.e., the index-digit: small *vs*. the palm-hand: large). According to the size-coding-hypothesis, we predicted shorter Response Times (RTs) when the response and the object sizes matched together than when they mismatched. In Experiment 2, 3 and 4, we went further by investigating which factors of Experiment 1 allowed the size coding of responses: (1) the size of switch and/or (2) the size of the effector part used to press each switch.

2. Experiment 1

2.1. Method

2.1.1. Participants

Twenty-two participants (6 females; 21 right-handed; m_{age}= 19.6 years; s_{age} = 0.8) with normal or corrected-to-normal visual acuity and without color perception issues (e.g., colorblind) participated to the experiment. All participants were naïve to the goal of the experiment.

2.1.2. Materials and apparatus

We used 12 pictures of fruits and vegetables: six of large fruits or vegetables usually grasped with a power-grip (i.e., apple, avocado, banana, eggplant, lemon, and pear) and six of small fruits or vegetables usually grasped with a precision-grip (i.e., cherry, grape, hazelnut, peanut, radish, and strawberry). All pictures were presented against a white background and in a visual size matching the actual size of the depicted fruits and vegetables (large objects ≈ 10° of visual angle and small objects ≈ 3°). We more specifically designed three versions of each picture (grayscale, blue and orange). These pictures were already used by Heurley et al.

(submitted) (see Appendix; to find all pictures used, see Heurley et al., 2020). We also used a response device similar to the one originally used by Ellis and Tucker (2000). It was composed of two parts: a small cube (1 cm^3) containing a very small switch and a larger PVC cylinder (10 cm tall and 3 cm in diameter) with a large switch placed to the free side of the cylinder (Figure 1).

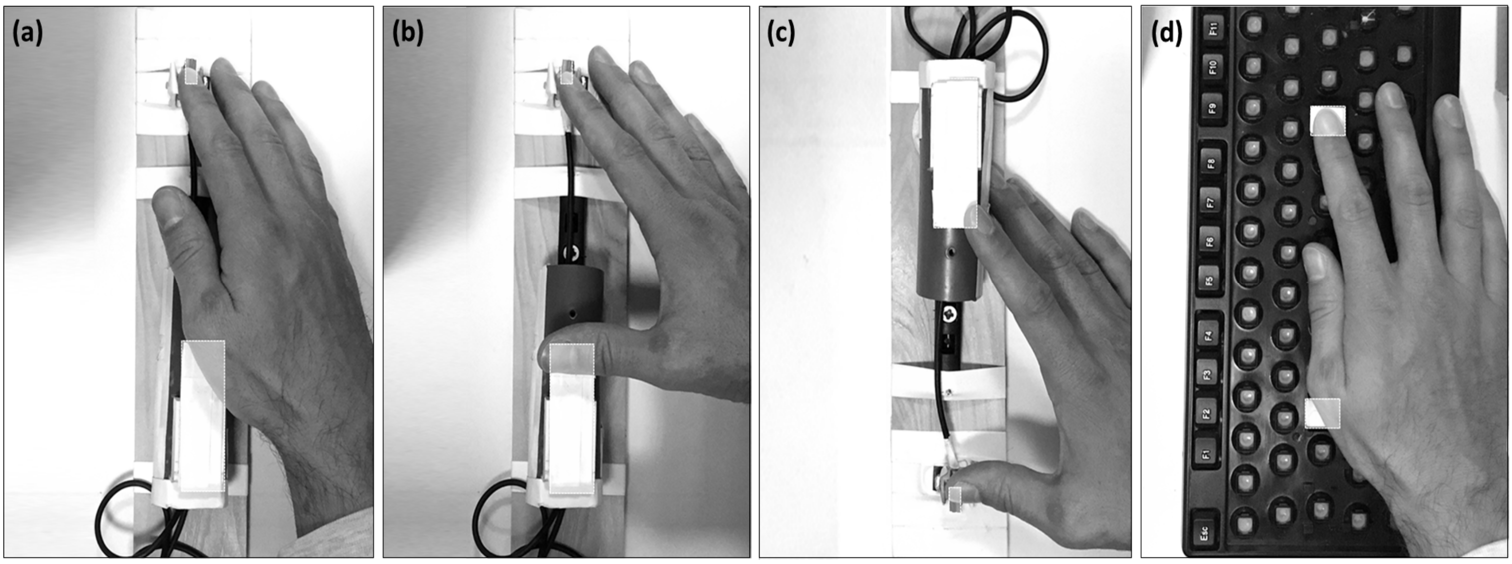

Figure 1 Various kinds of response alternatives and their associated devices used in each experiment (seen from above): (a) Experiment 1, (b) Experiment 2, (c) Experiment 3, and (d) Experiment 4. On each picture, when switches were occulted by the hand, a white transparent square have been added to better understand where switches were located, their size and how participants were instructed to press them.

2.1.3. Procedure

The experiment was run in a quiet room where each participant was seated facing a monitor (23"; refresh rate: 60 Hz; placed at 60 cm). In order to ensure that each participant correctly knew each fruit and vegetable, the experiment began with two preliminary phases. In the first one, the twelve pictures were presented successively with the name of the fruit/vegetable written below. Participants simply read aloud the name of each item. The second was similar except that names were no longer presented below each picture (see Bub, Masson & Cree, 2008, for a similar preparation). Then, a familiarization phase began. During each trial, a fixation cross was first presented at the center of the screen (500 ms) followed by a picture of a fruit/vegetable in grayscale for 200, 400, or 800 ms (Stimulus Onset Asynchrony, SOA). Then, the fruit/vegetable turned orange or blue. The task was to categorize, as soon as possible, the colors of the pictures. Participants were instructed to press the large-switch with their palm-hand while they have to press the small-switch with their index-digit. The device was fixed to a board, itself fixed on the table right in front of the participant (Figure 1a). In addition, the experimenter explained to the participants the mapping between colors and each response switch (i.e., large-switch for blue *vs.* small-switch for orange; counterbalanced between participants). Following the response, a blank screen appeared for 2500 ms. Both responses were recorded using E-prime 2.0 on an HP-Probook-650G1 2.40 GHz computer. After the familiarization phase (24 trials), a test phase took place.

Each trial followed the same procedure. This phase was composed of 144 trials: eight test pictures (cherry, grape, hazelnut, strawberry, apple, avocado eggplant, and pear) randomly presented 18 times, nine times in blue and nine times in orange. There were 48 trials with each prime duration (SOA = 200, 400 or 800 ms). Finally, participants completed a short questionnaire and the Edinburgh Handedness Inventory (Veale, 2013).

2.2. Results and discussion

We examined the RTs with a mixed-design ANOVA with participants as a random factor, the size of objects (large *vs.* small), the responses type (palm-hand/large-switch *vs.* index-digit/small-switch), the SOA (200 ms vs. 400 ms vs. 800 ms) as within-subject factors and the mapping (large-switch/blue *vs.* small-switch/blue) as a between-subject factor. We only analyzed RTs because there were too few errors to analyze response accuracy. Accordingly, we removed familiarization trials, incorrect trials (2.01% of data), and trials for which participants' RTs were below 200 ms or above 1200 ms (0.14% of data) from the analyses (to find all raw data and all analysis performed, see Heurley et al., 2020).

