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Enhancing recognition memory in adults through differential outcomes

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ABSTRACT

It has been widely demonstrated that the differential outcomes procedure (DOP) facilitates both the learning of conditional relationships and the memory for the conditional stimuli in animal subjects. For conditional discriminations in humans, the DOP also produces an increase in the speed of acquisition and/or final accuracy. However, the potential facilitative effects of differential outcomes in human memory have not been fully assessed. In the present study, we aimed to test whether this procedure improves performance on a recognition memory task in healthy adults. Participants showed significantly better delayed face recognition when differential outcomes were used. This novel finding is discussed in the light of other studies on the differential outcomes effect (DOE) in both animals and humans, and implications for future research are presented.

Previous studies have demonstrated that the differential outcomes procedure (DOP) may be useful as a technique for facilitating the learning of conditional symbolic relationships (for a review, see Urcuioli, 2005). The DOP involves reinforcing each sample stimulus/correct choice combination of a discrimination task with a distinct outcome. For example, one stimulus/choice combination (e.g., tone — press left lever) is followed by the delivery of sucrose whereas the alternative combination (e.g., light — press right lever) leads to the access of food. When this training procedure is applied, learning is faster and final accuracy is higher than when the reinforces are randomly presented (the non-differential outcomes procedure; e.g., the correct choice of left lever is followed by a random presentation of one of the two possible outcomes — food in one trial, sucrose on the following one, and so on). This enhancement of accuracy and acquisition observed under differential outcomes conditions has been called the differential outcomes effect (DOE, Trapold, 1970; Trapold & Overmier, 1972).

Most findings have provided support for the expectancy theory originally proposed by Trapold and Overmier (1972) as an explanation for the DOE (e.g., Edwards, Jagielo, Zentall, & Hogan, 1982; Peterson, 1984; Urcuioli & DeMarse, 1997). This theory states that the subject learns something specific about the qualitative and quantitative properties of the outcomes and develops unique expectancies for the specific outcomes. The theory argues that the expectancies are classically conditioned to the sample stimuli that signal which reinforcer is contingent on responding (the choice of the comparison stimuli). What makes training with differential outcomes so effective is that it allows for the unique expectancies to become discriminative cues that serve as additional guides for choice behavior. Thus, the subject develops an expectation of the specific reward before the actual reinforcer is presented. Under a non-differential-outcomes condition organisms still develop outcome expectancies but because the expectancies are common to both choices, they do not add any additional information for subjects to base their decisions on.

Shepp was one of the first authors to suggest a possible positive effect of the DOP on human learning (Shepp, 1962;1964). More recently, the differential outcomes training has been shown to be effective in adults with Prader–Willi syndrome (Joseph, Overmier, & Thompson, 1997) and low IQ (Estévez, Overmier, Fuentes, & González, 2003; Malanga & Poling, 1992), as well as those without mental handicaps (Easton, 2004; Estévez et al., 2007; Legge & Spetch, 2009; Miller, Waugh, & Chambers, 2002; Mok & Overmier, 2007). In addition, this training benefit was extended to children with (Estévez et al., 2003) and without (Estévez & Fuentes, 2003; Estévez, Fuentes, Mari-Beffa, González, & Alvarez, 2001; Maki, Overmier, Delos, & Gutmann, 1995; Martínez, Estévez, Fuentes & Overmier, 2009) Down's syndrome.

Curiously, although the DOP has also been shown to improve memory-based performance after delays in animals (e.g., Demarse & Urcuioli, 1994; Savage, Pitkin, & Careri, 1999), so far, to our knowledge, only two

