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DIREITOS DE AUTOR E CONDIÇÕES DE UTILIZAÇÃO DO TRABALHO POR TERCEIROS

Universidade do Minho, 5 de junho de 2022

Maria Barroso da Silva

(Maria Veiga de Araújo Barroso da Silva)

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STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration.

I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

Universidade do Minho, 5 de junho de 2022

Maria Barroso da Silva

(Maria Veiga de Araújo Barroso da Silva)

Efeitos da Literacia no Reconhecimento de Objetos: Evidência a Partir de um Paradigma de *Priming* Negativo

Resumo

Evidência recente mostra que aprender a ler e a escrever tem um impacto profundo, não só na vida dos indivíduos e das sociedades, mas na cognição em geral. Neste trabalho analisámos se o viés à direita que a literacia parece instigar no reconhecimento visual de palavras em ortografias em que a maioria das letras apresentam características distintivas à direita, pode ser também observado no reconhecimento visual de objetos. Para isso, conduzimos dois estudos. O Estudo 1 procurou analisar efeitos de direccionalidade (direita-esquerda) no reconhecimento visual de objetos (animais) na ausência de estímulos verbais (letras), para determinar a linha base do processamento. No Estudo 2, recorremos ao paradigma de *priming* negativo para analisar como a apresentação de letras espelho e não-espelho com orientação à direita e esquerda afetou a linha base determinada pelo Estudo 1. Os resultados mostraram que a presença de letras alterou de forma significativa a forma como imagens iguais do mesmo animal apresentadas em direções opostas foram reconhecidas. Especificamente, os resultados revelaram um efeito de *priming* negativo quando essas imagens foram antecedidas de letras-espelho orientadas à direita, como antecipado. Revelaram também a presença desse efeito quando as imagens desses animais foram antecedidas de letras não-espelho orientadas à esquerda.

Palavras-chave: Letras espelho, letras não-espelho, mecanismo de generalização em espelho, efeito de *priming* negativo.

Literacy Effects on Objects' Recognition: Evidence From a Negative Priming Paradigm

Abstract

Recent studies showed that learning to read and write has a profound impact not only on the lives of individuals and societies but on cognition as a whole. In this work, we analyzed whether the right-asymmetry bias that literacy seems to instigate in the visual recognition of words from orthographic systems in which most letters have their distinctive features on the right can also be observed in the visual recognition of objects. Two studies were conducted. Experiment 1 aimed to analyze directionality effects (right-left) on the visual recognition of objects (animals) in the absence of verbal stimuli (letters) to establish the baseline processing. In Experiment 2 we used a negative priming paradigm to analyze how the presence of mirror and non-mirror right- and left-oriented letters previously to the images of the animals affected the baseline determined by Experiment 1. Results showed that the presence of letters changed significantly the recognition of images of the same animal presented in opposite directions. Specifically, the results revealed a negative priming effect when these images were preceded by right-oriented mirror letters, as expected. They also revealed the presence of this effect when the images of these animals were preceded by left-oriented non-mirror letters.

Keywords: Mirror letters, non-mirror letters, mirror generalization mechanism, negative priming effect.

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Introduction

Reading and writing, a system of visual symbols representing the units of a specific spoken language, are relatively recent human cultural inventions. The oldest writing system known is from less than 6,000 years ago (Huettig et al., 2018). This is too recent an event in the history of our species to enable humans to be born prepared to read or write, unlike what is observed with speaking (Dehaene-Lambertz et al., 2002; Soares, Silva, et al., 2021). Actually, the acquisition of these abilities leads to alterations in human development, especially in the brain (e.g., Dehaene-Lambertz et al., 2018; Huettig et al., 2018), with several studies showing that a literate individual's brain is structurally and functionally different from an illiterate individual's one (e.g., Fernandes et al., 2018; Huettig et al., 2018; Malik-Moraleda et al., 2018). Although humans are not born with cerebral areas specific for reading and writing, learning how to read, creates a cerebral area in the primary visual cortex to respond appropriately to the requirements of this new cultural function. This area, known as the visual word form area (VWFA; Ahr et al., 2018), is activated selectively towards verbal-visual stimuli, such as letters and written words regardless of the orthographic system (Ahr et al., 2018; Dehaene & Cohen, 2007; Fischer, 2011; Saygin et al., 2016). To explain the emergence of this area, Dehaene and Cohen (2007, 2011) proposed the neuronal recycling hypothesis, claiming the brain recruits neurons' networks in the left ventral visual cortex (an area already related to visual recognition of other stimuli, such as faces, animals, and objects) to reading. Consequently, the neurons specialized in the recognition of writing symbols inherit some properties from the recycled neurons. One of these properties is the *mirror generalization mechanism*, also known as mirror invariance, which allows the correct identification of faces, objects, and animals, regardless of their orientation (Axelrod & Yovel, 2012; Kietzmann et al., 2012). Although this mechanism is adaptive for multiple purposes (see Rollenhagen & Olson, 2000 for a review), it also may impair letters and words' recognition in languages with enantiomorphs (i.e., mirror letters). Mirror letters such as "b", "d", "p", and "q" in the Latin alphabet, are letters whose mirror images correspond to other letters in the alphabet. Thus, conversely to other objects, to correctly distinguish "*bom*" from "*dom*" the visual word recognition system should process "b" and "d" not as mirror images of the same object, but as different letters. For that purpose it has been claimed that the visual word recognition has to inhibit this mechanism, even though traces of the mirror letters cost (i.e., higher reaction times and lower accuracy rates in recognizing mirror letters or words containing these letters relative to non-mirror letters) are observed not only in developing readers but also in proficient readers (e.g., Duñabeitia et al., 2011, 2013; Perea et al., 2011; Soares et al., 2019). For instance, Perea et al. (2011) using a lexical decision task (go/no-go) combined with the masked priming paradigm showed that at early stages of visual word recognition both fourth-grade Spanish developing readers and adult Spanish proficient readers revealed longer response times and lower accuracy rates in the recognition of words containing mirror letters (mirror words, such as "*IDEA*" [idea]), but not of words without them (control words, such as "*ARENA*" [sand]). Specifically, they asked participants to decide as fast and accurately as possible if the strings of letters that appeared on the screen were or were not Spanish words. Critically, target words were preceded by 50 ms pseudoword primes that could be the same as the targets (identity condition; idea-IDEA; arena-ARENA); the same as the target except that the critical letter was substituted by its reversal (mirror-letter condition; ibea-IDEA; aꞁena-ARENA); the same as the target except that the critical letter was substituted by an orthographic control letter, in Experiments 1 and 2 (ilea–IDEA, acena–ARENA); or by a missing character, in Experiment 3 (i ea–IDEA, a ena–ARENA). Although none of the computational models of visual word recognition (e.g., Coltheart et al., 2001; Davis, 2010; Grainger & Jacobs, 1996; see Soares, Lages, et al., 2021 for un extended discussion), can account for the mirror-letter interference effect observed at early stages of visual word recognition, Perea et al. (2011) suggested that because reversal letters have two potential attractors (i.e., the nodes corresponding to the letters "b" and "d") and non-reversal letters have only one potential attractor (i.e., the letter node corresponding to "r", because "ꞁ" cannot activate any grapheme), it is possible the interference effect, observed for words containing reversal letters, to arise from the lateral inhibition connections that reversal letters establish between each other at the letter level of processing. However, in two subsequent studies, Soares et al. (2019) e Soares, Lages, et al. (2021) challenged these claims.