The ANOVA revealed a statistically significant main effect of SOA, $F(2, 20) = 67.76$, $p < .001$, $\eta_p^2 = 0.77$. According to the corrected significance threshold (corrected test-wise $\alpha = .02$ after a Bonferroni correction considering a family of three comparisons), comparisons showed that RTs were significantly longer in the 200 ms-SOA condition (m = 468 ms; s = 58) than 400 ms-SOA condition (m = 434 ms; s = 53), $F(1, 20) = 66.33$, $p < .001$, $\eta_p^2 = 0.77$, and significantly longer in the 200 ms than in the 800 ms-SOA condition (m = 426 ms; s = 53), $F(1, 20) = 113.48$, $p < .001$, $\eta_p^2 = 0.85$. In addition, RTs were marginally longer in the 400 ms-SOA condition than in the 800 ms-SOA, $F(1, 20) = 5.34$, $p = .03$, $\eta_p^2 = 0.21$. The ANOVA also revealed a statistically significant main effect of response type, $F(1, 20) = 27.17$, $p < .001$, $\eta_p^2 = 0.58$. Indeed, RTs were significantly longer when participants pressed the large-switch with their palm-hand (m = 465 ms; s = 58) than when they pressed the small-switch with their index-digit (m = 420 ms; s = 48). Interestingly, the ANOVA revealed a statistically significant interaction between the size of the objects and responses type, $F(1, 20) = 41.83$, $p < .001$, $\eta_p^2 = 0.68$. Based on the corrected significance threshold (corrected test-wise $\alpha = .03$ after a Bonferroni correction considering a family of two comparisons), planned comparisons showed that palm-hand/large-switch RTs were shorter for large objects (m = 453 ms; s = 52) than for small ones (m = 477 ms; s = 62), $F(1, 20) = 26.01$, $p < .001$, $\eta_p^2 = 0.57$. Conversely, index-digit/small-switch RTs were faster for small objects (m = 409 ms; s = 41) than for the large ones (m = 431 ms; s = 51), $F(1, 20) = 16.00$, $p < .001$, $\eta_p^2 = 0.44$ (Figure 2a). The ANOVA failed to reveal any other main effects or interactions, especially the three-way interaction between SOA, size of objects, and response types, $F(2, 20) = 1.22$, $p = .31$, $\eta_p^2 = 0.06$.

Our results confirmed our main prediction. Responses that were possibly coded as large were facilitated by large compared with small objects and the reverse pattern was true for responses that were possibly coded as small. Such results strongly support the size-coding hypothesis. Indeed, it seems that large objects usually associated with a power-grip and small objects usually associated with a precision-grip can potentiate non-grasping manual responses coded respectively as large and small and not only compatible grasping behaviors. In Experiment 2, we wanted to go further and to test more directly whether the size coding of responses relies mainly on the size of switches or on the size of effector parts used. Therefore, we instructed participants to press the small-switch with their index-digit and the large-switch with their thumb-digit (Figure 1b). While there is a clear difference of size between the index-digit and the palm-hand, it is no longer the case between the index- and the thumb-digit. If the size coding of responses is due to the switch size, we should still observe a potentiation effect despite that the used effectors were comparable in size.

Furthermore, it is noteworthy that Experiment 1 led to two other effects of a secondary importance. First, the longer the SOA was, the shorter RTs were. Such a facilitation was already reported in experiments using a similar protocol (e.g., Ferrier et al., submitted). Longer SOA presumably allowed a longer action preparation resulting in shorter RTs. Second, we observed that RTs were shorter when participants pressed the small-switch with their index-digit compared to the condition where they pressed the large-switch with their palm-hand. Such a difference could come from (1) a difference between latencies of each switch, (2) a difference between using the index-digit and the palm-hand or (3) both factors. Next experiments were also designed to address these alternative explanations.

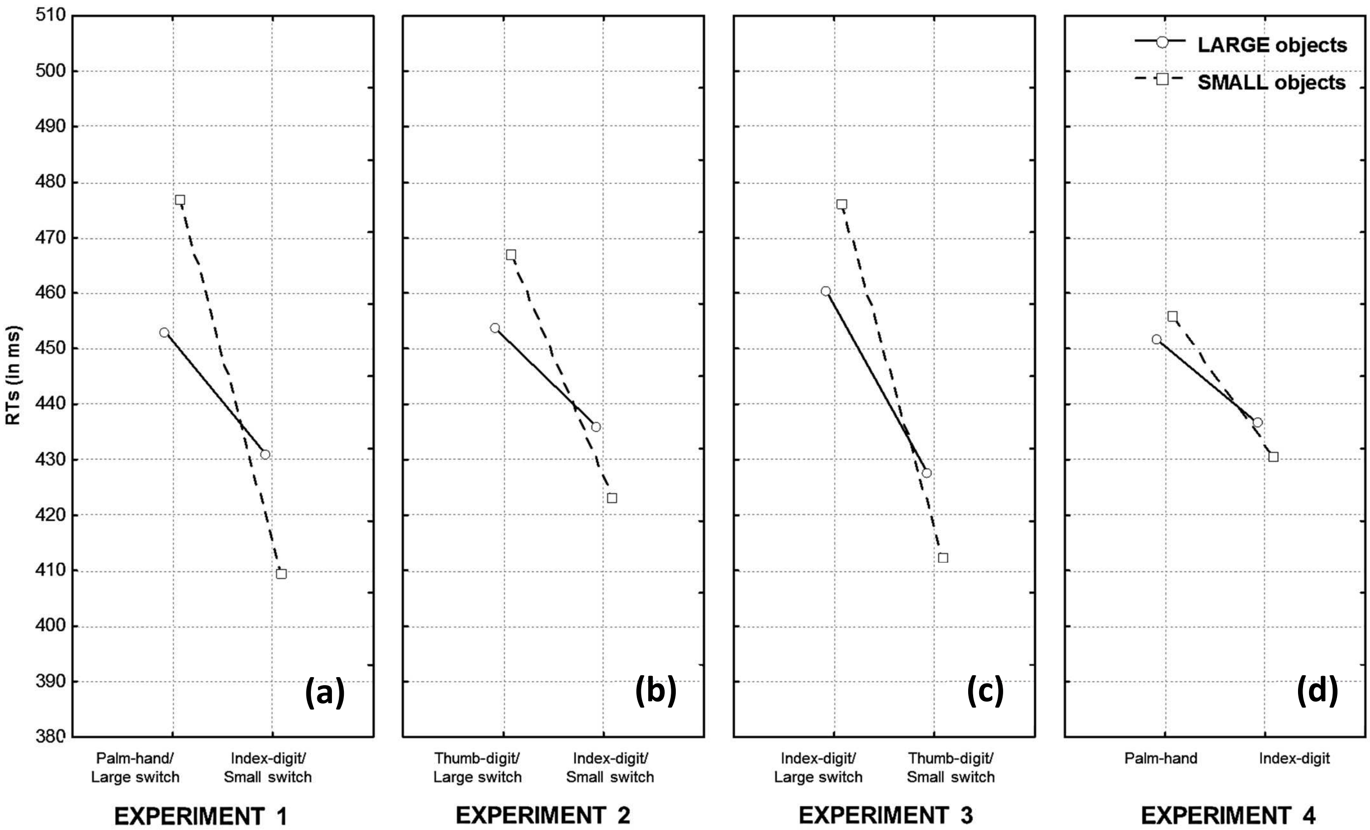

Figure 2 Mean RTs (ms) according to the size of objects (large *vs*. small), the responses type (varying in each experiment), and experiments: (a) Experiment 1 (palm-hand/large-switch *vs*. index-digit/small-switch); (b) Experiment 2 (index-digit/small-switch *vs*. thumb-digit/large-switch); (c) Experiment 3 (index-digit/large-switch *vs*. thumb-digit/small-switch); and (d) Experiment 4 (palm-hand *vs*. index-digit).

