“ 2×3 ” primes naming “6”: Evidence from masked priming

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It is a common assumption for multiplication-solving models that single-digit multiplications are automatically retrieved. However, the experimental evidence for this is based on paradigms under suspicion. In this research, we employed a new procedure with the aim of assessing the automatic retrieval of multiplication more directly. In two experiments, multiplication automatism was studied using briefly presented primes (stimulus onset asynchrony = 48 msec) in a number-naming task. In Experiment 1, in the congruent conditions, the target and the prime were the same numbers (e.g., prime, 6; target, 6) or the target was the solution to the multiplication prime (e.g., prime, $2 \times 3 =$; target, 6). In the incongruent conditions, no relationship existed between the primes and the targets (e.g., prime, 32; target, 6; or prime, $4 \times 8 =$; target, 6). Experiment 2 explored the relevance of the equal sign for the multiplication-priming effect. Data showed that naming was faster when the solution of the multiplication prime matched the target, as compared with the incongruent condition (multiplication-priming effect), and that these effects were found irrespective of the presence of the equal sign. The fact that this priming effect was found even though the participants were unaware of the presentation of the primes supports the automatic character of single-digit multiplication. We conclude by arguing that this procedure is highly valuable for exploring the mechanisms involved in simple arithmetic solving.

Multiple mechanisms exist for solving single-digit multiplications. Research has shown that people use such strategies as counting, adding, or memory retrieval (see, e.g., Hecht, 1999; LeFevre et al., 1996; Romero, Rickard, & Bourne, 2006; Roussel, Fayol, & Barrouillet, 2002). Nevertheless, most researchers have assumed that the most common way that adults solve single-digit multiplication is by means of the retrieval of stored knowledge representations. The precise mechanisms involved in retrieving the solution from memory are not clear. Some authors have suggested that operands activate their solution by means of associations (e.g., Rickard, 2005; Roussel et al., 2002; Siegler & Jenkins, 1989). It has been suggested that operands can activate a representation that includes both the operands and the solution to that operation (e.g., Campbell, 1995; Manly & Spoehr, 1999). It has also been argued that operands can activate their solution as well as multiples of the problem's operands because they are represented in an interrelated network (e.g., Ashcraft, 1992; Campbell, 1987; Stazyk, Ashcraft, & Hamann, 1982).

Independently of the mechanisms involved in single-digit multiplication retrieval, it is a common assumption in the literature that this process is automatic; that is, single-digit multiplications are retrieved quickly, effortlessly, and without intention. This assumption is the focus of the present research.

The experimental support for the automatic character of single-digit multiplication retrieval has come mainly from the existence of interference in different tasks (see Galfano,

Rusconi, & Umiltà, 2003, for a review). In the *cross-operation-interference paradigm*, it is observed that people are slower in rejecting false additions when the stated result is the correct result of a multiplication (associative lure; e.g., $3 + 4 = 12$; see, e.g., Winkelman & Schmidt, 1974; Zbrodoff & Logan, 1986). In the *within-operation-interference paradigm*, people are slower in rejecting a false multiplication when the stated result is a multiple of one of the operands (associative lure; e.g., $3 \times 4 = 16$; see, e.g., Lemaire, Abdi, & Fayol, 1996; Stazyk et al., 1982).

Following a procedure called the *number-matching paradigm* (LeFevre, Bisanz, & Mrkonjic, 1988), Thibodeau, LeFevre, and Bisanz (1996) presented participants with pairs of numbers, which, after a variable time interval (60, 100, 120, 220, or 350 msec), were replaced by a number probe. The participants had to decide whether the probe was one of the numbers previously presented or not. Results showed that with short stimulus onset asynchronies (SOAs), participants took a longer time rejecting items in which the probe was the solution to the multiplication of the previous operands (e.g., 3 6 and 18) than items in which the probe was unrelated to the initial pair (e.g., 3 6 and 14). In addition, Galfano et al. (2003) found, using an SOA of 120 msec, that the interference effect extended to the above and below nodes of the multiplication that was activated by the presentation of two numbers (i.e., seeing 3 6 would interfere with 15 through the below node 3×5).

Although these data suggest that multiplication solutions are automatically activated, the interference stud-

ies posed some problems when it came to exploring the automaticity of multiplication. (1) Participants' arithmetic knowledge is explicitly required in some experimental tasks (e.g., cross- and within-operation-interference paradigms). (2) In many of the experiments, there is room for strategic processes in the task, since SOAs are usually larger than 250 msec (see Neely, 1991), and this does not seem adequate when a process like multiplication solving is studied, where other procedures different from memory retrieval exist—that is, strategic processes such as adding or counting (see, e.g., Hecht, 1999; LeFevre et al., 1996; Romero et al., 2006). (3) In research that employed SOAs shorter than 250 msec, the operands are always explicitly shown to the participants, and this could facilitate the appearance of retroactive priming effects. (4) The tasks presented to the participants are usually unnatural (e.g., verification, number-matching paradigm).