Specifically, in the 2019 work, Soares and colleagues, using a more controlled pool of European Portuguese words containing either the mirror letter "b" (b-words as "*base*"[base]) or the mirror letter "d" (b-words as "*dose*"[dose]), and applying the same paradigm used by Perea et al. (2011), showed that reliable mirror-letter interference effects were observed for d-words but not for b-words both in adult skilled readers and fifth-grade children, thus indicating that the directionality (right vs. left) of the reversal letters cannot be disregarded when examining the cost of suppressing the mirror-generalization mechanism at the early stages of visual word recognition. These results were interpreted by Soares et al. (2019) according to the implicit right-orienting rule hypothesis (Fischer, 2011, 2018; Fischer & Luxembourger, 2018; Fischer & Tazouti, 2012; Soares, Silva, et al., 2021), developed to account for the errors produced by children in writing, once they tend to revert left-oriented letters and digits to the right (e.g., "Ⴑ" instead of "J" and "Ɛ" instead of "3"), but not the other way around. Fischer and colleagues. claimed that since most letters in the Latin alphabet have their distinctive features to the right, as exposure to print increases, children implicitly learn this rule and apply it at the early stages of reading/writing acquisition when letter/word representations are not yet stable. In the same vein, Soares et al. (2019) claimed that because left-oriented letters might have less stable orthographic representations, even in adult proficient readers, the visual word recognition system may have more difficulties in inhibiting or suppressing the mirror generalization mechanism when the letters violate the dominant (right) letter-orientation rule than when they conform it, hence explaining the right-asymmetry bias observed in the mirror-letter interference effect at early stages of visual word recognition. In a subsequent study using the same paradigm, Soares, Lages, et al. (2021) extended this effect for words containing non-reversal letters, hence demonstrating once again that unless one assumes that, at the earliest stages of visual word recognition (i.e., from the perception of visual features to sub-lexical orthographic processing), there is some sort of statistical computation of the right-left regularities presented in letters of a given language, one cannot account for the right-asymmetry bias observed in the visual word recognition of words containing reversal and non-reversal letters.

Although the activation of the mirror generalization mechanism has been proved to negatively impact the visual recognition of words containing left-oriented mirror and non-mirror letters, other studies using a negative priming paradigm have also shown that the inhibition of the mirror generalization mechanism for mirror letter recognition has also detrimental effects on visual objects' recognition (e.g., Ahr et al., 2016, 2017, 2018; Borst et al., 2015; Foisy et al., 2017). Specifically, in this paradigm introduced by Borst et al. (2015), participants were asked to judge as quickly and accurately as possible if a pair of letters, in the prime, and a pair of animals or buildings drawings, in the probe, were the same or not. In the primes, the pairs could correspond to the same (e.g., b-b, a-a) or different (e.g., b-d; a-h) mirror or non-mirror letters. In the probes, the pairs could also correspond to the same or different animal/building, in the same or opposite directions. Borst et al.(2015) were focused on the effect that the suppression of the mirror generalization mechanism for correct recognition of mirror letters pairs (b-d) had on the recognition of objects (animals/buildings) that were the same presented in a mirror position. Therefore, they only analyzed response times and accuracy rates of identical probes presented in opposite (mirror) directions preceded by different mirror and non-mirror primes. The rationale beyond the manipulation was if correct discrimination of mirror letters pairs (b-d) involved the inhibition of the mirror generalization mechanism, then it should take longer to identify objects (animals/buildings) as the same when presented in opposite (mirror) directions preceded by different mirror letters pairs than by non-mirror letters pairs. As expected, the results showed that the inhibition of the mirror generalization mechanism for mirror letter discrimination hindered the recognition of two animals, but not two buildings, as the same when presented in mirror directions relative to the presentation of non-mirror letters in the primes. These results, observed with French adult proficient readers, were then replicated for French school-aged children (Ahr et al., 2016) and also when objects (Ahr et al., 2017) and faces (Ahr et al., 2018) were used as probes instead of animals. They were also observed when the mirror and non-mirror letters used in the primes were embedded in pseudowords (e.g., Foisy et al., 2017), thus showing that the interference effect caused by the inhibition of the mirror generalization mechanism for letters/pseudowords' recognition extends beyond the language domain. This also agrees with other studies using other paradigms showing that literacy impacts cognition in multiple ways (e.g., Fernandes et al., 2016, 2018; Kolinsky et al., 2011; Kolinsky & Fernandes, 2014; Soares, Silva, et al., 2021).

The work presented in this thesis emerges from the confluence of these two lines of research. Specifically, we aimed to analyze whether the right-asymmetry bias observed in the visual recognition of words containing reversal and non-reversal letters may also be observed in the visual recognition of objects (animals) when using a negative priming paradigm, which would provide further evidence for other collateral side effects of learning to read on cognition. Two experiments were conducted. Due to the novelty of the study, Experiment 1 was conducted to analyze directionality effects on objects' (animals) recognition when no letters were used as primes - i.e. to establish the baseline which the results of Experiment 2 would be compared with. Experiment 2 followed Borst et al. (2015) paradigm manipulating, in the primes, the type (mirror vs. non-mirror) and the orientation (right vs. left) of the letters pairs presented to participants and, in the probes, the position (opposite vs. same position) and orientation (right or left) in which the pairs of animals were presented to the participants. If the right-asymmetry bias observed in the visual recognition of words containing mirror and non-mirror letters that literacy seems to instigate also affects the visual recognition of objects, participants should be faster and/or more accurate at deciding that two images of the same animal presented in opposite directions correspond to the same animal when presented on the right than on the left positions. Furthermore, given that previous studies have shown that the visual word recognition system has more difficulty in inhibiting the mirror generalization mechanism in words containing left-oriented than right-oriented letters, we expected the magnitude of the negative priming effect to be higher when these letters present a right rather than left-orientation.

Method

Participants

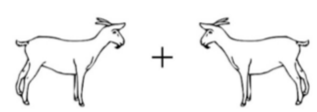
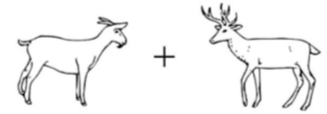
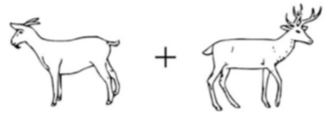
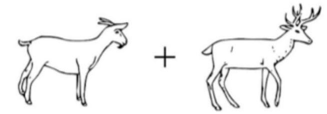
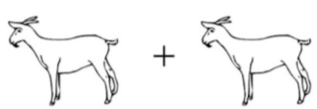
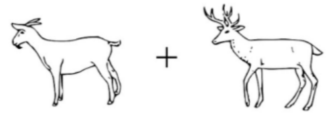
Thirty-one students (24 female, *M* = 20.42, *SD* = 3.39) in Experiment 1 and 32 students in Experiment 2 (27 female, *M* = 20.88, *SD* = 2.70) from the University of Minho took part in this study in exchange for course credits. All participants were native speakers of Portuguese, with normal or correctedto-normal vision and no reported history of learning or language disabilities and/or neurological problems. All were right-handed as assessed by the Portuguese adaptation of the Edinburgh Handedness Inventory (Espírito-Santo et al., 2017; Oldfield, 1971). Written informed consent was obtained from each participant and the study was conducted with the approval of the local Ethics Committee (CEICSH 035/2022).