3. Experiment 2

3.1. Method

Twenty-two participants (5 females; 18 right-handed; m_{age} = 19.8 years; s_{age} = 0.8), all naïve to the experiment's goal, with normal or corrected-to-normal visual acuity and without any color perception issues participated to the experiment. We used exactly the same pictures, response device and procedure as in Experiment 1. The only difference was that we instructed participants to press the large-switch with their thumb-digit (and not with their palm-hand) and the small-switch with their index-digit (Figure 1b).

3.2. Results and discussion

As in Experiment 1, we conducted a mixed-design ANOVA on RTs with participants as a random factor, the size of objects (large vs. small), the responses type (thumb-digit/large-switch vs. index-digit/small-switch), the SOA (200 ms vs. 400 ms vs. 800 ms) as within-subject factors and the mapping (large-switch/blue vs. small-switch/blue) as a between-subject factor. We removed familiarization trials, incorrect trials (2.24% of data), and trials for which each participant's RTs were below 200 ms or above 1200 ms (0.22% of data) from the analyses.

The ANOVA revealed a statistically significant main effect of SOA, $F(2, 20) = 43.52$, $p < .001$, $\eta_p^2 = 0.69$. According to the corrected significance threshold (corrected test-wise α = .02 after a Bonferroni correction considering a family of three comparisons), RTs were significantly longer in the 200 ms-SOA condition (m = 469 ms; s = 66) than in the 400 ms-SOA condition (m = 437 ms; s = 60), $F(1, 20) = 45.57$, $p < .001$, $\eta_p^2 = 0.69$, as well as than in the 800 ms-SOA condition (m = 429 ms; s = 57) was significant, $F(1, 20) = 69.92$, $p < .001$, $\eta_p^2 = 0.78$. RTs were marginally longer in the 400 ms-SOA condition than in the 800 ms-SOA condition, $F(1, 20) = 5.34$, $p = .03$, $\eta_p^2 = 0.21$, $F(1, 20) = 3.86$ $p = .06$, $\eta_p^2 = 0.16$. The main effect of response type was also statistically significant, $F(1, 20) = 20.28$, $p < .001$, $\eta_p^2 = 0.50$. RTs were significantly longer when participants pressed the large-switch with their thumb-digit (m = 460 ms; s = 64) than when they pressed the small-switch with their index-digit (m = 430 ms; s = 59). More important, the interaction between the size of the objects and response type was statistically significant, $F(1, 20) = 18.85$, $p < .001$, $\eta_p^2 = 0.49$. Thumb-digit/large-switch RTs were shorter for large objects (m = 454 ms; s = 63) than for small ones (m = 467 ms; s = 65), $F(1, 20) = 8.68$, $p = .008$, $\eta_p^2 = 0.30$. Conversely, index-digit/small-switch RTs were shorter for small objects (m = 423 ms; s = 55) than for large ones (m = 436 ms; s = 62), $F(1, 20) = 4.91$, $p = .04$, $\eta_p^2 = 0.20$ (Figure 2b). Nevertheless, this last comparison was no longer statistically significant after applying Bonferroni correction even if it fell very close to the corrected threshold (corrected test-wise α = .03 after a Bonferroni correction considering a family of two planned comparisons). In addition, the ANOVA also revealed that the three-way interaction between SOA, size of objects and response types was statistically significant, $F(2, 20) = 10.84$, $p < .001$, $\eta_p^2 = 0.35$ (for all panned comparisons, see Table 1). No other main or interaction effects were statistically significant.

Table 1 Results of performed planned comparisons on RTs (in ms) between conditions where large and small objects were presented for each SOA (200, 400 and 800 ms) and for each response types (thumb-digit/large-switch *vs*. index-digit/small-switch). We report RTs mean in ms (standard deviation), the F details and if there is a significant or a non-significant effect (S and NS respectively) according to the corrected significance threshold (corrected test-wise α = .008 after a Bonferroni correction considering a family of six planned comparisons).

SOA	Response types	Large objects	Small objects	F data			
200 ms	Thumb-digit/large-switch	471 (61)	505 (54)	$F(1, 20) = 13.49$	$p = .002$	$\eta_p^2 = 0.40$	*S*
	Index-digit/small-switch	468 (72)	433 (55)	$F(1, 20) = 9.06$	$p = .007$	$\eta_p^2 = 0.31$	*S*
400 ms	Thumb-digit/large-switch	447 (69)	454 (66)	$F(1, 20) = 0.57$	$p = .57$	$\eta_p^2 = 0.03$	*NS*
	Index-digit/small-switch	429 (52)	418 (44)	$F(1, 20) = 1.31$	$p = .27$	$\eta_p^2 = 0.06$	*NS*
800 ms	Thumb-digit/large-switch	443 (55)	443 (56)	$F(1, 20) = 0.01$	$p = .93$	$\eta_p^2 = 0.00$	*NS*
	Index-digit/small-switch	412 (46)	418 (63)	$F(1, 20) = 0.52$	$p = .48$	$\eta_p^2 = 0.03$	*NS*

Taken together these data support the possibility that the size coding of responses (and in turn the potentiation effect) could merely come from a difference in the size of targeted switches. Indeed, in the present experiment, the size of the used effector parts remained constant because participants had to use their index- and their thumb-digit to respond. Interestingly, the potentiation effect was moderated by the SOA. More specifically, the effect only occured for a 200 ms-SOA condition. We will discuss more specifically this moderation in the "General Discussion" section according to the results of the three other experiments.

A possible limit of Experiment 2 is that some participants could code their thumb-digit as larger than their index-digit. If so, the sizes of switches and of effector parts used were still confounded. Thus, we ran a new experiment to better dissociate both factors. Our strategy was to reverse the mapping between the size of switches and responses. More precisely, participants had to press the small-switch with their thumb-digit and to press the large-switch with their index-digit. Accordingly, opposite predictions could be made. If the size coding and, in turn, the potentiation effect were due to the size of switches, seeing large objects should facilitate pressing the large-switch with the index-digit compared with seeing small objects. Moreover, seeing small objects should facilitate pressing the small-switch with the thumb-digit compared with seeing large objects. In contrast, if the size coding and, in turn, the potentiation effect were due to the size of the used effector part, seeing large objects should facilitate pressing the small-switch with the thumb-digit (i.e., the larger effector part) compared with seeing small objects. Moreover, seeing small objects should facilitate pressing the large-switch with the index-digit (i.e., the smaller effector part) compared with seeing large objects.