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published studies have explored this issue in humans. In an extension to a clinical population of the work in an animal model of Korsakoff syndrome reported by Savage and Langlais (1995), Hochhalter, Sweeney, Bakke, Holub, and Overmier (2000), trained four patients with alcohol-related amnesia to recognize which of two faces matched a previously seen face. This task seems easy, but it is difficult for people with alcohol dementia due to their impaired short-term working memory. One patient did not show any difference in matching accuracy when trained with differential and non-differential outcomes, and his data was not included in the statistical analyses. The other three patients showed improved recognition memory at a delay of 5 s when differential outcomes were arranged — not differing from normal individuals. At longer delays, however, patients showed low accuracy regardless of the type of training used. Although these results are very promising, the small sample of the study and the large variability showed by patients' responses do not allow a clear assessment of the potential of the DOP for aiding memory in humans. More recently, we have conducted a study with adults older than 64 years of age (López-Crespo, Plaza, Fuentes, & Estévez, 2009). Participants had to perform a face discrimination task under two memory intervals, short (5 s) and long (30 s). The results showed that, contrary to younger adults, the older adults' performance dropped when delay intervals were increased and non-differential outcomes were arranged. However, when differential outcomes were used older adults' performance was unaffected by delay interval and remained at a relatively high level.

Given the scarce number of studies that have demonstrated the benefit of the DOP in human memory, more research is needed to explore the relevance of this procedure for improving long and short-term memory. In the two experiments reported here, we aimed to provide further evidence of the DOE in young adults without cognitive deficits performing a facial recognition memory task under conditions of differential and non-differential outcomes.

1. Experiments 1a and 1b

The main aim of the present experiments was to test whether the DOP would improve short-term memory in humans. Given that previous research has shown that the DOE is modulated by the difficulty of the task (Estévez et al., 2001;2007; Legge & Spetch, 2009), two different version of a recognition task were used. In Experiment 1a, the participants had to report whether the photograph of the face they had seen a few seconds earlier (sample stimulus) was among the six faces they were seeing (comparison stimuli). In Experiment 1b, the difficulty of the task was increased by using a distraction task to prevent rehearsal. Participants were asked to count backwards by threes during the delay interval.

2. Method

2.1. Participants

In all experiments reported in this paper, participants were undergraduate students from the University of Almería (Spain) and they received course credits for their participation and the chance to win one of the six prizes that were raffled off at the end of the experiments. Experiment 1a had twenty-six participants (M age = 21.3, SD = 3.6) and Experiment 1b had thirty-four participants (M age = 19.6, SD = 2.03). All of them had normal or corrected-to-normal vision.

2.2. Stimuli and materials

The stimuli and materials were identical for the two experiments. The stimuli used were color photographs of male faces taken from a front perspective and they were presented on a blank background on a color monitor (VGA) of an IBM/PC compatible computer. These photographs showed Caucasian adult men wearing suits and neckties and standing in front of a white background (see Supplementary material for a figure depicting all the faces used in the experiments). The E-prime program (Psychology Software Tools, 1999) controlled the presentation of the stimuli as well as collection of the reaction times (RTs) and accuracy data.

The photographs measured 5.5 × 6.5 cm and could be displayed either individually in the centre of the screen (sample stimulus), or grouped in a 3 × 2 grid (comparison stimuli) equidistant from the borders. The position of the photographs on the 3 × 2 grid was randomly arranged. Six pictures of a landscape served as secondary reinforcers along with the phrase "You have won a ticket for (the name of a specific primary reinforcer)". A pendrive, a pack of 50 CD-R discs, a pack of 50 DVD-R discs, a book, a game and a CD wallet were used as primary reinforcers. These reinforcers were raffled off at the end of the experiment.

2.3. Procedure

Participants were tested individually in a quiet room. In Experiment 1a, each participant read the following instructions that appeared on the computer screen (the following is translated from Spanish): "In this experiment each trial begins with a central fixation point (+). Then a male face will appear. You must pay attention because after a variable time interval six male faces will come up. Your task is to decide if the first face you saw is among these six faces. If your response is correct, you will see a picture of a landscape along with the phrase 'You have won a ticket for (the name of a specific prize that will be raffled at the end of the study)'. If your response is wrong, a white screen will appear for several seconds. The more accurate your responses are, the more tickets you will win for the raffle and the more chance you will have of winning one of the prizes. Remember that you must try to respond as accurately and as quickly as possible. When you are ready, please press the space bar to begin".

After reading the written instructions, participants were required to emit a correct response during a practice trial, to ensure correct understanding of the instructions. If participant made an incorrect response, instructions were repeated and more practice trials were given until a correct response was made. Nobody failed the first practice trial.