Recent research has suggested that the number-matching task might be inadequate for measuring the automatic retrieval of arithmetical facts. García-Orza and Damas (2008) have found interference effects in cue–probe pairs that are nonassociatively related (e.g., cues, 10 17; probe, 24; and cues, 13 84; probe, 97). The within-operation and cross-operation (lure) effects in verification tasks are thought to be caused by the activation of the solutions corresponding to the incorrect operation (e.g., $3 + 4 = 12$). According to Zbrodoff and Logan (1986, 1990), once the two operands are encoded, activation should spread to both the sum and the product. However, more recent research has shown that familiarity plays a bigger role in this task than does solution retrieving (Campbell & Tarling, 1996). Since associative lures are more similar to correct representations in stored arithmetical fact knowledge (and hence, more familiar) than are nonassociative lures (e.g., $3 + 4 = 12$ is more similar to $3 \times 4 = 12$, an arithmetical fact stored in participants' knowledge, than $3 + 4 = 8$ is to $3 + 4 = 7$), it could be argued that the interference effect in verification tasks might be due not to the automatic retrieval of the solution, but to the familiarity of the whole stimuli (note that in verification tasks, both the operands and the solutions are provided). In other words, since a verification decision can be made on the basis of familiarity, the associative lure effect is not necessarily a consequence of automatic arithmetical fact solving. Moreover, in more recent research, Romero et al. (2006) have documented the use of strategies different from memory retrieval in verification tasks with single-digit multiplications.

For these reasons, it seems important to use other procedures to examine whether multiplication solutions are automatically activated. In the present research, single-digit multiplications were presented briefly as masked primes in a number-naming task. To avoid undesired effects, the prime was masked, which additionally supported the automatic character of the process. The rationale of the procedure was as follows: If 2×3 is automatically retrieved, it should facilitate the processing of 6; similarly, it might also be considered that the presentation and activation of the solution of an incongruent problem (e.g., 4×8) could make it difficult to process a target number (e.g., 6).

Using problems as masked primes in a naming task with a brief SOA had many advantages: (1) Since the operands were not consciously seen, strategic effects, such as the expectation that the observation of the primes could induce, were avoided; (2) it allowed us to directly test whether single-digit multiplications are automatic, avoiding the effects that the use of operands in the frame of other problems or in displays where each operand appears independently of the other could cause; and (3) the task was very natural for the participants, since they had only to name the targets.

During the course of our research, Jackson and Coney (2005; see also Jackson & Coney, 2007, for the role of individual differences) published research in which problems were used as primes, although they were not masked. Participants were presented with numbers as targets and additions and multiplications as primes in three SOA conditions: 120, 240, and 1,000 msec. Regarding multiplications, they got priming effects in the 240- and 1,000-msec SOA conditions and found priming effects with the smaller SOA only for small problems (i.e., when both operands were equal to or lower than 5). These data add support to the view of multiplication as an automatic process. Jackson and Coney (2005) used an SOA (120 msec) short enough to avoid *proactive* effects on the response to the target, but since the primes were consciously presented, there was a chance for *retroactive* effects to appear. In other words, even though the actual process of identifying the target could be unaffected by the prime, the realization of the relationship between the prime and the target could lead to faster decisions in the following trials (see Forster, Mohan, & Hector, 2003). We used masked priming in the present research to avoid these undesirable retroactive effects.

Masked priming is a well-known paradigm (for reviews, see Forster, 1998; Forster et al., 2003) that has recently been used in some number-processing studies (e.g., Naccache & Dehaene, 2001; Reynvoet & Brysbaert, 2004). For instance, Reynvoet and Brysbaert (2004, Experiment 2) explored whether semantically related numbers facilitate number naming, using SOAs of 43, 57, 86, and 115 msec. These researchers used both verbal and Arabic numbers as masked primes and targets in an across-notation design (target, six; prime, 6; and target, 6; prime, six). They found that priming decreased as the distance between the prime and the target increased (regarding Arabic numbers, this implies that six is primed more by 6, primed less by 5, and primed slightly by 4). Naccache and Dehaene, using Arabic and verbal notation, also found distance-related priming effects in a magnitude judgment task (i.e., *Is the target larger or smaller than 5/five?*) using a masked prime that was presented for 43 msec. In a subsequent experiment, they also confirmed that this masked priming effect was semantic and not due to response association effects (Greenwald, Abrams, Naccache, & Dehaene, 2003). It would seem that masked priming is a paradigm well suited for exploring number-processing mechanisms and, interestingly for us, presents the opportunity to study whether a prime can influence the processing of a target even though it is not overtly recognized by the participants. This would support the idea of multiplication as an automatic process.

In this research, Arabic notation was always used throughout the course of the experiments. Numbers and single-digit multiplications were presented as masked primes with an SOA of 48 msec. In Experiment 1, in the congruent condition, either the target and the prime were the same number or the target was the solution to a multiplication presented as a prime. In the incongruent condition, the target and the prime were different numbers, or the multiplication presented as a prime was not related to the target. In Experiment 2, we replicated Experiment 1 and explored the role of the equal sign in multiplication priming.

EXPERIMENT 1

The effects of multiplication priming were explored in this experiment. Participants were exposed to numbers that could be preceded by congruent or incongruent masked numbers and multiplications. Repetition priming effects were expected, as had previously been obtained in other research. According to the hypothesis of the automatic retrieval of single-digit multiplication, shorter naming times were expected in the congruent multiplication condition than in the incongruent multiplication one.