4. Experiment 3

4.1. Method

Twenty-two participants (5 females; 20 right-handed; $m_{\text{age}} = 20.3$ years; $s_{\text{age}} = 1.7$) participated to this experiment. They were all naïve to the goal of the experiment and with normal or corrected-to-normal visual acuity as well as without color perception issues. The experiment was similar to Experiment 2 except that we instructed participants to press the large-switch with their index-digit and the small-switch with their thumb-digit (Figure 1c).

4.2. Results and discussion

We conducted a mixed-design ANOVA on RTs with participants as a random factor, the size of objects (large vs. small), the responses type (thumb-digit/small-switch vs. index-digit/large-switch), the SOA (200 ms vs. 400 ms vs. 800 ms) as within-subject factors and the mapping (large-switch/blue vs. small-switch/blue) as a between-subject factor. We removed familiarization trials, incorrect trials (2.38% of data), and trials for which each participant's RTs were below 200 ms or above 1200 ms (0.42% of data) from the analyses.

The ANOVA revealed a statistically significant main effect of SOA, $F(2, 20) = 37.60$, $p < .001$, $\eta_p^2 = 0.65$. According to the corrected significance threshold (corrected test-wise $\alpha = .02$ after a Bonferroni correction considering a family of three comparisons), RTs were significantly longer in the 200 ms-SOA condition ($m = 464$ ms; $s = 67$) than in 400 ms-SOA condition ($m = 438$ ms; $s = 76$), $F(1, 20) = 39.02$, $p < .001$, $\eta_p^2 = 0.66$, and significantly longer in the 200 ms than in the 800 ms-SOA condition ($m = 430$ ms; $s = 69$), $F(1, 20) = 66.34$, $p < .001$, $\eta_p^2 = 0.77$. In addition, RTs were marginally longer in the 400 ms-SOA condition than in the 800 ms-SOA condition, $F(1, 20) = 4.55$, $p = .04$, $\eta_p^2 = 0.19$. A main effect of response type was also statistically significant, $F(1, 20) = 16.51$, $p < .001$, $\eta_p^2 = 0.45$. RTs were significantly longer when participants pressed the large-switch with their index-digit ($m = 468$ ms; $s = 67$) than when they pressed the small-switch with their thumb-digit ($m = 420$ ms; $s = 69$). The interaction between the size of the objects and responses type was statistically significant, $F(1, 20) = 9.14$, $p = .007$, $\eta_p^2 = 0.31$. RTs when participants pressed the large-switch with their index-digit were significantly shorter for large objects ($m = 460$ ms; $s = 61$) than for small ones ($m = 476$ ms; $s = 72$), $F(1, 20) = 6.86$, $p = .02$, $\eta_p^2 = 0.26$. RTs when participants pressed the small-switch with their thumb were shorter for small objects ($m = 412$ ms; $s = 69$) than for large ones ($m = 428$ ms; $s = 67.50$), $F(1, 20) = 4.55$, $p = .04$, $\eta_p^2 = 0.19$ (Figure 2c). Nevertheless, this last comparison was no longer statistically significant after applying Bonferroni correction even if it fell very close to the corrected threshold (corrected test-wise $\alpha = .03$ after a Bonferroni correction considering a family of two planned comparisons). Moreover, the ANOVA did not reveal any other statistically significant main or interaction effects[1], especially the three-way interaction between SOA, size of objects and response types, $F(2, 20) = 0.48$, $p = .62$, $\eta_p^2 = 0.02$.

The results suggested a potentiation effect in the present experiment. Interestingly, such effect supports that the size coding was driven by the size of switches and not by the size of effector used (i.e., digit). Indeed, the facilitation of responses occurred according to the matching between the sizes of objects and switches and not according to the matching between the sizes of objects and digits. For instance, large objects facilitated a response on the large-switch even if participants used the index-digit. Therefore, even if one could argue that

[1] It is noteworthy that the ANOVA revealed a statistically significant three-way interaction between the SOA, the response types, and the mapping that is not directly relevant for our main purpose. Indeed, for each mapping and each SOA, difference between RTs reach the significance threshold (all $p < 0.05$) except when the mapping was large-switch-blue and the SOA was 400 ms, $F(1, 20) = 3.35$, $p = .08$, $\eta_p^2 = 0.14$, and when the mapping was small-switch-blue and the SOA was 800 ms, $F(1, 20) = 4.28$, $p = .05$, $\eta_p^2 = 0.18$.

a size difference could be used to discriminate the index- and the thumb-digit, the effect was nevertheless drove by the switch's size. Furthermore, it is also noteworthy that the potentiation effect was not moderated by the SOA unlike in Experiment 2. Even if Experiments 2 and 3 suggest that the size coding of responses may rely on the size of switches, the size of the used effector parts could also matter in some situations like in our Experiment 1. Indeed, the size difference between the palm-hand and the index-digit was maybe more salient than those between the index and the thumb, which could also have favored the size coding of responses. Accordingly, we conducted a fourth experiment in which we selected switches with a similar size (i.e., keyboard keys) and where participants were instructed to press them either with their palm-hand or index-digit. If a size difference between the used effector parts promotes the size coding of response, a potentiation effect should be observed.

5. Experiment 4

5.1. Method

As in previous experiments, 22 participants (five females; 18 right-handed; m_{age}= 19.8 years; s = 1.3) participated in the experiment. All were naïve about its goal, had normal or corrected-to-normal visual acuity, and did not report any color perception issues. Originally, our sample included 22 participants, but two participants were discarded due to instruction disrespect. In order to avoid a difference that could possibly undermine the statistical power of the present experiment compared to the three others, we recruited two additional participants. We used the same apparatus and procedure as in our previous experiments except that participants no longer replied on a device composed by large and small switches but on two keys of an AZERTY keyboard. Participants were instructed to press the S key with their palm-hand and the L key with their index-digit (all the other keys have been removed; Figure 1d). It is noteworthy that both keys have a similar size.

5.2. Results and discussion

We conducted a mixed-design ANOVA on RTs with participants as a random factor, the size of objects (large vs. small), the responses type (palm-hand vs. index-digit), the SOA (200 ms vs. 400 ms vs. 800 ms) as within-subject factors and the mapping (palm-hand/blue vs. index-digit/blue) as a between-subject factor. We removed familiarization trials, incorrect trials (2.26% of data), and trials for which each participant's RTs were below 200 ms or above 1200 ms (0.30% of data) from the analyses.

