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Does the implicit outcomes expectancies shape learning and memory processes?

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Abstract

Does the explicit or implicit knowledge about the consequences of our choices shape learning and memory processes? This seems to be the case according to previous studies demonstrating improvements in learning and retention of symbolic relations and in visuospatial recognition memory when each correct choice is reinforced with its own unique and explicit outcome (the differential outcomes procedure, DOP). In the present study, we aim to extend these findings by exploring the impact of the DOP under conditions of non-conscious processing. To test for this, both the outcomes (Experiment 1A) and the sample stimuli (Experiment 1B) were presented under subliminal (non-conscious) and supraliminal conditions in a delayed visual recognition memory task. Results from both experiments showed a better visual recognition memory when participants were trained with the DOP regardless the awareness of the outcomes or even of the stimuli used for training. To our knowledge, this is the first demonstration that the DOP can be effective under unconscious conditions. This finding is discussed in the light of the two-memory systems model developed by Savage and colleagues to explain the beneficial effects observed on learning and memory when differential outcomes are applied.

Keywords: implicit processes, differential outcomes procedure, visual recognition memory

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We are continually making choices throughout our lives, choices that are usually followed by different consequences. For example, when crossing the road, the green light coincides with cars stopping allowing you to cross the road safely; on the contrary, the red light could be paired with cars passing, making road crossing a riskier option. In such situations, could the explicit or implicit knowledge of the consequences of our choices shape the way we learn and memorize information about them? This is a crucial question that has been indirectly and only partially addressed by research investigating the effect of administering differential (or specific) outcomes versus non-differential (or random) outcomes in discriminative learning tasks, and, more recently, in working memory.

The simple manipulation of administering differential outcomes, paring a unique outcome with each target stimulus or each correct stimulus-response sequence, is known as the differential outcomes procedure (DOP). To better understand this, let us consider a group of participants having to perform a delayed facial recognition task. That is, they have to remember faces that they have just seen (e.g., a man with a black beard, and a man with red hair and a moustache) and respond after a delay by selecting them among a group of distractor faces. When the DOP is applied, the correct recognition of each face is followed by a specific outcome. For example, participants only get the feedback “well done” when they correctly identify the face of the man with a black beard. Next, if the face is now the man with red hair and a moustache, the phrase “fantastic” will appear exclusively paired with it. By contrast, under the non-differential outcomes condition (NOP) there is not a predetermined and specific association between the faces and the outcomes. Therefore, participants receive a random phrase (e.g. “well done” or “fantastic”) following their correct responses.

Previous studies have demonstrated that the DOP is effective in optimizing discriminative learning and visuospatial recognition memory in healthy people (e.g., Easton, 2004; Esteban, Vivas, Fuentes, & Estévez, 2015; Estévez et al., 2007; López-Crespo, Plaza, Fuentes, & Estévez, 2009; Martínez, Estévez, Fuentes, & Overmier, 2009; Miller, Waugh, & Chambers, 2002; Mok & Overmier, 2007; Molina, Plaza, Fuentes, & Estévez, 2015; Plaza, Estévez, López-Crespo, & Fuentes, 2011; Plaza, Molina, Fuentes, & Estévez, 2018). The DOP also helps to improve the same cognitive processes in populations with neurocognitive deficits (e.g., Carmona, Vivas, & Estévez, 2019; Esteban, Plaza, López-Crespo, Vivas, & Estévez, 2014; Estévez, Fuentes, Overmier, & González, 2003; Hochhalter, Sweeney, Bakke, Holub, & Overmier, 2000; Joseph, Overmier, & Thompson, 1997; Martínez et al., 2012; Plaza, López-Crespo, Antúnez, Fuentes, & Estévez, 2012). Taken together, these findings indicate that the DOP is a very promising, economic, and effective technique; which can be applied in diverse settings, such as schools and mental health clinics.