Method

Participants. Forty-five undergraduate and graduate students at the University of Málaga, from 18 to 35 years of age ($M = 19.8$, $SD = 3.4$), participated as volunteers in this experiment. All were native speakers of Spanish, had normal or corrected-to-normal vision, and were naive regarding the purpose of the study. One participant was excluded from the analysis for having more than 25% errors in a previous arithmetic task (see below). Another participant was excluded for having more than 20% naming times greater than 1,000 msec. A third student was eliminated for reporting prime visibility, in both objective ($d' > 3$) and subjective measures (see the Results section). Forty-two participants (7 of them male, 35 female) remained for the analysis.

Apparatus. The stimuli were presented on a color monitor, with refresh cycles of 16 msec, connected to a PC (Pentium 133) running under the MS-DOS program Experimental Runtime System (ERTS; Beringer, 1999). A microphone and voice relay connected to the computer measured reaction times (RTs). After each response, the experimenter wrote down the participant's answer on a response sheet to verify its correctness.

Stimuli and Procedure. Before the experimental task, the participants had to perform a paper-and-pencil arithmetic task consisting of 24 single-digit multiplications and 24 subtractions (a two-digit first operand, a single-digit second operand). This task was employed to detect participants with specific problems in single-digit calculation.

For the experimental task, the participants sat in front of a computer monitor located at an approximate distance of 60 cm. They were instructed to name aloud, as quickly and accurately as possible, the target number presented on the monitor. Before seeing the target, they were exposed to two different types of masked primes: a number (repetition priming) or a single-digit multiplication (multiplication priming). These primes could also be congruent or incongruent with the targets. In the congruent condition, the prime and the target were the same number (e.g., prime, 6; target, 6), or the solution to the multiplication prime matched the target (e.g., prime, 2×3 ; target, 6). In the incongruent condition, the target and the prime were different numbers (e.g., prime, 32; target, 6), or the solution to the multiplication prime did not match the target (e.g., prime, 4×8 ; target, 6).

Both operands of the multiplication primes were always single-digit Arabic numbers higher than 1 and different from each other (ranging from 2×3 to 8×9), the first operand always being lower

than the second one. The multiplication stimuli included both operands, the "×" symbol between them, and ended with the "=" symbol. Those multiplications that shared with the solution one number in the same position were not included in the experiment; this affected $3 \times 5 = 15$ and $6 \times 8 = 48$. In those cases in which the solutions of multiplications coincided (e.g., 3×6 and 2×9), only one pair was used. Twenty-three multiplications that agreed with these requirements were selected. The results of the selected multiplication primes (ranging from 6 to 72) in Arabic notation were employed as targets and as number primes in the repetition priming condition. A complete list of the stimuli is presented in the Appendix.

Each experimental trial consisted of the following sequence of events. First, a forward mask made up of four hash symbols (####) was presented for 250 msec. Then the prime was presented for 32 msec (synchronized with the refresh cycle of the screen), followed by the mask for 16 msec. The target, which appeared 48 msec after the prime, remained on the screen until it was named. An interval of 2 sec elapsed between a response on a given trial and the beginning of the next trial. In order to reduce physical overlap between prime and target, the font of the primes was smaller than that of the targets. All the stimuli were presented in yellow on a gray background and were centered on the screen. No mention concerning the primes was made to the participants.

Each participant saw the 23 targets four times, making a total of 92 experimental trials, half of them congruent and the other half incongruent. In each of these blocks, there was a total of 46 different primes, one half multiplications and the other half numerals. The order of trials was randomized. At the beginning of the experiment, a short practice block (8 trials different from the experimental stimuli) was presented to the participants.

Assessment of prime visibility. Prime visibility was assessed using both subjective and objective measures. Immediately after the experimental task, the participants were asked about the sequence of the presentation. Primes were considered visible if the participants reported the presence of numbers before the target presentation. Later, the participants were informed of the presence of the prime and were asked to perform a forced choice prime detection task (e.g., Naccache & Dehaene, 2001; Ratinck, Brysbaert, & Fias, 2005). They had to decide, by pressing the designated keys, whether the briefly presented number primes, or the solution to the multiplications presented as primes, matched the target (identity number task). The trial presentation was identical to the sequence of stimuli in the experimental study, but only 12 (out of 23) stimuli were presented in each of the four conditions. As a practice, four trials taken from the eight practice trials of the priming experiment were also included.

Results

Masked priming. Naming errors (0.9% of the data) and microphone errors (2.72% of the data) were excluded from the analysis. A range of between 250 and 1,000 msec was established for the analysis of the results; naming times out of this range were eliminated (0.18% of the data). Since the percentage of errors was lower than 1%, no analysis was performed on errors. Table 1 presents the naming times in the different conditions.