The ANOVA only revealed two statistically significant main effects. First, there was a significant main effect of SOA, $F(2, 20) = 19.20$, $p < .001$, $\eta_p^2 = 0.49$. Based on the corrected significance threshold (corrected test-wise $\alpha = .02$ after a Bonferroni correction considering a family of three comparisons), RTs were significantly longer in the 200 ms-SOA condition (m = 461 ms; s = 54) than in the 400 ms-SOA condition (m = 440 ms; s = 56), $F(1, 20) = 15.97$, $p < .001$, $\eta_p^2 = 0.44$, and were significantly longer in the 200 ms than in the 800 ms-SOA condition (m = 429 ms; s = 50), $F(1, 20) = 39.91$, $p < .001$, $\eta_p^2 = 0.61$. In addition, RTs were marginally longer in the 400 ms-SOA condition than in the 800 ms-SOA condition, $F(1, 20)$ =

5.80, p = .03, η_p^2 = 0.22. Second, there was a significant main effect of response type, $F(1, 20)$ = 7.59, p = .02, η_p^2 = 0.28. RTs were longer when participants pressed the key with their palm-hand (m = 454 ms; s = 57) than when they pressed the other key with their index-digit (m = 433 ms; s = 51). Interestingly, the ANOVA did not reveal any other statistically significant main or interaction effects. Especially, the Object Size x Response Type interaction was not statistically significant, $F(1, 20)$ = 1.06, p = .32, η_{p}^2 =.05 (Figure 2d). Despite of this lack of statistical significance, the patterns of results was consistent with the presence of this interaction, at least in our sample. RTs when participants responded with their index-digit were shorter for small objects (m = 430 ms; s = 50) than for large ones (m = 437 ms; s = 52), $F(1, 20)$ = 1.03, p =.32, η_{p}^2 =.05. RTs when participants responded with their palm-hand were shorter for large objects (m = 452 ms; s = 57) than for small ones (m = 455 ms; s = 58), $F(1, 20)$ = 0.48, p = .50, η_{p}^2 =.02. However, both comparisons failed to reach the significance threshold corrected for multiple comparisons (corrected test-wise α = .03 after a Bonferroni correction considering a family of two comparisons). Moreover, the SOA x Object Size x Response Type interaction also failed to reach the significance threshold, $F(2, 20)$ = 0.48, p = .62, η_{p}^2 =.02. Implications of these last results are directly discussed in the general discussion.

6. Additional analyses

To go further and to better understand the reported data, we conducted three additional analyses. The first compared the size of the potentiation effect between Experiment 1 and 2. The second aimed to compare the potentiation effect between Experiment 2 and 3. The last was a power analysis used to investigate whether our sample size was large enough to properly detect a potentiation effect.

6.1. Cross-experiment analysis between Experiment 1 and 2

Our four experiments convincingly support the hypothesis that a difference in the switch size can lead to a potentiation effect. Indeed, even when the grasping component of responses was removed, merely seeing small and large manipulable objects still facilitated responses on a small- and large-switch, respectively (see Experiment 1, 2, and 3). The effector size did not seem to matter (see Experiment 4). Nevertheless, the size of the observed potentiation effect varied across the experiments. Especially, the potentiation-effect size reported in Experiment 1 (i.e., m = 23 ms; s = 16; η_p^2 = 0.68) was larger than the potentiation-effect size reported in Experiment 2 (i.e., m = 13 ms; s = 14; η_p^2 = 0.49). Thus, even if the switch can lead to a potentiation effect, the effector size could also matter. Maybe both independent variables have contributed to the effect size in Experiment 1. To investigate this possibility, we conducted a cross-experiment analysis specifically dedicated to test the effect-size differences between Experiments 1 and 2.

6.1.1. Method

We computed a potentiation effect by participant for each experiment ($n_{\text{Experiment 1}} = n_{\text{Experiment 2}} = 22$). More precisely, we subtracted mean RTs in compatible conditions to the mean RTs in non-compatible conditions. Accordingly, positive values represented a facilitation effect in compatible conditions (compared with the compatible ones, what we called "potentiation effect") while negative values represented a facilitation effect in non-compatible conditions (compared with compatible ones).

6.1.2. Results and discussion

We conducted a mixed-design ANOVA on the size of the potentiation effect with participants as a random factor, the SOA (200 ms vs. 400 ms vs. 800 ms) as a within-subject factor and the experiment (Experiment 1 vs. Experiment 2) as a between-subjects factor. We did not include the mapping (palm-hand/blue vs. index-digit/blue) because it never moderated the potentiation effect in the previous analyses. As we did before, familiarization trials, incorrect trials, and trials for which each participant's RTs were below 200 ms or above 1200 ms were removed from the analyses. We didn't apply a filtering on the size of the potentiation effects themselves.

Interestingly, the ANOVA revealed a statistically significant main effect of experiments, $F(1, 42) = 4.26$, $p = .045$, $\eta_p^2 = 0.09$. More precisely, the size of the potentiation effect observed in Experiment 1 ($m = 23$ ms; $s = 16$) was significantly larger than the one observed in Experiment 2 ($m = 13$ ms; $s = 14$). The ANOVA also revealed a statistically significant main effect of SOA, $F(2, 42) = 7.85$, $p < .001$, $\eta_p^2 = 0.16$. First, according to the corrected significance threshold (corrected test-wise α = .02 after a Bonferroni correction considering a family of three comparisons), the size of the potentiation effect in the 200 ms-SOA condition ($m = 31$ ms; $s = 23$) was marginally larger than the one in the 400 ms-SOA condition ($m = 18$ ms; $s = 20$), $F(1, 42) = 4.52$, $p = .04$, $\eta_p^2 = 0.10$, which was marginally smaller than the one in the 800 ms-SOA condition ($m = 5$ ms; $s = 18$), $F(1, 43) = 4.12$, $p = .049$, $\eta_p^2 = 0.09$. However, the size of the potentiation effect was significantly larger in the 200 ms-SOA condition than in the 800 ms-SOA condition, $F(1, 42) = 13.28$, $p < .001$, $\eta_p^2 = 0.24$. Because the size of the potentiation effect progressively decreased as SOA increased, we compared the size of the potentiation effect to 0 for each SOA. Our goal was to test if the potentiation effect was still statistically significant at 800 ms-SOA. Interestingly, the size of the potentiation effect differed significantly from 0 in the 200 ms-SOA ($F(1, 42) = 34.98$, $p < .001$, $\eta_p^2 = 0.45$) and 400 ms-SOA ($F(1, 42) = 18.22$, $p < .001$, $\eta_p^2 = 0.30$) conditions but not in the 800 ms-SOA conditions ($F(1, 42) = 1.87$, $p = .18$, $\eta_p^2 = 0.04$). This last result suggests a disappearance of the potentiation effect at 800 ms-SOA.

Finally, the SOA x Experiment interaction failed to reach the significance threshold, $F(2, 42) = 2.20$, $p = .12$, $\eta_p^2 = 0.05$. The results of this analysis are discussed in the "General Discussion" in light of the other analyses.

6.2. Cross-experiment analysis between Experiment 2 and 3

We compared Experiment 2 and 3 to overcome a limitation of separate analyses and to better support the size-coding account. Indeed, in both experiments, the potentiation effect was statistically significant when participants had to use the large-switch (whatever the effector-part used). More precisely, participants were faster when they saw a large than a small object. We observed the reversed pattern when participants had to use the small-switch (whatever the effector-part used). Nevertheless, this last difference failed to reach the statistical significance threshold corrected for multiple comparisons in Experiments 2 and 3. In the present analysis, we combined data from both experiments in order to increase our data set. We expected a statistically significant potentiation effect for both responses as predicted by the size-coding account.

6.2.1. Method

We combined data sets of Experiment 2 and 3. Thus, we had a total of 44 participants ($n_{\text{Experiment 2}} = n_{\text{Experiment 3}} = 22$).