It is worth noting that in all the aforementioned studies, the target stimuli as well as the outcomes were supraliminally presented thus allowing its explicit processing. Accordingly, when participants assigned to the DOP condition have been asked which outcome was paired with each discriminative stimulus following the training, they have responded correctly (see Maki, Overmier, Delos, & Gutman, 1995). Thus, although the main goal of these studies has been specifically to explore the potential benefits of the DOP on learning and memory in different populations, it could be said that, based on their procedures, both processes are affected by the explicit or *conscious* knowledge of the outcomes. However, no studies have addressed whether the *unconscious* knowledge of the consequences of our choices would equally influence learning and memory. If so, this finding would have relevant applied implications with strong significance for current theories.

To our knowledge, very little research has been done on the cognitive and neural mechanisms underlying the DOP, particularly in humans. The most accepted explanation with the strongest empirical support is the one proposed by Savage and colleages (e.g., Savage, Pitking, & Careri, 1999; Savage, 2001; Savage, & Ramos, 2009) based on animal research. This theory, the two-memory systems model, suggests that there are two different memory systems: (i) prospective, activated when the DOP is applied; and (ii) retrospective, activated when the outcomes are not specific of the associations to be learned or of the target stimuli (the NOP condition). Continuing with the previous example, an implicit association between the target stimulus (e.g., a man with a black beard) and its unique outcome (e.g., the phrase “well done”) is established under the DOP condition. A Pavlovian association like this is responsible for creating unique reward expectancies (or implicit-prospective memory representations of the forthcoming outcome). This prospective memory system is largely implicit and has been linked to the functioning of glutamatergic pathways by Savage and colleagues. After several training trials, the presentation of the target stimulus automatically activates the expectancy of its unique outcome. This expectancy (or Pavolovian conditioned anticipatory state) has discriminative or functional stimulus-like properties and, therefore, can be used to guide the selection of the correct response independent of target stimulus information (e.g., Overmier, Savage, & Sweeney, 1999; Savage, Buzzetti, & Ramirez, 2004). Noteworthy, expectancies are also functionally different thant rememberign a past event. For instance, they are more persistent than retrospective memories (e.g., Overmier, Savage, & Sweeney, 1999) and are unaffected by hippocampal lesions (e.g., Savage et al., 2004). A theoretical assumption of the two-memory systems model is that the Pavolovian-induced expectancy of the forthcoming outcome is maintained throughout the delay interval in delayed matching-to-sample tasks. In other words, the unique expectancy of the phrase “well done” facilitates the subsequent recognition of the face of a man with a black beard after the delay, without a representation of such stimulus being activated and maintained in working memory. By contrast, when the NOP is applied, there is no specific information available about the forthcoming outcomes so participants would have to remember the target stimulus they have just seen (e.g., the face of a man with a black beard) during the delay to correctly solve the task. This process would require a retrospective memory system associated with the hippocampus that is dependent on Acetylcholine.

There has been only one study exploring the basic mechanisms underlying the DOP in humans using functional magnetic resonance imaging (fMRI), and the results seem to support the two memory systems model. Mok, Thomas, Lungu, and Overmier (2009), using a delayed matching-to-sample task with young adults, observed that separate brain regions are recruited when differential or non-differential outcomes are used. Namely, when DOP was used, the lateral posterior parietal cortex, and more specifically the angular gyrus, was activated during the blank delay between the offset of the sample stimulus and the onset of the choice stimuli. By contrast, when the NOP was applied, greater hippocampal (medial temporal lobe) activation was observed. Furthermore, in the DOP condition, areas specific to the sensorial processing of the outcome (auditory vs. visual), were also activated during this delay. These findings were used to suggest that the expectation of an outcome, elicited by the sample stimulus, may indeed be represented in prospective memory. In an extension of this study, Mok (2012) argued that short-term retrospective (NOP) and prospective (DOP) memory processes (i) are mediated by two different subsets of the default brain network (the medial temporal lobe would be involved in monitoring what has just happened –the cue or sample stimulus- whereas the lateral parietal lobe would be implicated in prospective processing of what is forthcoming –the outcome-) and (ii) might be spontaneously engaged not requiring a deliberate and effortful activation.