Two-way ANOVAs were performed for participants (F_1) and items (F_2) on mean correct naming times, with type of prime (multiplication vs. repetition) and congruency (congruency vs. incongruency between prime and target) as within factors. The ANOVA revealed a significant main effect of type of prime [$F_1(1,41) = 16.24$, $p < .001$; $F_2(1,22) = 29.51$, $p < .001$], showing that naming times were significantly shorter when the targets were preceded by numbers than when they were preceded by multiplications. A significant effect of congruency also arose [$F_1(1,41) = 15.25$, $p < .001$; $F_2(1,22) = 25.16$, $p < .001$],

showing that targets preceded by congruent primes were named more quickly than those preceded by incongruent ones. No interaction between congruency and type of priming was found [$F_1(1,41) = 1.12, p = .29$; $F_2(1,22) = 0.97, p = .33$; see Figure 1].

The lack of interaction suggests that the size of the priming (congruency) effect was similar for repetition and multiplication priming. However, since our main goal was to study multiplication priming effects, a separate analysis was carried out regarding the type of prime. As was expected, naming times for repetition priming were shorter when the prime and target had the same value ($M = 520.9, SD = 66.3$) than in the incongruent condition ($M = 534.6, SD = 70.4$). This showed a repetition priming effect of 13.7 msec [$t_1(41) = 3.48, p < .01$; $t_2(22) = 3.15, p < .01$]. More important, for multiplication priming, the participants were 8.3 msec faster when the target was the result of the multiplication presented as the prime ($M = 536.1, SD = 63.3$) than when it was not the result of that problem ($M = 544.4, SD = 70.6$). This difference was significant in the participant analysis [$t_1(41) = 2.23, p < .05$] and was marginally significant by items [$t_2(22) = 1.83, p = .08$], showing a multiplication priming effect.

Prime visibility. A major point in the design of the experiment was that the participants were not able to report information about the primes. This ensured that the activation of the solutions to single-digit multiplication was highly automatic.

Subjective measures of prime visibility, taken after the end of the experiments, showed that only 1 of the participants reported the appearance of numbers and arithmetical problems before the targets. This participant was also able to get a high score on objective measures of visibility ($d' > 3$; see below), which suggests that the primes were visible for her. For these reasons, she was eliminated from the experiment and was not considered in any analysis (see the Participants section above). However, the analysis carried out with this participant included did not change the pattern of results described in the Experiment 1 section.

Figure 1. Naming times (in milliseconds) for congruent and incongruent primes for each type of priming (multiplication and repetition) in Experiment 1.

Subjective measures suggested that the rest of the participants were unaware of the primes during the naming task. An objective and direct measure assessing prime visibility consisted of computing d' scores (treating the identity trials as signal and the nonidentity trials as noise) for the two priming conditions in the forced choice prime detection task. In the repetition priming condition, individual d' values ranged from -1.60 to $+1.88$ ($M = -0.017$, median = 0.000). In the multiplication priming condition, individual d' values ranged from -1.12 to $+0.92$ ($M = 0.002$, median = 0.000). And t tests against the null mean indicated that the means were not significantly different from 0 (both $ps > .8$), suggesting a lack of awareness.

To carefully check whether the observed priming effects were limited to those participants who could identify the primes above chance—that is, those with higher d' s—two regression analyses were carried out, following Greenwald, Draine, and Abrams's (1996) procedure. In this method, the priming effect is the dependent variable, and the visibility measure the predictor (see also Naccache & Dehaene, 2001, for a demonstration of this method). Linear regressions for repetition and multiplication priming showed nonsignificant correlations between d' and an index of the amount of priming [repetition priming, $r = -.29, F(1,40) = 3.8, p = .06$; multiplication priming, $r = .05, F(1,40) = 1.02, p = .751$]. More relevant, the constant terms of the regression, which are considered the measure of the residual priming effect for a d' of zero, were significantly greater than zero ($p < .05$) in both regressions (see Figures 2A and 2B).

In agreement with the subjective measures collected at the end of the experiment, the objective measures obtained in the identity number task suggest that the participants were not aware of the identity of the prime in the repetition or in the multiplication priming. In addition, regression analyses confirmed that the repetition priming and, what is more important, the multiplication priming effects took place under unconscious presentation.

Discussion

The main finding of this experiment was the presence of multiplication priming effects. The participants named numbers about 8 msec more quickly when they were preceded by congruent multiplications. These data suggest that the participants, although not required to solve multiplications, activated their solutions automatically. Visibility ratings, both subjective and objective, indicate that the participants were not aware of the primes. Also, when the influence of the primes' visibility was excluded from the analyses by means of regressions, the data still support the existence of the priming effect in the multiplication priming. Therefore, the results are consistent with those of other research in which other procedures were used to study multiplication-solving automaticity (e.g., verification tasks, number-matching tasks).

It is also worth pointing out that main effects of type of prime were also found, showing that the participants were about 12 msec faster when the prime was a number than when it was a multiplication. This difference is probably related to the different complexity of the primes. It should

Figure 2. Independence of priming (panel A, repetition priming; panel B, multiplication priming) and d' values in Experiment 1. A priming index for each participant in each type of priming was calculated as $I = 100 \times (\text{mean reaction time [RT] for incongruent items} - \text{mean RT for congruent items}) / (\text{mean RT for congruent items})$. This index was plotted against d' values for each participant in the forced choice prime detection task. Linear regression curves and corresponding 95% confidence intervals are shown. The intercept was significant in both types of priming [repetition priming, $t(40) = 3.62, p < .001$; multiplication priming, $t(40) = 2.15, p < .05$], which, as has been suggested by Greenwald, Draine, and Abrams (1996), indicates priming without consciousness.

not be forgotten that the multiplication primes consisted of two single digits and “ $\times$ ” and “ $=$ ” signs. This display, perceptually more complex, should induce more processing than the previous presentation of only one number (see Reynvoet, Caessens, & Brysbaert, 2002, for a similar argument). This result is also consistent with the fact that multiplication solving would take extra time, as compared with single-number processing.