6.1.2. Results and discussion

We conducted a mixed-design ANOVA on RTs with participants as a random factor, the size of objects (large vs. small), the responses type (large-switch vs. small-switch) as within-subject factors and the experiment (Experiment 2 vs. Experiment 3) as a between-subjects factor. We did not include the mapping nor the SOA because we did not have any specific predictions for these variables. As we did before, familiarization trials, incorrect trials, and trials for which each participant's RTs were below 200 ms or above 1200 ms were removed from the analyses.

The ANOVA revealed a statistically significant main effect of response type, $F(1, 42) = 34.52$, $p < .001$, $\eta_p^2 = 0.45$. RTs were significantly longer when participants pressed the large-switch whatever the effector ($m = 464$ ms; $s = 59$) than when they pressed the small-switch ($m = 425$ ms; $s = 56$). The ANOVA failed to reveal either a statistically significant main effect of the experiment, $F(1, 42) = 0.00$, $p = .96$, $\eta_p^2 = 0.00$, or of the size of objects, $F(1, 42) = 0.01$, $p = .94$, $\eta_p^2 = 0.00$. As expected, the ANOVA revealed a statistically significant interaction between the size of the objects and the responses type, $F(1, 42) = 24.24$, $p < .001$, $\eta_p^2 = 0.37$. Based on the corrected significance threshold (corrected test-wise $\alpha = .03$ after a Bonferroni correction considering a family of two comparisons), planned comparisons showed that large-switch RTs were shorter for large objects ($m = 457$ ms; $s = 56$) than for small ones ($m = 472$ ms; $s = 60$), $F(1, 42) = 15.67$, $p < .001$, $\eta_p^2 = 0.27$. Conversely, small-switch RTs were faster for small objects ($m = 417$ ms; $s = 56$) than for the large ones ($m = 432$ ms; $s = 56$), $F(1, 42) = 9.77$, $p < .003$, $\eta_p^2 = 0.19$. The ANOVA failed to reveal any other statistically significant interactions, especially the three-way interaction between the experiment, the size of objects and the response, $F(2, 42) = 0.17$, $p = .68$, $\eta_p^2 = 0.00$.

Accordingly, increasing our data set by merging data of Experiment 2 and 3 revealed that a potentiation could be statistically significant for both response possibilities. It is also interesting to note that the mean size of the potentiation effect (i.e., the difference between non-compatible and compatible conditions) was approximately the same for responses performed on the large-switch ($m = +15$ ms; $s = 24$) and responses performed on the small-switch (m = +14 ms; s = 30) while there was a difference between the partial eta square (η_p^2 for large-switch = 0.27 vs. η_p^2 for small-switch = 0.19). This peculiar pattern will be discussed in the general discussion.

6.3. Power analysis

One could argue that our experiments were underpowered. This is a legitimate concern given that we planned our sample size based on those of previous studies rather than conducting a power or precision analysis. Thus, we assessed whether our research design could detect our effect of interest with proper statistical power given our sample size using G*Power 3 (Faul, Erdfelder, Lang, & Buchner, 2007). Our smallest effect of theoretical interest was the Object Size x Response Type interaction effect on RTs. As it is often difficult to know what particular value of effect size to include in a power analysis, we conducted several power analyses allowing to have a range of possible values of statistical power rather than just one value. This approach is more sensitive than considering only one value as it better reflects the uncertainty inherent to all power analyses than relying only on a single value.

We conducted a random-model meta-analysis using ESCI (Cumming, 2012) to better estimate the size of the Object Size x Response Type interaction effect on RTs. Including our four experiments resulted in a *Hedges' g* = 0.93, 95% CI for δ = [0.17, 1.78]. As predicted given the differences in research design for some of our experiments, including all four experiments led to a very large overall between- experiment heterogeneity (I^2 = 88.66 %)[2].

Thus, the meta-analytical effect size could have underestimated the true effect because of the relatively small effect observed in Experiment 4. Including the first three experiments resulted in a *Hedges' g* = 1.25, 95% CI for δ = [0.79, 1.81]. However, the overall between-study heterogeneity (I^2 = 55.23 %) was still large, which was predictable according to the relatively larger effect size observed in Experiments 1. Finally, including only Experiments 2 and 3 yielding a *Hedges' g* = 1.02, 95% CI for δ = [0.68, 1.44] with virtually no between-experiment heterogeneity (I^2 = 0.00%). Regular power analyses indicated that our research design had a statistical power of 98.66%, 99,99%, and 99.53 % to detect these effects, respectively (two-tailed repeated measure test, α = .05) with a sample size of 22 participants (for all results, see Table 2).

To avoid being too optimistic, we also conducted safeguard power analyses (Perugini, Gallucci, & Costantini, 2014) using the lower limit of the 60% CI of the effect sizes as our smallest effect sizes of interest. For such worst-cases scenarios, the analyses indicated that our research design had a statistical power of 79.95%, 99.80%, and 98.01% to detect effects as large as *Hedges' g* = 0.63, 1.08, and 0.90, respectively (two-tailed repeated measure test, α = .05). Thus, given our current knowledge about our minimum effect size of interest, our research design had reasonable chance to detect it even in the worst-case scenario (i.e., 79.95% statistical power).

[2] As Cumming (2012, p. 217) reminded I^2 expresses the amount of between-experiments variability (over the total variability) that cannot be explained by random sampling error and reflect actual differences in the effect sizes that could be rather explained by actual differences between research designs.

Table 2 Results of the regular and safeguard power analyses according to various potential values of the expected effect size.

	REGULAR POWER ANALYSES			SAFEGUARD POWER ANALYSES		
Meta-analysis	**Expe. 1 to 4**	**Expe. 1 to 3**	**Expe. 2 & 3**	**Expe. 1 to 4**	**Expe. 1 to 3**	**Expe. 2 & 3**
Effect size	0.93	1.25	**1.02**	*0.62*	1.08	0.90
Power (%)	98.66	99.99	**99.53**	*79.95*	99.90	98.02

Note. The most plausible scenario and the worst-case scenario according to our current data are highlighted in bold and italic fonts, respectively.

7. General Discussion

Our goal was to test whether the potentiation of grasping behaviors (e.g., Ellis & Tucker, 2000) can be explained by an overlap of a size code indifferently used to represent manipulable objects and responses. Such a size-coding-hypothesis is clearly opposed to the idea that potentiation effect relies on the activation of grasping motor representations during the mere perception of manipulable objects as argued in various embodied views (e.g., Barsalou, 2008). Results of our four experiments strongly support the size-coding-hypothesis. Indeed, in our experiments the performed responses were no longer grasping behaviors compatible or not with presented objects, but mere keypress responses associated to different sizes codes. Despite of this, graspable objects still elicited a potentiation effect. More precisely, when participants had to press a large-switch, shorter RTs occurred when large manipulable objects were presented (e.g., an apple) than when small manipulable objects (e.g., a cherry) were. We obtained a reverse pattern when participants had to press a small-switch. In sum, data reported support the critical hypothesis that manipulable objects do not only facilitate power- and precision-grip-responses but also more classical keypress responses when they are associated with a large/small size code.