Despite current support to the idea that the DOP stimulates implicit memory systems, and thus is largely unaffected by consciousness and explicit expectations, this aspect has remained a theoretical assumption and has never been tested. The present study will provide first evidence on the role of awareness in the DOP with important implications for theoretical models and its applications in humans. To do so, both the outcomes (Experiment 1A) and the sample stimuli (Experiment 1B) will be presented under subliminal (non-conscious) and supraliminal (conscious) conditions in a delayed visual recognition memory task. Subliminal presentation aims to eliminate the subjective visibility of the stimuli by masking and displaying them for a few milliseconds (e.g., Breitmeyer & Ogmen, 2006). The provided information is therefore inaccessible to consciousness and it cannot be reported (Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006), although their processing still can be boosted by increasing attention to them (Dehaene et al., 2006). By contrast, supraliminal presentation allows the subjective visibility of the stimuli and its access to consciousness. According to the two-memory systems theory, we should observe the beneficial effect of applying the DOP under conditions of non-conscious processing, since (i) the association established between the sample stimulus and the specific outcome is formed via an implicit process (Pavlovian associations) and (ii) the activation and maintenance of these reward expectancies also depends on an implicit prospective memory system. Thus, we should observe a similar magnitude of the DOP effect under subliminal or supraliminal presentations of either the cue stimulus or the outcome.

Regarding to the NOP condition, we propose two possible hypotheses. 1) If, as the two-memory systems theory indicated, explicit processing is required to maintain active the memory of the cue during the delay, performance should improve (faster and/or more accurate) with the supraliminal condition as compared to the subliminal one. This is due, among other factors, to the superior encoding of supraliminal visuospatial information (Salti et al., 2015). 2) By contrast, if, as Mok (2012) suggested, this retrospective process can be spontaneously engaged (without a deliberate intention and depending on the default brain network), then it is possible that the subliminal processing of the cue would be enough to activate it. If this was the case, then performance should be equivalent in both conditions (subliminal vs. supraliminal). Finally, according to Savage and colleagues, since the NOP does not depend on the expectancy of the outcomes and is activated by retrospective memory, responses in the delayed visual recognition task should be the same regardless of how the outcomes are presented (subliminally vs. supraliminally) in the NOP condition.

Experiments 1A and 1B

The main aim of these experiments was to test whether the DOP would still improve visual recognition memory in healthy adults with subliminal (unconscious) presentations applied either to the outcomes (Experiment 1A) or to the sample stimuli (Experiment 1B). To do so, reaction times (RTs) and accuracy were measured to compare subliminal and supraliminal conditions in both experiments.

Method

Participants. In the two experiments included here, participants were undergraduates from the University of Almería (Spain). We conducted a priori power analysis with the G*Power software 3.1.9.2 (Faul, Erdfelder, Lang, & Buchner, 2007) to determine the minimum required sample size to detect both main effects and interactions (between-subjects factors). With an alpha = .05 and power = .80, the analysis revealed that thirty-six participants were required to detect a small-medium effect size (d=0.44). The effect size expected is based on previous studies concerning to the DOP in healthy adults (e.g., Plaza et al., 2018).

Forty-four participants (ranging in age from 18 to 38 years, M = 20.9, SD = 4.9) and forty-six participants (ranging in age from 18 to 36 years, M = 20.8, SD =3.2) volunteered in experiments 1A and 1B, respectively. These opportunistic samples included 10 males and 34 females (Experiment 1A) and 14 males and 32 females (Experiment 1B). Written informed consent was obtained from all participants. The study was approved by the University of Almería Human Research Ethics Committee and was conducted in accordance with the Declaration of Helsinki. Participants reported normal or corrected-to-normal vision and were naïve with respect to the purposes of the experiment. They received extra course credit for their participation and the chance to win one of the prizes that were raffled off at the end of the study.

Setting and materials. The stimuli were displayed on a black background on a colour monitor (15-inch VGA monitor) of an IBM-compatible computer. The E-prime software (Psychology Software Tools Inc., 2012) controlled the stimulus presentation as well as the collection of the participant's responses (latency and accuracy data). Participants were tested individually in quiet rooms with identical sound and lighting conditions.