Stimuli

Eight black-and-white line drawing animals (5.5° x 3.7°) taken from Borst et al. (2015) were used as targets in Experiment 1 and as probes in Experiment 2. Additionally, for Experiment 2, eight letters (i.e., b, d, p, q, t, g, f, and j) written in 96-pt Segoe UI Light font (2° × 3.6°) were used as primes. Of these, four were mirror letters (i.e., b, d, p, and q), and the other four were not (i.e., t, g, f, and j). The non-mirror letters were selected according to their right-left directionality, to control for mirror letters' right-left directionality. The letters' directionality was classified according to where their distinctive features are (right vs. left) from a vertical axis that can be traced from its center. From this rationale, the reversal letters "d" and "q" and the non-reversal letters "g" and "j" were considered left-oriented letters, whereas the reversal letters "b" and "p" and the non-reversal letters "t" and "f" were considered right-oriented letters. In both experiments, the stimuli (animals in Experiment 1 and letters and animals in experiment 2) were presented in pairs. In each pair, one of the stimuli was positioned 0.6° to the right and the other 0.6° to the left of a fixation cross (0.48° × 0.48°) placed in the center of the computer screen. Each letter pair could correspond to either the same mirror or non-mirror letter (identical pairs) or to different ones (different pairs). Animals pairs followed the same manipulation - they could correspond to the same animal (identical pairs) or to different animals (different pairs). Moreover, the orientation of the letters/animals pairs (right vs. left) was also manipulated, so that half of the identical reversal and non-reversal letters and animals faced right, whereas the other half faced left. Different pairs of reversal and non-reversal letters and animals followed the same manipulation (see Figure 1 for a depiction). Note that in the case of the stimuli presented in opposite directions, the right versus left classification was assigned considering the orientation of the first stimulus in a pair. For example, the 'p-q' or the  pairs are considered right-oriented because the first element in the pair corresponds to a right-oriented letter/animal. It is also worth noting that the classification of the type of stimulus (mirror vs. non-mirror) in Figure 1 was based, in the case of the letters, on the mirror versus non-mirror nature of the letters considered in the pairs, whereas in the case of the animals, that was attributed considering whether both animals were presented in the opposite (mirror condition) or in the same direction (non-mirror condition).

Figure 1.

Illustration of the 16 Experimental Prime-Probe Conditions

		Primes		Probes	
Type	Orientation	Identical pairs	Different pairs	Identical pairs	Different pairs
Mirror	Right	p + p	p + q		
	Left	q + q	q + p		
Non-mirror	Right	f + f	f + j		
	Left	j + j	j + f		

For Experiment 1, the 16 animals pairs (considering the identical and different pairs and the position of each animal in the pair) in all four conditions (mirror left, mirror right, non-mirror left, and non-mirror right) lead to a total of 64 possible combinations. Each was presented a total of eight times, amounting to a total of 512 experimental trials. Data collection occurred in one session.

For Experiment 2, due to the number of stimuli and demand of the task, data was collected in two experimental sessions with 256 trials each. For this purpose, and to counterbalance stimuli across conditions, the stimuli were divided into four lists (i.e., two for letters and two for animals). Regarding the lists of letters, one had all combinations of the pairs b-d and t-g and the other had all combinations of the pairs p-q and f-j. Meanwhile, the division between the animals' lists was made according to the position of each animal in the pair. In List 1 horse, sheep, rhinoceros, and goat would always appear on the left of the fixation cross (regardless of the second animal being the same or different), and on List 2 donkey, bear, pig, and deer would always appear on the left of the fixation cross (once again regardless of the second animal being the same or different). With this division, in each session, eight letters' pairs and 32 animals' pairs were presented, meaning each letters' pair was paired one time with each animals' pair. Both the animals and the letters' lists were counterbalanced between each other and the participants. All participants were exposed to all stimuli. The order of the list's presentation was also counterbalanced across participants. Note that when presenting the lists to the participants, stimuli order was randomized, and each participant received a different sequence of trails.

Procedure

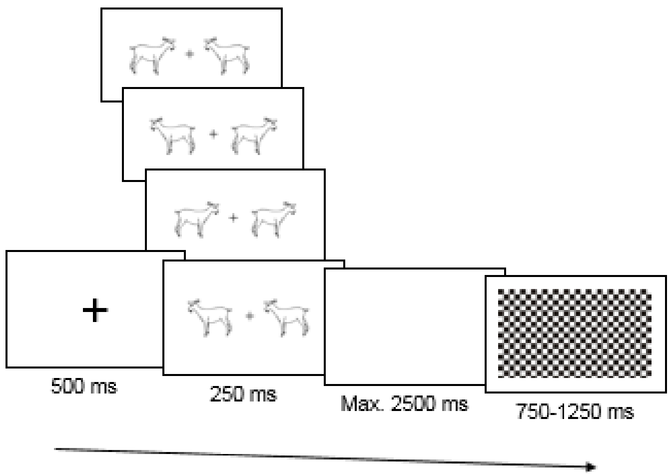
Participants were tested individually in a sound-proof booth at the facilities of the Human Cognition Lab (School of Psychology, University of Minho). Before performing the experimental task, they provided written informed consent and answered a language history questionnaire adapted from Li et al. (2014) to collect some sociodemographic and academic information, as well as language skills, using the software Qualtrics. Data collection occurred in one session in Experiment 1 lasting 45 min, and in two sessions lasting 45 and 30 minutes, respectively in the first and second sessions of Experiment 2. The first session was longer due to the linguist questionnaire taking about 15 minutes to answer.

In the experimental task, participants were asked to decide as quickly and accurately as possible if the pairs of animals (Experiment 1) or the pairs of letters and animals (Experiment 2) presented in each trial corresponded to the same or different letters/animals. Half of the participants were instructed to press the "M" key on their keyboard for the same letter/animal response and "Z" for the "different" letter/animal response. The other half of the participants received the opposite instructions (i.e., "Z" for "same" and "M" for "different") to control for laterality effects. The presentation of the stimuli and recording of responses (accuracy and latency) were controlled by the SuperLab™ 6.0 software. Prior to the experimental trials, participants were presented with 16 practice trials to familiarize them with the task. The practice trials followed the same manipulation as the experimental trials, though using different stimuli, also taken from Borst et al.'s (2015) work.

In Experiment 1, the task comprised 512 trials. Each trial consisted of a sequence of four events presented in black on a white 15" screen with a 60 Hz refresh rate (see Figure 2). The first event was a fixation cross that lasted for 500 ms followed by the presentation of the animal pair, which would last for 250 ms. A blank screen would be presented next and participants had to decide if the animals previously presented corresponded to the same animal or not. The blank screen lasted for 2,500 ms or until a response was recorded. Each trial would then end with a visual mask (750-1250 ms), which was presented to avoid any potential transfer processes between trials.

Figure 2.

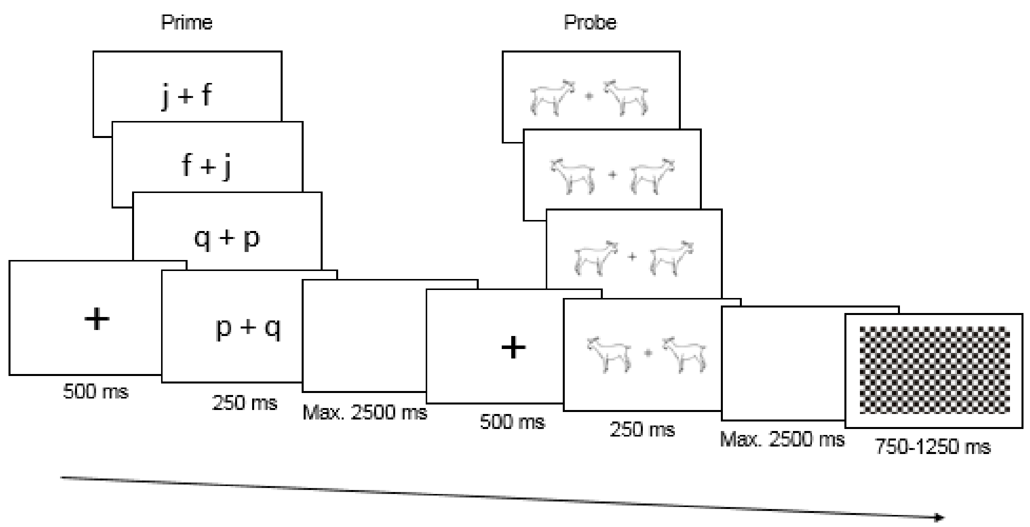
Experiment 1 Experimental Trial Events' Sequence