The test consisted of 96 trials grouped into two blocks of 48 trials each. On each trial, a central fixation point (an asterisk) appeared for one second. After an interval of 0.5 s a face was presented for 1.5 s. After another interval of 5, 10, 25 or 32 s (randomly selected), six faces were presented during 10 s or until a response was made. The participants had to decide whether the face they saw previously was or was not present among the choice stimuli. For affirmative responses, participants were required to press the "N" key on the keyboard; for negative responses, they had to press the "M" key. Following a correct response both a picture of a landscape and a phrase appeared on the screen for 2.5 s. Incorrect responses were followed by a blank screen during the same time as the outcome presentation (see Fig. 1). The trial was also scored as incorrect if participant did not emit a response in the 10 s period.

The procedures used in Experiment 1b were similar to those of Experiment 1a with the exception that following the presentation of the sample face a three-digit number appeared on the screen (e.g., 326) during the first second of the delay interval. Participants were instructed to count backwards aloud by threes until the presentation of the choice stimuli. Then, they had to decide again whether the face they saw previously was or was not presented as a choice stimulus. To verify that participants were actually doing the distracter task the experimenter was present in the experimental room during training at a distance of approximately 1.5 m.

In both experiments, each of the six sample stimuli (target faces) were repeated eight times per block. On half of the trials the sample stimulus was also presented as a choice stimulus (24 "yes" trials per block) and on the remaining half (24 "no" trials per block) six

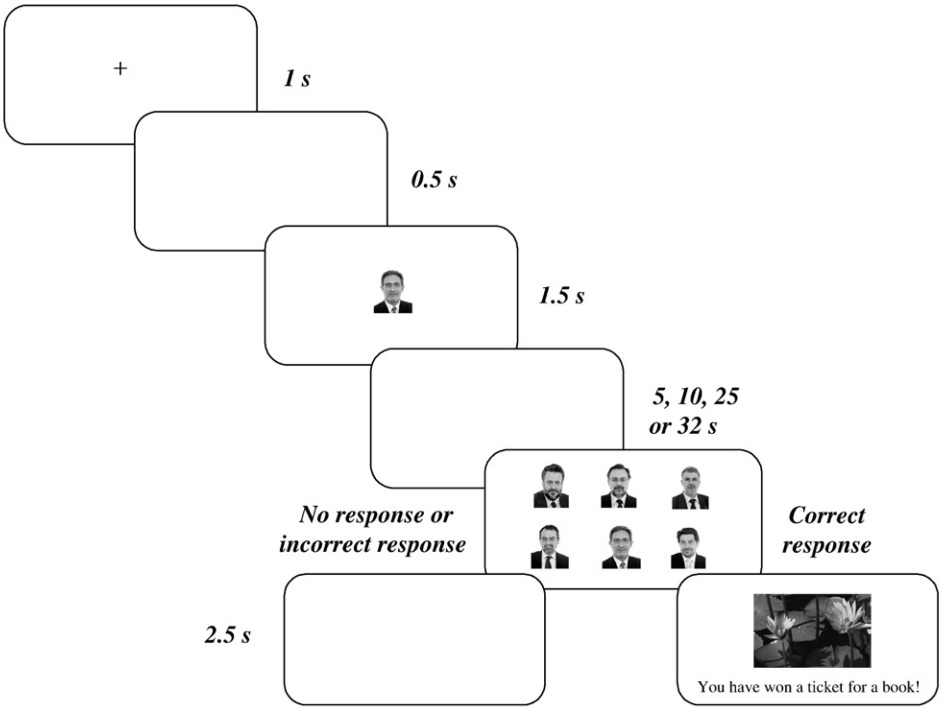

Fig. 1. Stimuli sequence (from left to right) used in Experiment 1a.

distractor stimuli (three faces from the sample stimulus set and three new faces) served as choice or comparison stimuli. Thus, each of the six target faces were presented eight times as a sample stimulus and twenty-four times as a comparison stimulus — four times as the correct choice and twenty times as a distractor. Six male faces served as new comparison stimuli, and they appeared twenty-four times per block, half in the "yes" trials and the other half in the "no" trials. Each sample stimulus was followed four times by each of the twelve possible comparison stimuli (the six target faces and the six new faces). The sample stimuli were counterbalanced across the four delay intervals (5, 10, 25 or 32 s) and each delay was tested 12 times per block. Trial presentation in each block was randomized and the two blocks of test trials were counterbalanced across participants. Participants always performed these two blocks one after the other with a rest period in between at the participant's discretion. When they were ready to continue, they could initiate the second block of trials by pressing the spacebar.