The analysis showed no interaction between congruency and type of prime; that is, the size of the repetition and the multiplication priming effects, although dissimi-

lar, did not differ statistically (13.7 vs. 8.3). This suggests that single-digit multiplications and numbers behave in closely similar ways, with both preactivating the same representation. Although it can be supposed that the identification of the operands (also numbers) may cause some interference, leading to differences between repetition and multiplication priming, as we stated above, differences between the two conditions were limited to the speed of the response, not to the size of the effect.

The experiment presented here shows that the solutions to single-digit multiplications unconsciously presented to participants were retrieved. This allowed them to name the targets significantly more quickly when these were preceded by a masked multiplication whose solution matched the target than when the prime was a multiplication whose solution was unrelated to the target. This priming effect took place without conscious report of the primes, suggesting that multiplications were retrieved automatically.

EXPERIMENT 2

There were two major aims in Experiment 2. The first was to replicate the results obtained in Experiment 1—that is, the multiplication priming effect. The 8-msec priming effect, although significant, was small, and replication of the effect was desirable. The second aim was related to the role of the equal sign in the priming effect. According to arithmetic syntax, the equal sign constitutes a statement of mathematical equivalence; however, in the context of simple arithmetical problems such as multiplications, it is seen as the symbol that should trigger the solving of the multiplication problem (e.g., Seo & Ginsburg, 2003). Therefore, Experiment 2 tested whether the same effects would be obtained when the equal sign was not included in the multiplication primes, as compared with when it was included.

The experimental design was the same as that in Experiment 1 (type of prime $\times$ congruency), but a new factor was added: presence of the equal sign. If the equal sign is not relevant to initiating the solving of multiplications, similar priming effects would be expected in multiplication conditions with or without equal signs. On the contrary, if it plays a role in the automatic activation of multiplication solutions, differences would be expected between those primes that included the equal sign and those that did not.

Method

Participants. Thirty-two undergraduate students of psychology and speech therapy from the University of Málaga participated as volunteers in the experiment. Their ages ranged from 19 to 34 years ($M = 20.5, SD = 3.2$); they had normal or corrected-to-normal vision and were naive regarding the purpose of the experiment. One participant was eliminated due to not finishing the experiment, and another subject was eliminated for not having Spanish as a native language. Three other participants were also excluded for having more than 18% missing data, due to errors, coughs, and microphone errors.

Apparatus. The apparatus was the same as that employed in Experiment 1.

Stimuli and Procedure. The procedure was the same as that in the former experiment, but in this case, we conducted two experimental sessions for each participant. One of them was exactly the

same as that in the previous experiment, but in the other, every other prime on the multiplication trials did not include the equal sign in its expression. Thus, the participants saw 23 targets eight times, grouped in two experimental sessions. In one session, repetition-congruent, repetition-incongruent, multiplication-congruent, and multiplication-incongruent primes were presented with the equal sign. In the other session, those same four conditions were presented, but without the equal sign. Experimental sessions were balanced across participants. The whole experiment was carried out on the same day, with at least a 5-min break between each experimental session.

Assessment of prime visibility. Prime visibility was assessed as in Experiment 1. Once the two experimental sessions were finished, the participants were asked whether they had seen numbers before target presentation. In addition, a forced choice prime detection task was carried out. It consisted of two sessions; in one of them, the equal sign appeared; in the other, it did not. Stimuli presentation and procedure were the same as those employed in the assessment of visibility in Experiment 1.

Results

Masked priming. Naming errors (0.5%) and microphone errors (0.9%), as well as times outside the 250- to 1,250-msec range (1.6% of the data), were excluded from the analysis.

A within-participants three-way ANOVA was performed by participants (F_1) and items (F_2) on mean correct naming times, with type of prime (multiplication vs. repetition), congruency (congruent vs. incongruent), and presence of an equal sign (presence vs. absence) as independent factors. The ANOVA revealed a significant main effect of congruency [$F_1(1,26) = 14.98, p < .01$; $F_2(1,22) = 15.98, p < .01$], showing that congruent targets were named significantly more quickly (9 msec) than noncongruent ones. Although responses in those conditions in which the prime did not include the equal sign were 11 msec faster, this difference was significant only in the item analysis [$F_1(1,26) = 1.2, p = .28$; $F_2(1,22) = 25.81, p < .001$]. There were no other significant main effects or interactions (see Figure 3).