In Experiment 2, the task comprised 512 trials distributed in two different sessions of 256 trials each. Every trial consisted of a sequence of seven events presented on a screen with the same characteristics as in Experiment 1 (see Figure 3). The first event was a fixation cross that lasted for 500 ms followed by the prime, which was presented on the screen for 250 ms. Then, a blank screen would follow, in which participants had to decide if the previously presented stimulus represented a similar or a different pair of letters. The blank screen would stay on for 2,500 ms or until a response was given. Following this blank screen, another fixation cross would appear lasting for 500 ms, before the presentation of the probe, which would last for 250 ms. As with the primes, a blank screen would be presented next and participants should provide an answer regarding the probe pairs (i.e., same or different), lasting for 2,500 ms or until a response was recorded. Each trial would then end with a visual mask (750-1250 ms), which was presented to avoid any potential transfer processes between trials. During the task, in each session, three pauses occurred (each after 64 trials passed) to allow participants to rest. The duration of the pauses was decided by the participants. They were instructed to resume the task whenever they felt ready.

Figure 3.

Experiment 2 Experimental Trial Events' Sequence



Results

Experiment 1

Reaction times (RT in ms) and proportion of correct responses (accuracy) were analyzed with linear mixed-effects (lme) models using the R software (Bates et al., 2011; Bates et al., 2015). The models were fit using the lme4 and lmerTest R packages (Bates et al., 2011; Bates et al., 2015; Kuznetsova et al., 2017) to contrast simple effects with differences of least squares means in the latency data. The analysis was conducted with random intercepts and the two repeated measurement factors (Pair Type: mirror|non-mirror; and Pair Orientation: right|lef) as fixed factors.

Incorrect responses (17.81% of the raw data) were excluded from the latency data. In addition, RTs that were below and above 2 *SD*s of the participants' means in each experimental condition were also removed (3.75% of the data). Accuracy data were analyzed based on the same model with a logistic link function. For the effects that reached statistical significance, the second degree of freedom of the *F* statistic was approximated using the Satterthwaite's method (see Satterthwaite, 1941; and Khuri et al., 1998 for a review). The *p* values were adjusted with Hochberg's method for all the post hoc and simple effects comparisons $\alpha \leq .05$ (see Benjamini & Hochberg, 1995; and Hochberg, 1988 for details). Table 1 shows response times and accuracy' averages per condition.

Table 1.

Mean Reaction Times (RT in ms) and Proportion of Correct Responses (Acc) per Experimental Condition in Experiment 1

Pair type	DVs	Pair orientation	
		Right	Left
Mirror	RT	366 (152)	392 (153)
	Acc	.93 (.26)	.90 (.31)
Non-mirror	RT	380 (152)	382 (153)
	Acc	.91 (.28)	.89 (.31)

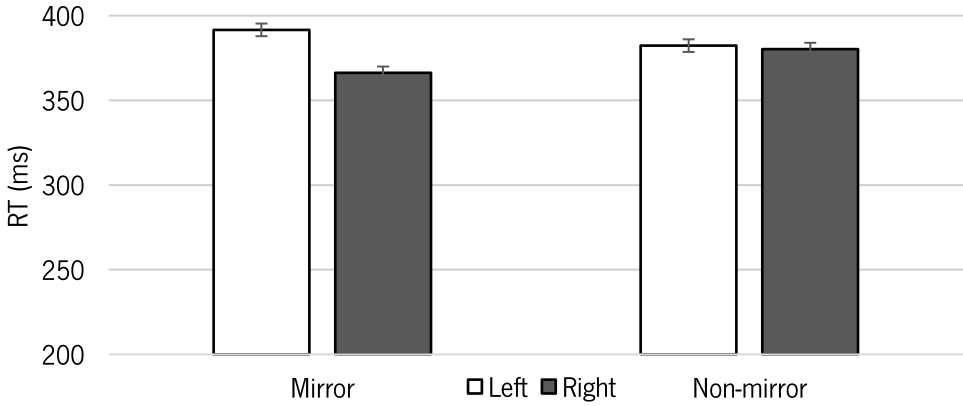
Note. Standard deviations are in parentheses. DVs stands for dependent variables.

Latency analyzes revealed a main effect of pair orientation, $F(1, 6787.50) = 18.41$, $p < .001$, indicating that participants took longer to respond to left-oriented pairs than right-oriented ones (373 ms vs. 386 ms). The two-fold interaction between pair type and pair orientation also reached statistical significance, $F(1, 6787.50) = 12.72$, $p < .001$ (see Figure 4). Post hoc comparisons revealed orientation differences only when pairs were in the mirror condition, in which participants gave faster responses to right-oriented pairs than left-oriented ones (366 ms vs. 392 ms, $p < .001$); in the non-mirror condition, no differences were observed. Moreover, when animals pairs were oriented to the right, participants were faster with mirror pairs than with non-mirror ones (366 ms vs. 380 ms, $p = .002$). When the pairs were oriented to the left, they tended to be faster, though only at a marginal level, with non-mirror pairs than with mirror ones (382 ms vs. 392 ms, $p = .051$). This shows an opposite tendency between left and right-oriented pairs.

Accuracy analyzes only revealed a main effect of pair orientation, $\chi^2(1) = 16.91$, $p < .001$, indicating that participants gave more accurate responses to right-oriented pairs than to left-oriented ones (.92 vs. .90).

Figure 4.

Mean Reaction Times (RT in ms) of Pair Type per Pair Orientation



Note. Bars indicated the standard error of the mean (SEM).

Experiment 2

In accordance with our hypotheses, as well as with the results reported in previous studies (e.g., Borst et al., 2015), the analyzes of Experiment 2 were restricted to prime-probe sequences in which the two letters differed and the two animals were identical. Reaction times (RT in ms) and proportion of correct responses (accuracy) were analyzed with linear mixed-effects (lme) models using the R software (Bates et al., 2011; Bates et al., 2015). The models were fit using the lme4 and lmerTest R packages (Bates et al., 2011; Bates et al., 2015; Kuznetsova et al., 2017) to contrast simple effects with differences of least squares means in the latency data. The prime-probe sequences' analysis was conducted with random intercepts and the four repeated measurement factors (Prime Type: mirror|non-mirror; Prime Orientation: right|left; Probe Type: mirror|non-mirror; and Probe Orientation: right|left) as fixed factors. Incorrect responses (6.45% of the primes and 11.38% of the probes' raw data) were excluded from the latency data. In addition, RTs that were below and above 2 *SD*s of the participants' means in each experimental condition were also removed (4.35% of the primes and 2.56% of the probes' data). Accuracy data were assessed based on the same model with a logistic link function. For the effects that reached statistical significance, the second degree of freedom of the F statistic was approximated using the Satterthwaite's method (see Satterthwaite, 1941; and Khuri et al., 1998 for a review). The p values were adjusted with Hochberg's method for all the post hoc and simple effects comparisons $\alpha \leq .05$ (see Benjamini & Hochberg, 1995, and Hochberg, 1988 for details).

Table 2 shows primes-probes sequences' RT and accuracy rates in each condition.

Table 2.