The stimuli were six white circular shapes with shaded sectors (see Figure 1 depicting the stimulus sequence) designed by one of the authors (I.C.) with the AutoCAD software (Autodesk, 2010). Four of them were presented as initial cue stimuli and the rest as comparison stimuli. The size of the shapes was 3^{o} x 3^{o} of visual angle and could be displayed either individually at the centre of the screen (sample stimulus), or in a 2 × 3 grid (comparison stimuli). Four reinforces (a pen drive, a five-euro bill, a key ring or a set of four pens) were used in the experiment and they were raffled off at the end of the study. Pictures of these prizes were used as outcomes. They appeared at the center of the screen along with both a congratulation phrase (“very well”, “well done”, “congratulations” or “very good”) and the phrase “you may win a” followed by the name of a reinforcer, after a correct choice. The phrases were in Courier New, size 12 and in white colour.

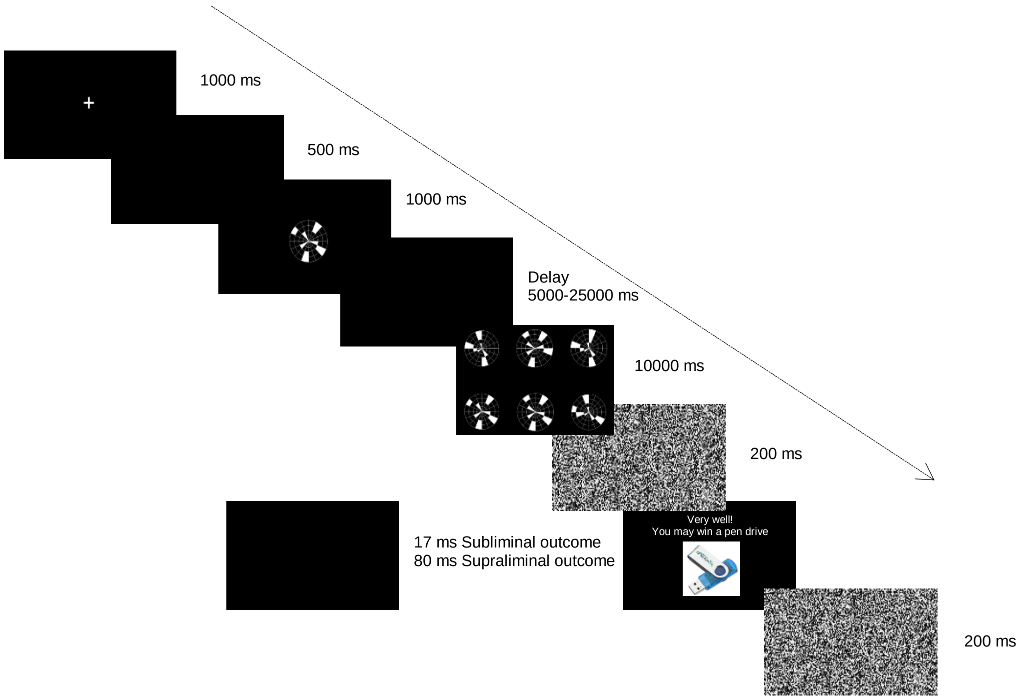

Figure 1. Stimulus sequence (from left to right) used in Experiment 1A.

Procedure

As a first step, we conducted two pilot studies to make sure that participants were not able to perceive the stimuli consciously. In the first one (N=62) we tested the following parameters: (i) stimulus presentation time (17 ms, 33 ms, 50 ms, 67 ms or 80 ms); (ii) pattern mask presentation time (100 ms or 200 ms), and (iii) type of pattern mask (simple or double). The studies showed that when the target stimuli, or the outcomes, were displayed for 17 ms, with a double pattern mask (before and after the stimulus) during 200 ms, all participants informed that they had seen no stimulus. With 33 or 50 ms and the same type of mask, most of the participants reported that they had seen some of them. Finally, when the stimuli appeared for 67 or 80 ms, all participants reported full conscious processing. In the second pilot study, we designed a decision task following the stimulus parameters. Eight circular sample stimuli and eight square sample stimuli were presented subliminally during 17 ms, with two pattern masks appearing before and after each of them for 200 ms. Each stimulus appeared twice, so the total number of trials was 32. For each trial, participants (N= 42) had to decide whether they had seen a circular or a square shape by pressing the “1” or “2” keys on the keyboard. Participants knew in advance that there was the same number of circular and square shapes. The results revealed a performance at chance for all participants demonstrating no indication of conscious processing of the stimuli.