Our various experiments also support that the size coding of responses critically relies on the size of the targeted switches. Indeed, results of Experiments 2 and 3, across which we varied the switch size and the effectors, indicated that the potentiation effect was only driven by the switch size. It is nevertheless noteworthy that the potentiation effect reported with the small switch seems less clear than the one reported for the large switch. Indeed, this effect failed to reach the corrected statistical significance threshold during planned comparisons. Nevertheless, when we merged data of Experiment 2 and 3 as in our second cross-experiment analysis, it became statistically significant[3]. In addition, despite the evidence conveyed by each individual experiment, the first cross-experiment analysis suggested that the potentiation

[3] Interestingly, the mean size of the potentiation effect (i.e., difference between compatible and non-compatible) was quite similar for both response possibilities (i.e., $m_{\text{large-switch}} = +15$ ms; $s = 24$ vs. $m_{\text{small-switch}} = +14$ ms; $s = 30$) but there was a difference between partial eta squares. More precisely, the partial eta square was larger for the small (i.e., 0.19) than for the large switch (i.e., 0.27). This pattern support that for the small switch compared to the large one, there was a larger variability of the potentiation effect between participants. Indeed, when we took a closer look at the standard deviation, we can see that it was larger for the potentiation effect on the small switch (i.e., 30 ms) compared to the one reported for the large switch (i.e., 24 ms). This increased variability diminished the power of the ANOVA to detect the mean difference. This explains why when we performed separate analysis, the effect failed to reach the statistical significance threshold and that we had to increase the size of the data set to get a statistically significant difference (for a discussion on the difference between standardized and non-standardized size effect, see Baguley, 2009).

effect found in Experiment 1 was significantly larger than the one reported in Experiment 2. This difference might suggest that both the switch size and the effector size explained the potentiation effect observed in Experiment 1. Thus, the effector size might only matter when there is also a difference between the sizes of the targeted switches. This hypothesis is consistent with the absence of a statistically significant potentiation effect in Experiment 4 where both responses only differed according to the effector size.

Nevertheless, because we did not performed an a priori power or precision analysis to determine the sample size (n = 22) of our experiments, it is possible to argue that the absence of a statistically significant potentiation effect in Experiment 4 could be due to an underpowered design. To overcome such a limit, we assessed whether our research design could detect our potentiation effect with proper statistical power given our sample size. This power analysis supported that our sample size was reasonably adequate even when we performed highly conservative power analysis (i.e., safeguard; see Perugini, Gallucci, & Costantini, 2014). Altogether, our data supported the idea that the switch size was enough to lead to a size coding of responses. In addition, the size of the used effector part could also matter but seemingly only when the size of switches differed. It is nevertheless noteworthy that such a conclusion about the effector size is only valuable when comparing responses performed with the palm-hand and responses performed with the index-digit. More generally, in experiments reporting a potentiation of grasping behaviors, usually two devices can be used each composed by a large component grasped with a power-grip and a small component grasped with a precision-grip. Thus, one could argue that in these experiments, the size of device parts could favor a size coding of actual responses alternatives resulting in a potentiation effect. Nevertheless, even if our experiments critically support the involvement of the size of switches, it is possible that the size of the used effector parts could also play a role for another kind of responses. For instance, when performing a power-grip, more digits are used and the tactile sensation on the palm-hand is larger than when performing a precision-grip. Such differences at the level of the used effector parts could also take part to the automatic size coding in more classical protocols.

Data of Experiment 2 suggested that the potentiation effect reported could be sensitive to the duration of the grayscale prime. Indeed, it only occurred for the shortest SOA (i.e., 200 ms compared with 400 ms and 800 ms). In this experiment, participants had to press the large-switch with their thumb-digit and the small-switch with their index-digit. Our main idea was that SOA might only moderate the size coding based on a difference between switch size, but not the size coding based on a difference between the sizes of effector parts. It could explain why the SOA moderation only occurred in Experiment 2 and not in Experiment 1. Unfortunately, results of Experiment 3 and 4 were not compatible with this view. As in Experiment 2, we only manipulated the size of switches in Experiment 3. Therefore, the SOA should also have moderated the potentiation effect, but it was not the case. Moreover, in Experiment 4, in which we only manipulated the size of effector parts, a potentiation effect should have occurred and should not have been moderated by the SOA. Again, data do not support this prediction because no potentiation effect occurred in this experiment. In addition, the cross-experiment analysis between Experiment 1 and 2 revealed a statistically significant main effect of SOA. More precisely, it seems that the size of the potentiation effect decreased when the SOA became longer. Moreover, the analysis revealed that even if the size of the potentiation effect was statistically significant for the 200 ms- and 400 ms-SOA, it is not the case for the 800 ms-SOA, suggesting a disappearance of the effect for this latter condition. This results partially matched results in the literature supporting that the temporal window of the potentiation effect of grasping behaviors is relatively transient. Indeed, Makris et al. (2011) only observed this effect when the grayscale prime lasted during 400 ms but not during 800 ms or 1200 ms, which match the results of our cross-experiment analysis, but did not match the results of our Experiments 1, 2, and 3 taken separately. In one of our recent study, we observed a potentiation effect only for a short SOA (i.e., for 200 ms, but not for 400 ms and 800 ms; Ferrier et al., submitted), which fits the results of our Experiment 2 but not those of our Experiments 1 and 3 or those of our cross-experiment analysis. In sum, these various results seem to suggest that even if the potentiation effect could be transient and moderated by the SOA, it is not enough reliable to clearly observed it with our current protocol. Futures researches should be specifically designed to study this temporal course and particular conditions inducing it especially considering that some studies were able to support the earlier and long-lasting nature of some potentiation effects (e.g. Pellicano, Koch, & Binkofski, 2017; Pellicano & Binkofski, 2020).

Our four experiments also exhibited two other results. First, responses were globally affected by the SOA. The longer SOA was, the shorter RTs were. We already reported such a main effect of SOA in previous studies (Ferrier et al., submitted). This link between RTs and SOA is well-known. Indeed, when the foreperiod (i.e., the delay between the warning signal, here the fixation cross, and the reaction signal, here the color change) varies (here, 200, 400, or 800 ms) within a block, the longest RTs are observed after the shortest foreperiod. This pattern perfectly fits our own data. It is assumed that when foreperiods are variable, such a pattern emerges because participants have few reliable information to help them in the proper timing of their preparation (Niemi & Näätänen, 1981). Another result is that there was a difference of RTs between response alternatives. More specifically, in Experiment 1, participants were slower to press the large-switch with their palm-hand than to press the small-switch with their index-digit. Two possible hypotheses can be assumed to explain this result. First, participants might have been slower to press the larger switch for technical reasons (e.g., the switch had longer response latencies). Second, participants might have been slower to perform an action with their palm-hand than with their index-digit. Experiment 2 and 3 support the first possibility. Indeed, participants were again longer to press the larger switch compared to the smaller one, independently of the digit used (i.e., index- or thumb-digit). In addition, Experiment 4 supports also the second hypothesis. Indeed, when switches were of a similar size, participants were longer to perform a response with their palm-hand compared to their index-digit. In sum, the difference reported in Experiment 1 is undoubtedly due to the fact that participants were both slower to perform a response with their palm-hand (than with their index-digit) and to press the large switch (than the small one). Nevertheless, this last possibility must be taken cautiously because it deserves a deeper technical investigation of the device.