Mean Reaction Times (RT in ms) and Proportion of Correct Responses (Acc) per Experimental Condition in Experiment 2

			Probe			
Prime			Mirror		Non-mirror	
Letter type	Letter orientation	DVs	Right	Left	Right	Left
Mirror	Right (b-d; p-q)	*RT*	408 (241)	441 (241)	365 (183)	401 (230)
		Acc	.90 (.30)	.85 (.36)	.90 (.30)	.91 (.29)
	Left (d-b; q-p)	*RT*	382 (155)	438 (204)	407 (219)	393 (179)
		Acc	.93 (.25)	.89 (.32)	.91 (.29)	.89 (.31)
Non-mirror	Right (f-j; t-g)	*RT*	377 (174)	438 (255)	396 (174)	419 (234)
		Acc	.92 (.27)	.84 (.37)	.90 (.30)	.89 (.31)
	Left (j-f; g-t)	*RT*	396 (193)	437 (222)	413 (210)	388 (197)
		Acc	.91 (.29)	.83 (.38)	.93 (.26)	.87 (.34)

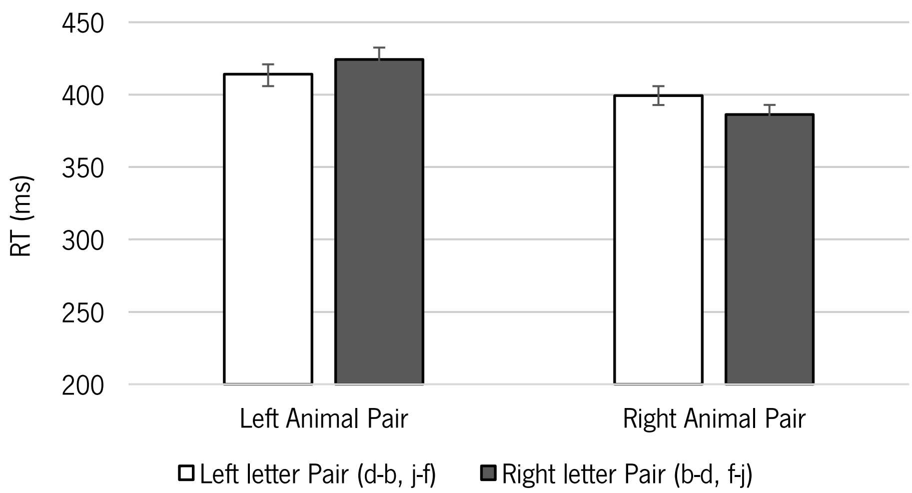
Note. Standard deviations are in parentheses. DVs stands for dependent variables.

Latency analyzes revealed a main effect of probe type, $F(1, 3430.00) = 17.43$, $p < .001$, indicating that participants were slower at recognizing pairs of identical animals facing opposite (mirror condition) than non-opposite positions (non-mirror condition; 414 ms vs. 398 ms). The main effect of probe orientation was also significant, $F(1, 3431.30) = 19.13$, $p < .001$, showing that participants were faster at recognizing identical animals facing right than left orientations (393 ms vs. 419 ms).

The interaction between prime and probe orientations was also significant, $F(1, 3430.60) = 5.14$, $p = .023$. Figure 5 presents a visual depiction of the effect. Post hoc comparisons indicated that orientation effects of the prime in the recognition of the probe (i.e., advantages when animals pairs were oriented to the right) were only verified when animals pairs were preceded by letters pairs that were also oriented to the right (e.g., b-d, f-j; right: 386 ms vs. left: 399 ms; $p = .027$). When animals pairs were oriented to the left, the letters pairs' orientation was indifferent (right: 224 ms vs. left: 414 ms $p = .366$). Moreover, effects of prime orientation were only observed when the probe was oriented to the right (right: 386 ms vs. left: 424 ms; $p < .001$), in such a way that participants were faster in congruency trails (primes and probes oriented to the right). When the prime was oriented to the left, the animals pairs' orientation was indifferent (right: 399 ms vs. left: 414 ms; $p = .135$).

Figure 5.

Mean Reaction Times (RT in ms) of Prime Orientation per Probe Orientation

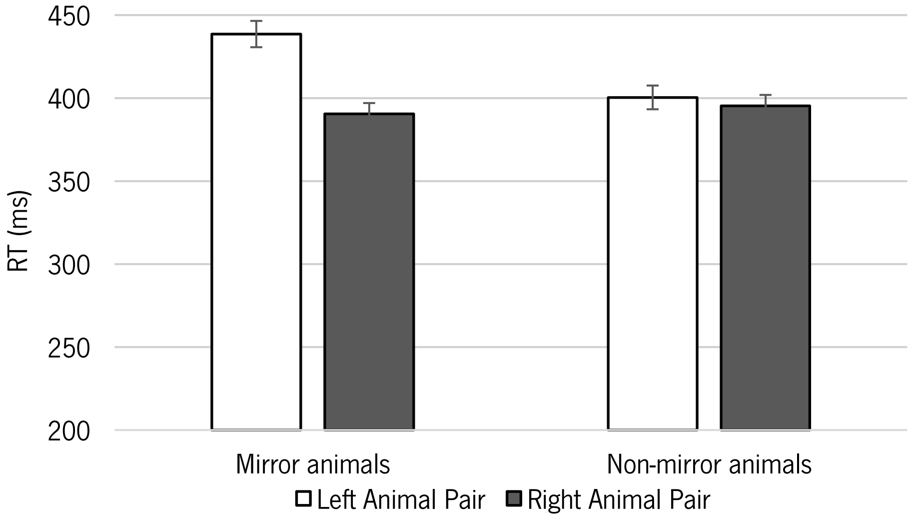


Note. Bars indicated the standard error of the mean (SEM).

Additionally, the two-fold interaction between probe type and probe orientation interaction also reached significance, $F(1, 3434.70) = 13.22$, $p < .001$. Figure 6 presents a visual depiction of the effect. As can be observed, probe orientation effects (i.e., right advantages over left) were only observed in animals pairs that were in mirror conditions (right: 391 ms vs. left: 439 ms; $p < .001$). Moreover, differences between the type of probe (mirror vs. non-mirror) were only observed when the probe was oriented to the left, in which they were faster in non-mirror positions than in mirror ones (mirror: 439 ms vs. non-mirror: 400 ms; $p < .001$). Post hoc comparisons indicated that orientation effects of the prime in the recognition of the probe (i.e., advantages when animals pairs were oriented to the right) were only verified when animals pairs were preceded by letters pairs that were also oriented to the right (e.g., b-d, f-j; right: 386 ms vs. left: 399 ms; $p = .027$). When animals pairs were oriented to the left, letters pairs' orientation was indifferent (right: 224 ms vs. left: 414 ms $p = .366$). Moreover, effects of prime orientation were only observed when the probe was oriented to the right (right: 386 ms vs. left: 424 ms; $p <.001$), in such a way that participants were faster in congruency trails (primes and probes oriented to the right). When the prime was oriented to the left, the animals pairs' orientation was indifferent (right: 399 ms vs. left: 414 ms; $p = .135$).

Figure 6.