For the final experiments, participants performed a delayed matching to sample task (DMTS). As in previous studies (e.g., López-Crespo et al., 2009; Plaza et al., 2012), a variable delay of 5 and 25 seconds was interposed between the offset of the sample stimulus and the onset of the comparison stimuli in both experiments. The task lasted approximately 20 minutes.

In Experiment 1A, each participant received the same verbal instructions, also written on the screen: “First, a central fixation point will appear. Then, it will be replaced by a circular shape presented for a short time. You must pay attention because, after a variable delay, you will have to identify the shape that you have just seen out of six different options by clicking on it with the mouse. When you are ready, please press the space bar to begin”. In addition, all of them were informed that (i) a masked outcome would appear after their responses (see Figure 1), (ii) even when they could not to see it, the outcome for the correct responses included a picture of one of four prizes along with both a congratulation phrase and the phrase ‘You may win a (the name of the specific prize)” whereas incorrect choices would be followed by a blank screen; (ii) the four prizes would be raffled off at the end of the study; and, (iii) the more accurate their responses were, the more tickets they would win for the raffle with higher chances of winning one of the prizes. Finally, participants were also asked to choose one of the comparison shapes as quickly as possible.

Each trial began with a fixation cross presented for 1000 ms (see Figure 1). After a blank brief period of 500 ms, a visual sample stimulus was displayed for 1000 ms followed by a variable delay of 5000 ms or 25000 ms with a blank screen. Then, six comparison stimuli (the sample stimulus plus five distractor shapes) appeared and remained on the screen until the participants responded by clicking with the left mouse button on one of the shapes, or 10 seconds were elapsed, whichever occurred first. The position of the correct sample stimulus among the comparison stimuli was counterbalanced. When the response was correct, the specific outcome was presented during 17 ms (subliminal condition) or 80 ms (supraliminal condition), right in between two masked patterns that appeared for 200 ms before and after the outcome. When the response was incorrect, the screen remained blank during the same time used for the outcome presentation (17 or 80 ms). The trial was also scored as incorrect if the participant did not emit any response in 10 s.

Participants were randomly assigned to one of the two experimental outcomes conditions, differential (DOP; N = 21) and non-differential (NOP; N = 23). In the DOP condition, each to-be-remembered stimulus was associated with one specific outcome so that the correct response to a particular stimulus was always followed by its own consequence. In the NOP condition, each correct response was followed by the random presentation of one of four possible outcomes. For 26 participants (12 in the DOP and 14 in the NOP condition), outcomes were presented subliminally, being supraliminal for the remaining participants (N=18; 9 in the DOP and 9 in the NOP condition). All of them performed four practice trials followed by 72 training trials, grouped in six blocks of 12 trials each. The order of the blocks and the position of the correct comparison stimulus on the screen were counterbalanced across participants. At the end of the experiment, each participant had to report whether they had perceived any shape in the masked outcome screen or not. They were not told that they would be tested later. Two participants, one in the NOP condition and one in the DOP condition, reported they had perceived an image. Although none of them knew the identity of the outcome, their data were not included in the statistical analysis.

In Experiment 1B, the procedure was similar to that used in the Experiment 1A with a few changes: i) The sample stimulus, instead of the outcome, was presented either subliminally (17 ms) or supraliminally (80 ms), interposed between two masked patterns that appeared for 200 ms (before and after the sample stimulus). ii) The number of sample stimuli and reinforcers was reduced from four to two. Previous pilot tests conducted in our lab revealed that when the sample stimulus was presented subliminally (instead of the outcomes), the task difficult substantially increased with participants performing close to chance. Therefore, we reduced the number of the sample stimuli to make the task easier. iii) Instructions were modified so that participants were asked to choose one comparison shape as quickly as possible, even if they had not seen any shape before the presentation of the choice stimulus. iv) Participants were also informed that when their responses were correct, they would see a picture of a prize along with both a congratulation phrase and the phrase ‘You may win a (the name of that specific prize)’; by contrast, the screen would remain blank for several seconds after their incorrect responses. v) The outcomes were displayed on screen for 1500 ms after the correct responses.