Finally, our data support the view suggesting that the potentiation effect of grasping behaviors could be due to a size coding of manipulable objects and actual responses alternatives (Masson, 2015; Proctor & Miles, 2014). Moreover, such data are particularly interesting because they support the possibility that responses in a two alternative-forced-choice task could be discriminated not only according to their left/right, far/near or up/down dimensions, but also according to the size dimension. This possibility extends the current version of the TEC and adds the size on the list of critical spatial features of actions (see Camus, Hommel, Brunel & Brouillet, 2018 and Coutté, Camus, Heurley & Brouillet, 2017 for converging evidences). To go further, it is noteworthy that our results cannot be taken as a guarantee that the more classical potentiation effect of grasping behaviors (e.g., Ellis & Tucker, 2000) can only be explained by the size-coding-hypothesis. Indeed, it is possible that when participants performed a power- or a precision-grip matching the kind of grips associated with manipulable objects two processes co-exist. First, a process coding the size of manipulable objects and of alternative responses would lead to a potentiation effect based on an representation of the size. Second, another process would be at stake when there is a match between the grasping representations automatically evoked by manipulable objects and the used grip. Indeed, recently, several studies have supported that the potentiation effect observed with manipulable objects with a handle oriented toward the right or left could involve both attentional processes and an automatic access to motor representations (e.g., Ambrosecchia, Marino, Gawryszewski & Riggio, 2015; Kourtis & Vingerhoets, 2015; Kostov & Janyan, 2012, 2015; Saccone, Churches & Nicholls, 2016). Future researches should be designed to test if it can be also the case for the potentiation of grasping behaviors.

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9. References

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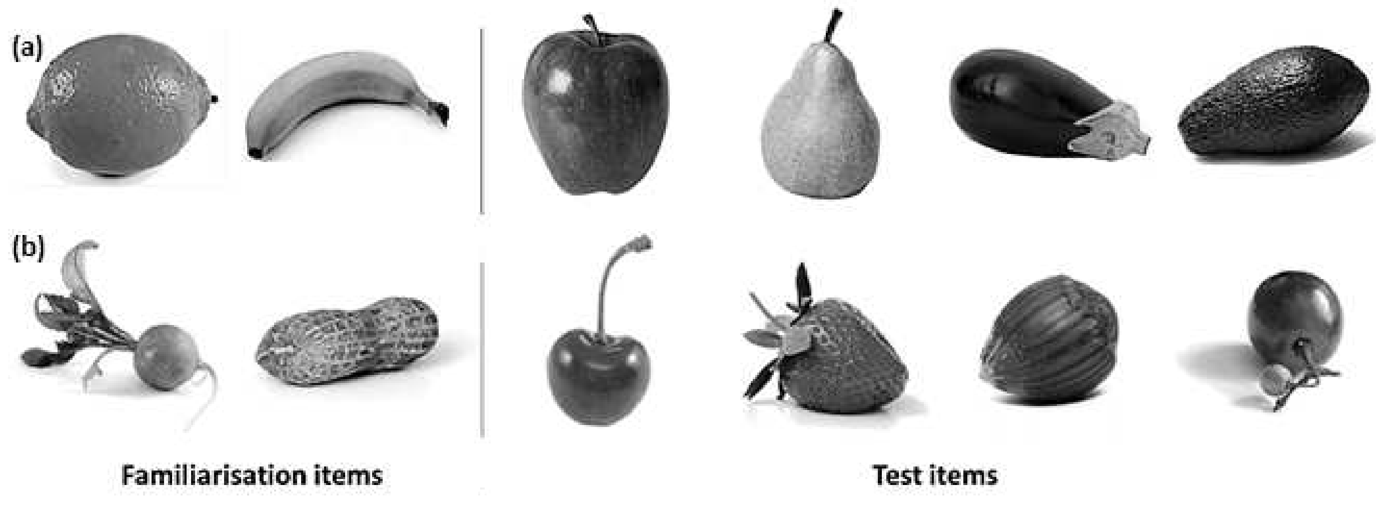
10. Appendix

Large (a) and small (b) objects used in both experimental phases.



11. Figure and table captions

Figure 1 Various kinds of response alternatives and their associated devices used in each experiment (seen from above): (a) Experiment 1, (b) Experiment 2, (c) Experiment 3, and (d) Experiment 4. On each picture, when switches were occulted by the hand, a white transparent square have been added to better understand where switches were located, their size and how participants were instructed to press them.

Figure 2 Mean RTs (ms) according to the size of objects (large vs. small), the responses type (varying in each experiment), and experiments: (a) Experiment 1 (palm-hand/large-switch vs. index-digit/small-switch); (b) Experiment 2 (index-digit/small-switch vs. thumb-digit/large-switch); (c) Experiment 3 (index-digit/large-switch vs. thumb-digit/small-switch); and (d) Experiment 4 (palm-hand vs. index-digit).

Table 1 Results of performed planned comparisons on RTs (in ms) between conditions where large and small objects were presented for each SOA (200, 400 and 800 ms) and for each response types (thumb-digit/large-switch vs. index-digit/small-switch). We report RTs mean in ms (standard deviation), the F details and if there is a significant or a non-significant effect (S and NS respectively) according to the corrected significance threshold (corrected test-wise $\alpha = .008$ after a Bonferroni correction considering a family of six planned comparisons).

Table 2 Results of the regular and safeguard power analyses according to various potential values of the expected effect size. Note. The most plausible scenario and the worst-case scenario according to our current data are highlighted in bold and italic fonts, respectively.

12. Footnotes

[1] It is noteworthy that the ANOVA revealed a statistically significant three-way interaction between the SOA, the response types, and the mapping that is not directly relevant for our main purpose. Indeed, for each mapping and each SOA, difference between RTs reach the significance threshold (all $p < 0.05$) except when the mapping was large-switch-blue and the SOA was 400 ms, $F(1, 20) = 3.35$, $p = .08$, $\eta_p^2 = 0.14$, and when the mapping was small-switch-blue and the SOA was 800 ms, $F(1, 20) = 4.28$, $p = .05$, $\eta_p^2 = 0.18$.

[2] As Cumming (2012, p. 217) reminded I^2 expresses the amount of between-experiment variability (over the total variability) that cannot be explained by random sampling error and reflect actual differences in the effect sizes that could be rather explained by actual differences between research designs.

[3] Interestingly, the mean size of the potentiation effect (i.e., difference between compatible and non-compatible) was quite similar for both response possibilities (i.e., $m_{\text{large-switch}} = +15$ ms; $s = 24$ vs. $m_{\text{small-switch}} = +14$ ms; $s = 30$) but there was a difference between partial eta squares. More precisely, the partial eta square was larger for the small (i.e., 0.19) than for the large switch (i.e., 0.27). This pattern support that for the small switch compared to the large one, there was a larger variability of the potentiation effect between participants. Indeed, when we took a closer look at the standard deviation, we can see that it was larger for the potentiation effect on the small switch (i.e., 30 ms) compared to the one reported for the large switch (i.e., 24 ms). This increased variability diminished the power of the ANOVA to detect the mean difference. This explains why when we performed separate analysis, the effect failed to reach the statistical significance threshold and that we had to increase the size of the data set to get a statistically significant difference (for a discussion on the difference between standardized and non-standardized size effect, see Baguley, 2009).