Mean Reaction Times (RT in ms) of Probe Type per Probe Orientation



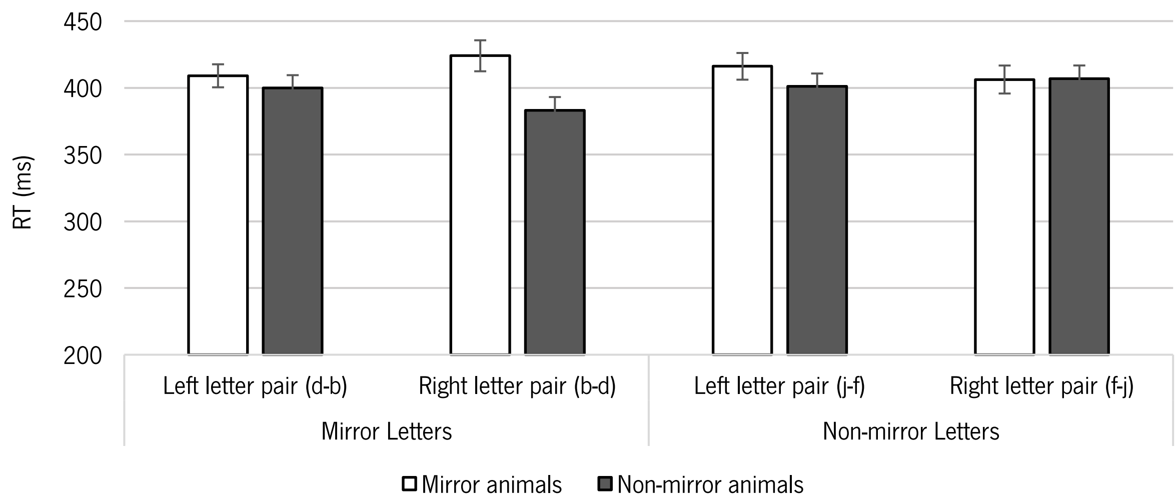
Note. Bars indicated the standard error of the mean (SEM).

A three-fold interaction between prime type, prime orientation and probe type also reached significance, $F(1, 3429.80) = 5.30$, $p = .021$. Figure 7 presents a visual depiction of the effect. The post hoc comparisons showed that when probes were preceded by mirror right-oriented letters (i.e., b-d, p-q), participants took longer to identify two animals as the same when they were presented in mirror condition than when they were presented in non-mirror condition (mirror: 424 ms vs. non-mirror: 383

ms, $p < .001$). However, when probes were preceded by non-mirror right-oriented letters (i.e., f-j, t-g), differences across probe type (mirror vs. non-mirror) vanished. When probes were preceded by left-oriented non-mirror letters pairs (i.e., j-f, g-t), participants were also slower to identify two animals as the same when they were presented in mirror condition than in non-mirror (mirror: 416 ms vs. non-mirror: 401 ms, $p = .001$). But when probes were preceded by left-oriented mirror letters pairs (i.e., d-b, q-p) there were no differences between probes in mirror and non-mirror conditions. Additionally, post hoc comparisons showed that when non-mirror probes were preceded by right-oriented primes, participants were faster when they were mirror letters (i.e., b-d < f-j; mirror: 383 ms vs. non-mirror: 407 ms; $p = .011$). Moreover, when non-mirror probes were preceded by mirror letters pairs, participants were faster with right-oriented letters pairs than with left-oriented ones (i.e., b-d < d-b; right: 383 ms vs. left: 400 ms; $p = .043$).

Figure 7.

Mean Reaction Times (RT in ms) of Prime Type, Prime Orientation, and Probe Type's Interaction

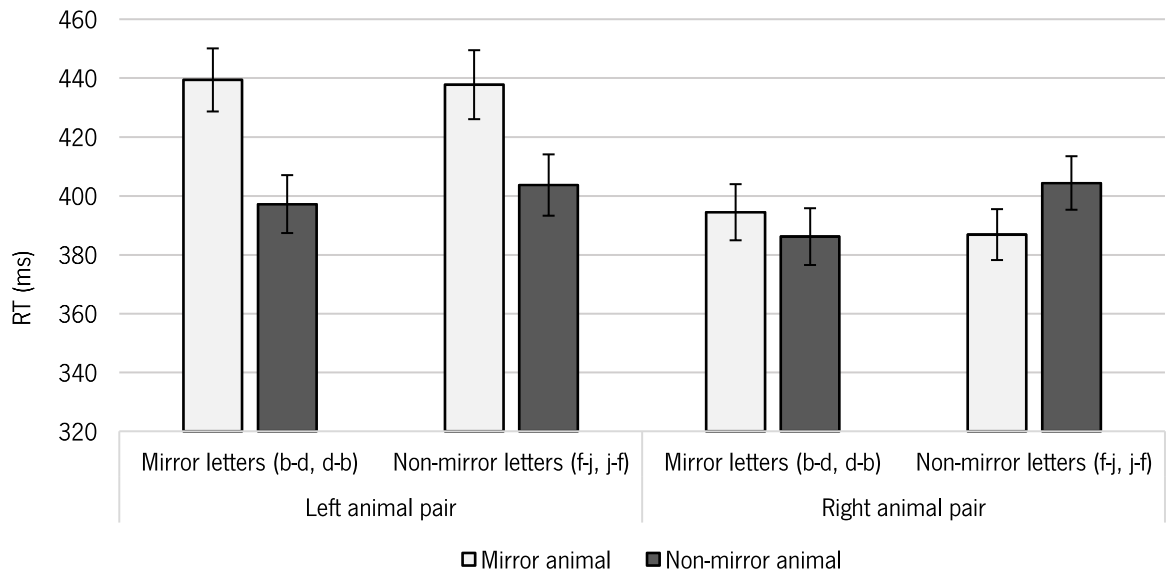


Note. Bars indicated the standard error of the mean (SEM).

The three-fold interaction prime type, probe type, and probe orientation also reached significance, $F(1, 3434.2) = 5.42$, $p = .020$. Figure 8 presents a visual depiction of the effect. Post hoc comparisons showed that when the probe was oriented to the right, participants were faster with non-mirror probes than mirror ones (386 ms vs. 394 ms) when they were preceded by mirror letters pairs ($p = .042$). When they were preceded by non-mirror letters pairs there were no significant differences between mirror and non-mirror right-oriented probes ($p = .134$). When animals pairs were left-oriented, participants responded much slower when the probe was in a mirror condition than in a non-mirror one whether they were preceded by mirror letters pairs (397 ms vs. 439 ms; $p < 0.001$) or by non-mirror letters pairs (403 ms vs. 437 ms; $p < .001$). Moreover, in the non-mirror right-oriented probe condition participants had faster RTs when the probe was preceded by mirror letters pairs than by non-mirror ones (386 ms vs. 404 ms; $p = .015$). However, this difference between prime type was not observed either when the probe was in a mirror right-oriented condition ($p = .304$) or when it was in mirror ($p = .408$) or non-mirror left-oriented conditions ($p = .765$).

Figure 8.

Mean Reaction Times (RT in ms) of Prime Type, Probe Type, and Probe Orientation's Interaction

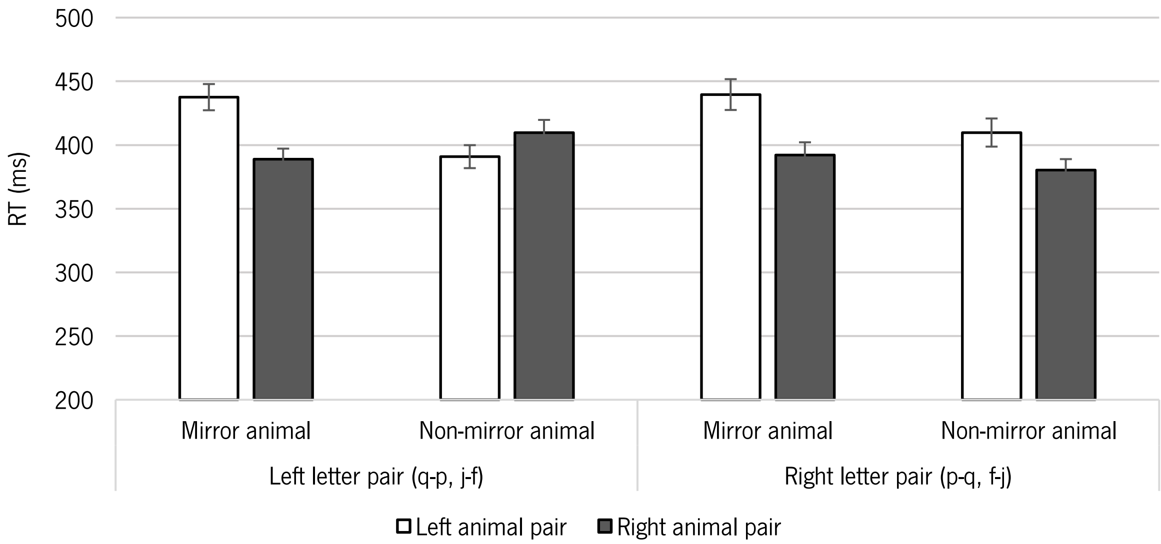


Note. Bars indicated the standard error of the mean (SEM).