As in Experiment 1A, participants were randomly assigned to one of the two experimental outcomes conditions, differential (DOP; N = 24) and non-differential (NOP; N = 22). For 26 participants (14 in the DOP and 12 in the NOP condition), the sample stimuli were presented subliminally; their presentation was supraliminal for the remaining participants (N=20; 10 in the DOP and 10 in the NOP condition).

At the end of the experiment, as in the Experiment 1A, participants had to report whether they had noticed any shape in the masked sample stimulus screen or not. None of them reported having perceived an image.

Statistical analysis

Percentages of correct responses and median correct response times for each participant were submitted to a 2 x 2 x 2 mixed ANOVA with Outcomes (DOP and NOP) and Type of presentation (subliminal and supraliminal) as the between-participants factors and Delay (5s and 25 s) as the within-participants factor. The statistical significance level was set at $p \leq .05$. Normality of data was checked using Kolmogorov-Smirnov test, and homogeneity of variance was tested using Levene's test. Results showed the normal distribution of data and the homogeneity of variance in all variables.

Results

Accuracy data. In Experiment 1A, the results showed that participants were more accurate in the DOP (71% correct responses) than in the NOP condition (54% correct responses), [main effect of Outcomes, $F(1,40)=15.11$, $p<0.001$, $\eta_p^2=0.27$]. The comparison between the subliminal and non-subliminal conditions did not show statistically significant differences [$F(1,40)=2.99$, $p=0.091$, $\eta_p^2=.07$] (see Figure 2, panel A). For theoretical reasons, despite the Outcomes x Type of presentation interaction not reaching significance [F (1,40)=1.10, p=0.30, η_p^2 =.02], we nevertheless tested whether the DOP showed the expected benefits in the subliminal group. The results revealed that accuracy was better in the DOP condition (72% correct responses) than in the NOP condition (60% correct responses), [main effect of Outcomes, F (1,24)=5.36, p=0.029, η_p^2 =0.18]. Similarly, in the supraliminal group, accuracy was better in the DOP condition (69% correct responses) than in the NOP condition (48% correct responses) [main effect of Outcomes, F (1,16)=9.17, p=0.008, η_p2 =0.36]. No main effect of Delay was found [F (1,40)=3.36, p=0.08, η_p2 =0.07]. No other variables nor interactions reached significance. (ps>0.05).

As mentioned earlier, the benefits of the DOP did not change depending on the type of presentation, but the mean accuracy data showed that these benefits were nearly twice as large in the supraliminal as in the subliminal condition. Subsequently we tested the equality of these outcomes conditions between the subliminal and supraliminal groups. The estimated Bayes factors (BF_{01}) suggested that the differences in masking for the DOP group were 3:1 times in favour of the Null Hypothesis, providing substantial evidence for the equality of the group means (Jarosz & Wiley, 2014). In the NOP group, there were no signs of improvement of learning due to consciousness with even a 0.7:1 tendency (albeit very weak) in favour of an unexpected alternative hypothesis that would see an increase in accuracy in subliminal rather than in the supraliminal group (See Figure 2).

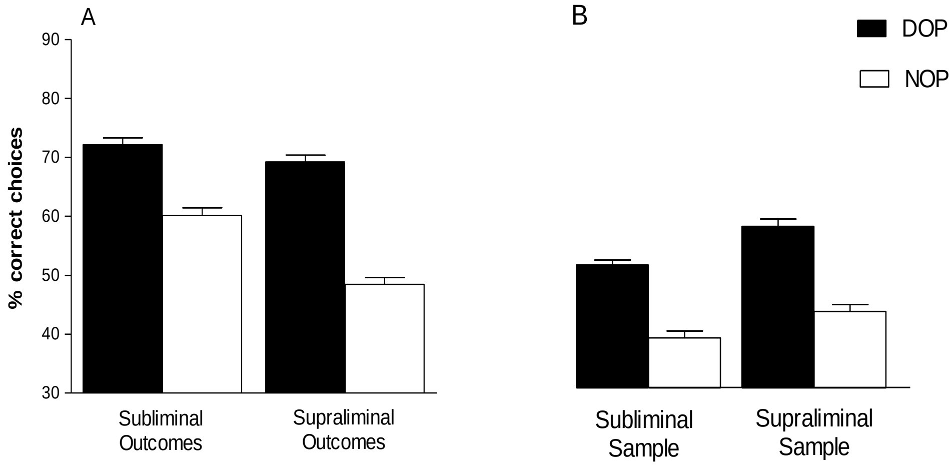

Figure 2. Mean percentage of correct responses obtained by participants in experiments 1A (panel A) and 1B (panel B) as a function of Outcomes (differential –DOP- vs. non-differential –NOP-) and Type of presentation (subliminal vs. supraliminal). Error bars represent the standard deviations.