Since our main interest was related to multiplications, we performed an analysis of the congruency and presence/absence of equal sign effects exclusively for items that included a multiplication prime. The ANOVAs showed a significant effect of congruency [$F_1(1,26) = 9.49, p < .01$], which was marginal in the item analysis [$F_2(1,22) = 3.43, p = .07$]. The participants were 7.9 msec faster when the target was preceded by a congruent multiplication. As in the previous ANOVA, the presence/absence of an equal sign was significant only in the item analysis [$F_1(1,26) = 1.93, p = .17$; $F_2(1,22) = 35.7, p < .001$]. The interaction between congruency and presence/absence of an equal sign did not reach significance [$F_1(1,26) = 0.83, p = .37$; $F_2(1,22) = 0.81, p = .38$], suggesting that the equal sign was not relevant to triggering the automatic retrieval of multiplication solutions.

Prime visibility. Subjective measures of prime visibility were taken at the end of the experiment. None of the participants reported seeing numbers before the targets appeared. To determine the influence of prime visibility over the different variables, we calculated four d' scores for each participant, one for each presence/absence of an equal sign and type of prime conditions, using the results

Figure 3. Naming times (in milliseconds) in Experiment 2 for congruent and incongruent primes in each type of priming (multiplication and repetition) and in the presence and absence of the equal sign.

of the forced choice prime detection task (objective measure). The minimum d' was -1.4 , and the maximum 1.18 , all medians being equal to 0 . Means for multiplication and repetition primes were, respectively, -0.04 and 0.02 for the absence of an equal sign and 0.1 and 0.18 for the presence of an equal sign. The d' values corresponding to multiplication trials were not significantly different from 0 (both $ps > .32$), although there was a tendency toward significance in the presence of an equal sign condition for repetition trials ($p = .06$), being far from significant in the equivalent condition in the absence of the equal sign ($p = .9$). We do not have an explanation for this difference.

As in Experiment 1, linear regressions between d' values and indexes of the amount of priming (I) were calculated for each condition. Regardless of the presence of an equal sign, multiplication trials showed the expected pattern for an unconscious priming effect (see Figures 4A and 4B). There was no correlation between d' and I values [$r = .15, F(1,25) = 0.62, p = .44$, in the absence of an equal sign; $r = .13, F(1,25) = 3.56, p = .07$, in the presence of an equal sign], and the constant term of regression was significantly greater than 0 (both $ps < .05$). However, for repetition trials, there was a significant correlation between d' and I values in those with an absence of an equal sign [$r = .39, F(1,25) = 4.53, p < .05$], the constant term of regression not being significantly different from 0 ($p = .19$). The pattern for the unconscious priming effect was present in the repetition trials with an equal sign [$r = .23, F(1,25) = 1.46, p = .24$; $t(25) = 3.45, p < .005$].

Discussion

In this experiment, we replicated the results of the previous experiment, finding a main effect of congruency: Arabic numbers were named more quickly when preceded by congruent multiplications or by the same numbers. Moreover, for the critical condition, the multiplication

Figure 4. Independence of multiplication priming and d' values in the presence of an equal sign (A) and in the absence of an equal sign (B) in Experiment 2. A procedure similar to that in Experiment 1 was followed. Linear regression curves and corresponding 95% confidence intervals are shown. The intercept was significant in both types of multiplication priming [$t(25) = 2.31, p < .05$, in the absence of an equal sign; $t(25) = 2.16, p < .05$, in the presence of an equal sign]. Data indicate priming without consciousness.

priming effect found was very similar to that in Experiment 1, about 8 msec. These results are confirmed by the regression analyses, in which we found the expected pattern for an unconscious priming effect, according to Greenwald et al. (1996).

Regarding the second aim of this experiment, exploring the role of the equal sign, data analyses led to two conclusions. When the equal sign was present, naming times were longer, presumably because it added visual complexity to prime stimuli, although differences were significant only by items. More important, the equal sign does not seem to have been important for the automatic activation of simple multiplication solutions, because the size of the multiplication priming effect was similar irrespective of the presence of the equal sign.

GENERAL DISCUSSION

In this study, we investigated whether unconsciously presented single-digit multiplications influence the naming of Arabic numbers. According to most models of arithmetic processing, single-digit multiplications are automatically retrieved, at least in most adults (e.g., Ashcraft, 1992; Campbell, 1987, 1995; Stazyk et al., 1982). Data from verification and number-matching tasks support these hypotheses; however, these paradigms are not free of criticisms. As was argued in the introduction, it is difficult to test automatic activation of solutions when arithmetical knowledge is explicitly asked for (verification tasks) or when operands and solutions are explicitly presented (number-matching tasks and verification tasks). A masked priming paradigm with briefly presented multiplication primes was used in our experiments. The results clearly showed shorter number naming times when targets were preceded by congruent operations than when targets were preceded by incongruent operations. And these effects took place, as was shown by visibility ratings and regression analyses, under unconscious presentation of the multiplication problems. The effect was found using a paradigm that fulfilled the requirements for automatic processing: absence of consciousness and intention—that is, processing without monitoring (Tzelgov, 1997). Since the arithmetic operations were presented briefly and masked; our participants were not conscious of them and did not have the intention of solving them.