Finally, the three-fold interaction between prime orientation, probe type, and probe orientation also reached significance, $F(1, 3434.40) = 5.78$, $p = .016$. Figure 9 presents a visual depiction of the effect. Post hoc comparisons showed an advantage to the right over the left when participants had to recognize similar animals in a mirror condition, whether they were preceded by right-oriented primes (e.g., p-q, f-j; 392 ms vs. 440 ms; $p < .001$), or by left-oriented ones (e.g., q-p, j-f; 389 ms vs. 438 ms, $p = < .001$). There was also an advantage to the right over the left when the probe was in a non-mirror condition and was preceded by right-oriented primes (380 ms vs. 410 ms; $p = .007$). However, when a non-mirror probe was preceded by a left-oriented prime (i.e., d-b, j-f) participants were faster with left-oriented probes than with right-oriented ones (410 ms vs. 391 ms; $p = .048$). Additionally, participants were also faster at recognizing non-mirror right-oriented animals pairs when they were preceded by right-oriented than by left-oriented letters pairs (380 ms vs. 410 ms; $p = .004$). This was not observed neither when the probe was in a mirror right-oriented condition ($p = .740$), nor when it was in a mirror ($p = .650$) or non-mirror left-oriented condition ($p = .077$).

Figure 9.

Mean Reaction Times (RT in ms) of Prime Orientation, Probe Type, and Probe Orientation's Interaction

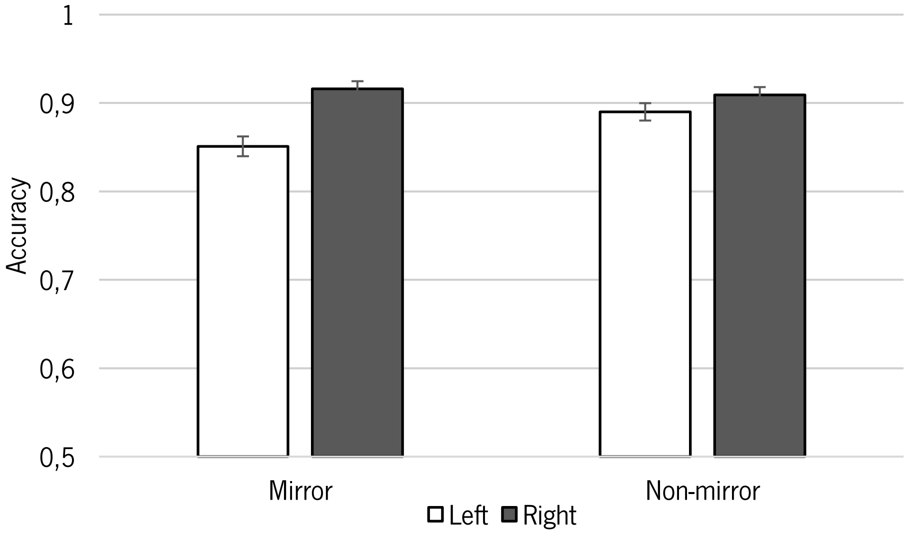


Note. Bars indicated the standard error of the mean (SEM).

In the accuracy data, the analyzes revealed a main effect of probe orientation, $\chi^2(1) = 19.03$, $p < .001$, showing that participants were more accurate at recognizing identical animals facing right than left orientations (.91 vs. .87). The two-fold interaction between probe type and probe orientation was also significant, $\chi^2(1) = 4.90$, $p = .027$. Figure 10 presents a visual depiction of the effect. Post hoc comparisons showed that when probes were in the mirror condition participants were more accurate when the animal pair was oriented to the right than to the left (.92 vs. .85; $p < .001$). However, when probes were in the non-mirror condition, they were equally accurate in both orientations ($p = .141$). Moreover, when the probe was oriented to the left participants were more accurate when the animals were in a non-mirror condition than in a mirror one (.89 vs. .85; $p = .007$). But when they were facing right there were no significant differences between the mirror and non-mirror conditions ($p = .558$).

Figure 10.

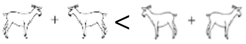
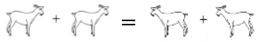
Proportion of Correct Responses (Accuracy) for Probe Type and Probe Orientation' Interaction



Note. Bars indicated the standard error of the mean (SEM).

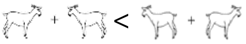
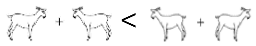
Discussion

In this study, we aimed to analyze for the first time whether the right-asymmetry bias on the visual recognition of words containing mirror and non-mirror letters is also observed in the visual recognition of objects (animals), indicative of a collateral side effect of learning to read on other aspects of cognition. For that purpose, we resorted to a negative priming paradigm introduced by Borst et al. (2015) and conducted two studies. The first aimed to analyze if there is some sort of directionality effect on the visual recognition of objects presented in mirror and non-mirror positions (right and left) in the absence of letters, which functioned as the baseline condition. The second, replicating Borst et al.'s (2015) work, manipulated the type (mirror vs. non-mirror) and orientation (right vs. left) of letters used as primes, and the way the objects (animals) were presented in the probes, as both elements of each pair could be presented in opposite (mirror) or non-opposite (non-mirror) positions, at right or left orientations. The rationale beyond this manipulation was if the right-asymmetry bias found in the suppression of mirror generalization mechanism on the visual recognition of words containing reversal and non-reversal letters also affects other aspects of cognition, participants should be faster and/or more accurate at deciding that two images of the same animal presented in opposite directions correspond to the same animal when presented on the right than on the left condition. Furthermore, given that previous studies have shown that the visual word recognition system has more difficulty in inhibiting the mirror generalization mechanism in words containing left-oriented than right-oriented letters, we expected the magnitude of the negative priming effect (i.e., more cost at recognizing two images of the same animal presented in opposite directions as the same when preceded by primes containing mirror rather than non-mirror letters) to be higher when those letters present a right rather than left-orientation.

The results obtained were clear cut and showed that the presentation of letters seems to change significantly the way participants processed the probes, even though in directions not fully expected. Specifically, the results from Experiment 1 showed a processing advantage (i.e., shorter recognition times and fewer errors) when pairs of identical mirror animals were presented to the right than when presented to the left (). When pairs of identical animals were presented in non-mirror positions, the orientation did not produce any effect (). Moreover, when animals pairs were oriented to the right, participants were faster at recognizing the animals as identical when they were in mirror than in non-mirror condition (). However, when the pairs were oriented to the left, they tended to be faster with non-mirror pairs than with mirror ones (), though only at a marginal level (p = .051). This shows an opposite tendency between left and right-oriented pairs. Although orientation effects were not expected in this experiment, the observed effect may be an artifact of the paradigm used. Note that participants were required to fix their gaze on the center of the computer screen, which may have caused that when the most distinctive part of the animals (i.e., their heads) was closer to the center it produced faster and more accurate responses.