In Experiment 1B, the analysis of the correct responses also revealed that those participants assigned to the DOP condition performed the task better than those who received non-differential outcomes after their correct responses (53% and 40% accuracy for the DOP and NOP conditions, respectively) [main effect of Outcomes $F(1,42)=14.64$, $p<0.001$, $\eta_p^2 = 0.26$]. As in the previous experiment, there were not differences between both types of presentation (subliminal vs. supraliminal; 44% vs. 49% correct responses for both conditions), [$F\ (1,42)=2.45$, $p=0.13$ $\eta_p^2 = 0.06$] (see Figure 2, panel B). Similarly to Experiment 1, for theoretical reasons we tested whether the DOP showed the expected benefits in the subliminal group (50% and 38% correct responses in the DOP and NOP conditions, respectively) [$F\ (1,24)=8.62$, $p=0.007$, $\eta_p^2 = 0.26$]. The same effect was found when analysing data from the supraliminal group (56% and 42% correct responses in the DOP and NOP conditions, respectively) [F

(1,24)=6.13, p=0.02, $\eta_p 2$ =0.254]. No main effect of Delay was found [F (1,42)=3.36, p=0.07, $\eta_p 2$ =0.07], nor any interaction between the three main factors (ps>0.05). Finally, the estimated Bayes factors (BF_{01}) suggested that the effect of the type of presentation was in favour of the null hypothesis 3:1 times for the NOP group and 2:1 for the DOP group confirming the absence of an impact due to consciousness on the different types of outcomes.

Latency data. The analysis of latency data from both experiments only showed a significant effect of Delay [F_{1A} (1,40)=12.48, p<0.01, η_p^2 =0.24; F_{1B} (1,42)=11.48, p<0.01, η_p^2 =0.21] indicating that participant's correct responses were faster in the short than in the long delay (3117 ms vs. 3380 ms and 4035 ms vs. 3772 ms for both delays in experiments 1A and 1B, respectively). No other effects, nor their interactions, were statistically significant (ps>0.05). Table 1 shows the mean correct RTs in the task as a function of Outcomes, Type of presentation and Delay.

Table 1. Median correct response times (in milliseconds) obtained by participants in experiments 1A and 1B as a function of Delay (5000 ms –short- vs. 25000 ms –long-) Outcomes (differential –DOP- vs. non-differential –NOP-) and Type of presentation (subliminal vs. supraliminal). The values in parenthesis are the standard error of the mean.

	DOP	**NOP**	**DOP**	**NOP**
Experiment 1A	*Subliminal outcomes*		*Supraliminal outcomes*	
Short-delay	3353.42	3212.11	2949.00	2952.06
	(257.44)	(238.34)	(297.26)	(297.26)
Long-delay	3669.58	3420.82	3133.00	3293.61
	(270.10)	(250.06)	(311.88)	(311.88)
Experiment 1B	*Subliminal samples*		*Supraliminal samples*	

Short-delay	4053.93	3864.54	3436.25	3734.00
	(270.59)	(292.27)	(252.05)	(252.05)
Long-delay	4424.14	4175.38	3373.35	4167.05
	(273.21)	(295.10)	(246.09)	(246.09)