Main effects of congruency and lack of an interaction between type of priming and congruency were found in both experiments. The size of the congruency effect, about 10 msec, was pretty small, as compared with other experiments. For instance, in a previous number-naming experiment using repetition masked priming (in which the targets were digits between 4 and 9 and Arabic and verbal numbers were used as primes), Reynvoet, Brysbaert, and Fias (2002) found repetition effects higher than 20 msec. Differences between their data and ours could be based on the different SOAs employed (115 vs. 48 msec), on the different magnitudes of the targets, or even on the different number of times the targets were presented in the experiments. More important, the lack of interaction between congruency and type of prime (multiplication vs. repetition) found in both experiments suggests that those processes involved in multiplication priming are closely similar to those involved in repetition priming and suggests that multiplications are solved quickly and without intention. Both number primes and multiplication primes activated a number representation that could be congruent or incongruent with the target, leading to differences in target-naming times. Regarding the mechanisms involved in the priming effect, a comment is needed here. Since no neutral condition was included in our experiments, following the procedure employed in other masked priming experiments (see, e.g., Naccache & Dehaene, 2001; Reynvoet & Brysbaert, 2004), it cannot be established whether our priming effects were facilitatory or inhibitory. Nevertheless, this does not challenge the value of our data; whether facilitatory or inhibitory, the priming effect can

take place with a pattern similar to that for repetition priming only if multiplication primes are solved.

Tzelgov (1997) has proposed that processing without monitoring is the defining feature of automatic processing. Monitoring was understood as an intentional setting of the goal of behavior and a continuous intentional evaluation of the output process, as long as it takes place. Under this definition, the author distinguished two modes of automatic processing. When automatic processing is part of the task but monitoring is set on a higher, superordinate level (e.g., word reading in sentence comprehension), this could be considered *intentional automatic processing*, and in these cases, it is really difficult to know whether that behavior is monitored or not. *Autonomous automatic processing* takes place when it is not part of task requirements (e.g., the Stroop task). Our priming experiment, since it employed unconsciously presented multiplications, might be conceived of as a test of automaticity according to Tzelgov's (1997; Tzelgov & Ganor-Stern, 2005) criteria. The solutions to single-digit multiplications were activated without monitoring—that is, without any intention regarding the goal of the task and without evaluation of the output process—because there was no conscious observation of the problem or of the execution of its processing. The processing of the multiplication problem was also autonomous, since it was not part of the task requirements. Moreover, the unconscious presentation gives another advantage to our paradigm: discarding retroactive mechanisms as responsible for the priming.

Our paradigm could be questioned because our task implies number naming and this could activate a mathematical way of processing, involving processes employed in simple arithmetic solving that lead to the multiplication-priming effect. On this view, priming might not be as automatic as supposed. However, we believe that this argument does not reduce the relevance of our conclusions. The multiplication problem is retrieved without intention and without conscious report of its presence, and this guarantees that the process will take place when the problem is overtly presented, as occurs when participants are required to solve it in a natural setting. Moreover, when our paradigm is compared with those classically employed to study single-digit problem automatism—namely, the number-matching task or the verification task—there is no doubt that the latter involve much more triggering of the mathematical-processing mode. In fact, calculation is explicitly required, and in the number-matching task, operands and results are explicitly shown, making the existence of an operation-based relationship between them easily detectable. Consequently, it can be concluded that the masking procedure and the SOA (48 msec) employed in the paradigm ensure that priming is due to the automatic processing of single-digit multiplications, confirming the data that has been obtained using interference paradigms (Galfano et al., 2003; Thibodeau et al., 1996). With the multiplication-priming paradigm, we avoid some of the criticisms these paradigms have received, and more important, we also identify that this priming takes place even when participants are fully unconscious of the operand's identity, as shown by the prime visibility test.

All through this research, we have considered the observed priming effect to be evidence of automatic retrieval of single-digit multiplications. However, to demonstrate evidence for anything beyond priming—that is, for automatic solving of single-digit multiplications—it would be necessary to show that the effect does not take place with targets that are table related to one of the operands presented as a prime (we thank an anonymous reviewer for suggesting this possibility). Many models of single-digit multiplication assume that operands activate their correct answer and related targets (e.g., Ashcraft, 1992; Campbell, 1987; Stazyk et al., 1982). Hence, it is possible that the multiplication-priming effect takes place not only when the target is the solution to the problem, but also when the problem is table related to the target (e.g., 6×7 could prime not only 42 but also the multiples of 6 [12, 18, 24, 30, 36, 48, and 54] and the multiples of 7). If this is happening, strictly speaking, it cannot be concluded that briefly presented multiplications are solved, but only that a certain amount of numbers are more or less equally activated when a single-digit multiplication is presented. Nevertheless, a reanalysis of our data could shed some light on this issue. In our stimuli, there were 11 incongruent primes that were table related to the targets (e.g., congruent, 2×9 , 18; incongruent, 6×7 , 18; 6×7 is related to 18 by means of 6×3) and 12 incongruent primes that were not table related to the targets (e.g., congruent, 3×8 , 24; incongruent, 5×7 , 24). If table-related primes prime the target more or less as congruent primes do, no (or smaller) congruency (priming) effects should be observed when table-related incongruent primes are involved, because both table-related incongruent primes and congruent primes prime the targets. In addition, the overall effect of priming found in our study would be due to the priming effects found when non-table-related incongruent primes are involved. In other words, an interaction between congruency and table-related primes (related vs. nonrelated primes) would be expected if table-related primes prime the target more or less as congruent primes do. The reanalysis of both experiments confirmed the lack of interaction effects between congruency and table-related primes [Experiment 1, $F_1(1,44) = 0.005$, $p = .9$, and $F_2(1,21) = 0.05$, $p = .8$; Experiment 2, $F_1(1,26) = 0.9$, $p = .4$, and $F_2(1,21) = 0.49$, $p = .5$]. That is, the size of the priming effect in the table-related primes (i.e., RTs in congruent primes minus RTs in incongruent table-related primes) was numerically similar—in fact, slightly higher—than the priming effect in the nonrelated primes (i.e., RTs in congruent primes minus RTs in incongruent non-table-related primes). These results suggest that table-related primes behave like non-table-related pairs and, hence, support the idea of a greater activation of the solution to the multiplication primes. (Note that, in our stimuli, we had only one incongruent prime that was a node adjacent to the product— 5×8 35—and the priming effect found for this item was similar to those found with other nonrelated incongruent primes.)