Nonetheless, the results obtained in Experiment 2 showed that the introduction of mirror and non-mirror letters oriented to the right and to the left previously to the presentation of the probes affected the way participants recognized images of the same animals presented in opposite and same positions, beyond what would be expected. Thus, considering that Experiment 1 revealed a by-default right advantage, even when no letters were presented as primes, the question at stake is how that effect was affected when participants were required to respond to right and left-oriented mirror and non-mirror letters presented as primes.

Specifically, the results from the three-fold prime type, probe type, and probe orientation interaction observed in Experiment 2 indicated that when the probe was oriented to the right, participants were faster with non-mirror probes than with mirror images of the same animal () only when they were preceded by mirror letter primes. When they were preceded by non-mirror letter primes the difference between mirror and non-mirror right-oriented probes was not significant ( ). This result is interesting and presents a major difference relative to results observed in Experiment 1 where participants were significantly faster at recognizing two images of the same animal presented in opposite (mirror) than in non-opposite (non-mirror) directions. They also suggest that the discrimination of two mirror letters as different in the primes seems to involve the suppression of the mirror generalization mechanism with a cost in the processing of the probes when presented in opposite (mirror) vs. non-opposite (non-mirror) directions, indicative of a negative priming effect, as observed in previous studies (e.g., Ahr et al., 2016, 2017, 2018; Borst et al., 2015; Foisy et al., 2017). It is also important to highlight that the pattern observed for right-oriented probes preceded by non-mirror letter primes also changed from Experiment 1 to Experiment 2, suggesting that the introduction of letters in the paradigm, even though non-mirror letters, affected the processing of the probes, in line with Soares, Lages, et al. (2021).

Furthermore, the three-fold prime orientation, probe type, and probe orientation interaction observed in Experiment 2 also revealed that the right vs. left orientation of the letters used in the primes cannot be disregarded as they also seem to affect the processing of the probes, as claimed Soares et al. (2019) and by Soares, Lages, et al. (2021), even though using another paradigm. Specifically, the results of that interaction showed that when two images of the same animal were preceded by right-oriented letters (e.g., p-q, f-j) participants were significantly faster at deciding that the two images were the same when they were presented to the right rather to the left, regardless of being presented in opposite () or in non-opposite () positions. However, when the probes were preceded by left-oriented letters (i.e., q-p, j-f), this right-asymmetry advantage is only observed when the probes were presented in opposite directions (). When the probes were presented in non-opposite positions participants were significantly faster at deciding that the two images were the same when they were presented to the left rather to the right (). These findings are interesting and seem to suggest that when the letters used as primes conform to the dominant right-orienting writing rule they seem to affect the processing of the probes more strongly than when they do not conform to that rule. Note that the results observed when probes were preceded by left-oriented letters replicate the ones observed in Experiment 1, when no letters were used at all. These results are in line with our predictions as they seem to suggest a right-orienting bias in objects' (animals) recognition, even though only when right-oriented letters were used as primes, regardless of being mirror or non-mirror letters.

Still, another interesting finding that arises from the three-fold interaction between prime type, prime orientation, and probe type is that the type of letter (mirror vs. non-mirror) and the orientation of the letters (right vs. left) used as primes seem also to produce some kind of effect. Indeed, the results from that interaction revealed that the cost of suppressing the abovementioned mirror generalization mechanism (longer response time at recognizing two animals as the same in opposite vs. non-opposite positions when preceded by mirror than non-mirror letter primes) was only observed for mirror right-oriented letters (i.e., b-d, p-q), but not for mirror left-oriented letters (i.e., d-b, q-p). Besides, the results also showed that the evidence of a negative priming effect was also observed when non-mirror letters were used as primes, but curiously for left-oriented letters (i.e., g-t, j-f), and not for non-mirror right-oriented letters (i.e., t-g, f-j). These findings are in line with our predictions even though they further demonstrate that the evidence of a negative priming effect can be observed not only when right-oriented mirror letters were used as primes, as expected, but also when left-oriented non-mirror letter primes were used instead, thus extending previous results using the negative priming paradigm (e.g., Ahr et al., 2016, 2017, 2018; Borst et al., 2015; Foisy et al., 2017). They also agree with Soares et al. (2019), Soares, Lages, et al. (2021) and Fisher and colleagues (e.g., Fischer, 2011, 2018; Fischer & Koch, 2016; Fischer & Tazouti, 2012) claims as they clearly indicate that the directionality of the letters matters and impacted visual objects' recognition, as our results demonstrate.

Although the interpretation of the effect observed for non-mirror left-oriented letters is not readily understandable, it is possible that because left-oriented letters tend to be more reversed into right-oriented letters, the visual word recognition system has to strongly suppress the mirror generalization mechanism to allow correct letter discrimination, hence explaining the effect. Furthermore, the fact that this effect occurs only for non-mirror left-oriented letters may stem from the fact that mirror left-oriented letters (i.e., d-b, q-p) are more perceptively distinctive than left-oriented non-mirror letters (i.e., g-t, j-f), hence explaining the effect.

Future research should nevertheless be conducted to further explain this effect. It should also replicate this study with pre-reading children, beginner readers, and illiterate adults to further explore whether the results observed in Experiment 1 are already indexing some kind of literacy effect on visual objects' (animals) recognition, as literature shows evidence that reading acquisition changes the way we process non-verbal stimuli in important ways (e.g., Abed, 1991; Fernandes et al., 2016, 2018; Kolinsky et al., 2011; Kolinsky & Fernandes, 2014; Soares, Silva, et al., 2021).

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Universidade do Minho

Conselho de Ética

Comissão de Ética para a Investigação em Ciências Sociais e Humanas

Identificação do documento: CEICSH 035/2022

Relatores: Emanuel Pedro Viana Barbas Albuquerque e Marlene Alexandra Veloso Matos

Título do projeto: *Rompendo a Simetria: Efeitos do reconhecimento de letras no reconhecimento de objetos*

Equipa de Investigação: Ana Paula de Carvalho Soares (IR), Departamento de Psicologia Básica, Escola de Psicologia, Universidade do Minho; Helena Manuela Mendes Oliveira Baldassarre, Investigadora do Centro de Investigação em Psicologia (CIPsi), escola de Psicologia, Universidade do Minho; Ana Duarte Campos Moura, Investigadora do Psychology Lab, Regent's University, Londres, Inglaterra; Maria Barroso da Silva, Estudante do Mestrado Integrado em Psicologia; Escola de Psicoogia, Universidade do Minho

PARECER

A Comissão de Ética para a Investigação em Ciências Sociais e Humanas (CEICSH) analisou o processo relativo ao projeto de investigação acima identificado, intitulado *Rompendo a Simetria: Efeitos do reconhecimento de letras no reconhecimento de objetos.*

Os documentos apresentados revelam que o projeto obedece aos requisitos exigidos para as boas práticas na investigação com humanos, em conformidade com as normas nacionais e internacionais que regulam a investigação em Ciências Sociais e Humanas.

Face ao exposto, a Comissão de Ética para a Investigação em Ciências Sociais e Humanas (CEICSH) nada tem a opor à realização do projeto nos termos apresentados no Formulário de Identificação e Caracterização do Projeto, que se anexa, emitindo o seu parecer favorável, que foi aprovado por unanimidade pelos seus membros.

Braga, 12 de abril de 2022.

O Presidente da CEICSH

(Acílio Estanqueiro Rocha)

Anexo: Formulário de identificação e caracterização do projeto