Discussion

One relevant question we might ask is whether being aware of the specific consequences of our actions is a necessary condition for them to have beneficial effects in cognition (as demonstrated by the DOP effect). The two-memory systems theory (e.g., Savage & Ramos, 2009) would claim this not be the case, because expectancies of the specific outcomes are implicitly formed via classical conditioning associations (i.e., sample stimulus-outcome). After several pairings, the presentation of the sample stimulus would activate the representation of its own and unique outcome and this can be used to make the correct choice. This activation is meant to be automatic and non-intentional, both characteristics of implicit memory systems. Thus, the unique expectancy of the outcome, represented in a prospective memory trace, could be implicitly formed and stay active for some time. Our findings are in agreement with this theory. DOP benefits in visual recognition memory were observed whether the specific outcomes were subliminal or supraliminal (Experiment 1A). Similar results were obtained regardless of the awareness of the sample stimulus (subliminal vs. supraliminal presentation, Experiment 1B). These results clearly show that the explicit knowledge of the sample is not necessary either for it to create and activate expectancies about its unique outcome. Given that the DOP effect was evident in both experiments across all conditions, the results clearly support the idea of an implicit-prospective memory process activated when the outcomes are differentially administrated. To our knowledge, this is the first time that the DOP effect has been reported under unconscious conditions.

Regarding the NOP, results from Experiment 1B are most relevant here. If, as suggested by the two-memory systems model (e.g., Savage & Ramos, 2009), the presence of non-differential outcomes triggers an explicit retrospective memory process, then a supraliminal sample should have been better remembered than the subliminal one. However, performance was similar in both conditions. This fits with the idea that this type of retrospective memory is activated spontaneously (Mok, 2012) without a deliberate intention. In fact, it seems that only a subliminal encoding of the stimulus is enough to engage it. Based on this finding, we would no longer be referring to this retrospective memory as explicit (in which we are aware of the stimulus and keep it active in memory, Graf & Schacter, 1985). Rather, we think of it as the activation of an implicit representation of the stimulus that has just been presented. Nonetheless, it is possible that this still is the same retrospective memory processes proposed by Savage and colleagues (see also Mok, 2012 and Mok et al., 2009) largely based around the activity of the hippocampus. Accordingly, and contrary to previous theories assigning to the hippocampus an exclusive role in explicit memory, recent studies have found that this brain region is involved in both explicit and implicit memory (e.g., Addante, 2015). To further confirm this, future neuroimaging studies should investigate whether the neurobiological mechanisms activated by the DOP are the same whether the processing is conscious or not.

Finally, it is worth noting that in Experiment 1A, despite the lack of interaction between the outcomes and the type of stimulus presentation, there is still a marginally better performance in the NOP condition when the outcomes were subliminally presented as compared to when the presentation was supraliminal [F (1,21)=4.02, p=0.056, η_p^2 =.16]. This effect could be explained in two different ways: (i) the supraliminal reward may interfere with retrospective working memory process (Zedelius, Veling, & Aarts, 2011; Zedelius et al., 2014) or (ii) the increase in conscious working memory load (having to remember the sample stimuli plus the four explicit outcomes) may have a detrimental impact on performance (Vogel, Woodman, & Luck, 2001; Awh, Barton, & Vogel, 2007). Further research is needed to clarify this issue.

To conclude, the present results are important to understand the cognitive mechanisms underlying the benefits observed in the human version of the DOP. In fact, we demonstrated that these beneficial effects depend on implicit mechanisms, as proposed by the two-memory systems, and can be observed regardless the awareness of either the sample stimulus or its associated outcome. Furthermore, we consider that these findings throw some light on how we process information in situations in which we know (consciously or not) the specific consequences of our choices. We think that, from an evolutionary perspective, being able to predict these consequences has been so crucial for survival that its benefits are observed even when they are unconscious. Thus, as soon as a stimulus-unique outcome association can be established, the way the brain processes the information seems to change to an implicit-prospective manner; helping optimizing the functioning of cognitive processes involved in memory and learning. This research has strong implications when applying the differential outcomes methodology at different stages of human brain development, in patients who have diminished conscious processing for a variety of reasons (such as brain injury or neurodegenerative impairments), or with disabilities specifically affecting explicit memory and/or executive functions (e.g., patients diagnosed with Alzheimer’s disease, Cushing’s syndrome or schizophrenia). Similarly, because we have shown that explicit knowledge of consequences would not be necessary for the DOP to improve memory and learning processes, our results further support its use as a powerful learning tool in educational contexts from early childhood to older people with or without cognitive deficits.

Conflict of interest

The authors report no conflicts of interest.

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