Other data lend support to this idea; the lack of differences in the size of the priming effect between repetition and multiplication priming clearly suggests, as was stated above, that multiplication primes behave like their solu-

tion and not like any other number, supporting the automatic retrieval of that number.

In the literature, we can also find support for previous arguments. Employing the number-matching task, Galfano et al. (2003) explored the interference effect produced by nodes adjacent to a product (2×3 8); the interference effects were around 15 msec, as opposed to the 32 msec found by Thibodeau et al. (1996), who explored the interference effect produced by a product (2×4 8). These findings suggest that the priming effect when the target is fully congruent with the prime should be different from that found when the target is only table related with the multiplication prime.

The arguments presented above, although not conclusive, suggest that our results are consistent with the automatic solving of multiplications.

Finally, at present, our experiments cannot shed light on the way single-digit multiplications are represented in our memory. Models that defend direct associations between operands and their solution (e.g., Rickard, 2005; Roussel et al., 2002; Siegler & Jenkins, 1989) and those that consider that multiple operands are activated by means of interrelated networks (e.g., Ashcraft, 1992; Campbell, 1987; Stazyk et al., 1982) can account for the present data in terms of automatic activation, which is a common assumption of all of them. Nevertheless, it is clear that the multiplication priming paradigm is well suited for becoming a valuable tool in disentangling these models in the future; for instance, it could provide information about the activation of the above or below nodes of a multiplication. It is important to comment that the experiments reported in this research were carried out mainly with psychology students, and these participants were heterogeneous regarding their expertise in mathematics. Although this suggests that the effect does not rely on expertise in mathematics, future studies should be carried out to identify the role of individual differences in the multiplication-priming effect.

CONCLUSION

The present experiments were designed to explore the retrieval of single-digit multiplications. Data show that multiplications can be solved very quickly and without intention and that the solution can be used to influence number naming even though the operands are unconsciously presented to participants, as shown by objective and subjective measures. The lack of an interaction between type of priming and congruency suggests that multiplications preactivate the same representation that the number prime does: the target's representation. Experiment 2 suggests that the equal sign is not relevant to triggering the automatism, since the effect also takes place when this sign is not present.

Some data suggest that different ways of solving single-digit multiplications exist: direct retrieval, counting, adding, derived facts, and so forth (see, e.g., Hecht, 1999; LeFevre et al., 1996; Romero et al., 2006; Roussel et al., 2002). Our experiments suggest that direct retrieval not only is a useful strategy, but also is applied automatically even under very brief presentations of problems. This re-

search supports the view that the masked priming paradigm using arithmetic problems as primes might be a valuable way of exploring the mechanisms involved in the retrieval of these arithmetic operations. It is well suited for studying the automatic solving of other operations, such as addition, division, or subtraction, allowing us to use natural tasks, such as naming, and to replace paradigms such as the number-matching task or the verification task, which are under suspicion. In addition, it can provide relevant information about the nature of multiplication representations in our memory. Time will tell whether the masked priming paradigm is as fruitful as it seems to be in the arithmetic-problem-solving domain.

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APPENDIX

Stimuli Used in Experiments 1 and 2

Congruent Multiplication Prime	Congruent Repetition Prime	Incongruent Multiplication Prime	Incongruent Repetition Prime	Target
2 × 3	6	4 × 8	32	6
2 × 4	8	2 × 7	14	8
2 × 5	10	3 × 8	24	10
2 × 7	14	2 × 3	6	14
2 × 8	16	4 × 7	28	16
2 × 9	18	6 × 7	42	18
3 × 4	12	3 × 9	27	12
3 × 7	21	4 × 9	36	21
3 × 8	24	5 × 7	35	24
3 × 9	27	5 × 9	45	27
4 × 5	20	7 × 8	56	20
4 × 7	28	7 × 9	63	28
4 × 8	32	6 × 9	54	32
4 × 9	36	2 × 4	8	36
5 × 6	30	2 × 9	18	30
5 × 7	35	5 × 8	40	35
5 × 8	40	8 × 9	72	40
5 × 9	45	5 × 6	30	45
6 × 7	42	3 × 7	21	42
6 × 9	54	2 × 8	16	54
7 × 8	56	3 × 4	12	56
7 × 9	63	2 × 5	10	63
8 × 9	72	4 × 5	20	72

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