There were two conditions in the experiments. Participants in the differential outcomes condition ($N = 12$) consistently received specific outcomes (e.g., a picture of an island and the phrase "You have won a ticket for a pendrive") following a correct response; that is, in this condition each sample stimulus was always associated with a particular outcome (one of six possible picture-phrase combinations). The participants in the non-differential condition ($N = 14$) were also rewarded for correct choices but the rewards given were randomized with respect to the particular face, so that one of the six possible picture-phrase combinations could appear in each correct trial. Thus, each target face in this condition was associated with all six reward combinations used in the experiment.

2.4. Data analysis

Median response times and accuracy for each experimental condition were analyzed using a 4×2 mixed ANOVA with Delay (5, 10, 25, and 32 s) as the within-subjects factor and Outcomes (differential vs. non-differential) as the between-subjects factor. Prior to analyzing the latency data, all RTs associated with error responses were removed and the median RT was calculated for each participant.[1] Greenhouse–Geisser (G–G) corrections were applied to the degrees of freedom of the repeated factor in order to correct for any violations of the assumption of sphericity, as assessed by Mauchly's W test.

3. Results

Table 1 shows the mean percentage of correct choices and the mean of the median correct RTs in the task as a function of Outcomes and Delay in both Experiments 1a and 1b.

3.1. Experiment 1a

The analysis of both accuracy and latency data revealed only a significant main effect of Delay [$F(2.3, 56.2) = 4.99$, $p < 0.01$ and $F(2.3, 54.9) = 3.20$, $p < 0.05$, respectively]. Participants were less accurate and slower for the higher delays (95%, 94%, 93%, and 91%; and 2323 ms, 2333 ms, 2438 ms, and 2399 ms, in 5 s, 10 s, 25 s and 32 s delays, respectively). The main effect of Outcomes and the Outcomes × Delay interaction was not significant [$ps > 0.05$].

3.2. Experiment 1b

As in the previous experiment, the ANOVA yielded a significant main effect of Delay when RTs were analyzed [$F(3, 96) = 5.46$, $p < 0.01$]. As expected, participants were slower (and performed worse, although the main effect of Delay was not significant with accuracy data) in the higher delays. Importantly, the analyses also revealed a significant main effect of Outcomes [$F(1, 32) = 4.4$, $p < 0.05$] when correct RTs were analyzed. That is, participants who received differential outcomes following correct responses were faster than those who received non-differential outcomes (2598 ms and 2965 ms, respectively). No other effects, nor their interaction, reached statistical significance [$ps > 0.05$].

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[1] There were no differences in the statistical pattern of the data if mean response times were analyzed.

Table 1
Mean percentages of correct responses, standard error of the mean (SE) and mean median correct RTs (in milliseconds) obtained by participants in the task as a function of Delay (5, 10, 25 and 32 s) and Outcomes (differential and non-differential) in Experiments 1a and 1b. n.s. = non-significant.

	5 s delay		10 s delay		25 s delay		32 s delay		Factors[a]	
	M	SE	M	SE	M	SE	M	SE	Outcomes	delay
Correct responses										
Experiment 1a										
Differential	96	1.23	94	1.65	94	2.17	92	2.29	n.s.	< .01
Non-differential	95	1.14	95	1.53	92	2.01	90	2.12		
Experiment 1b										
Differential	92	2.31	90	2.26	87	2.01	87	2.57	n.s.	n.s.
Non-differential	92	2.31	89	2.26	89	2.01	87	2.57		
Reaction times										
Experiment 1a										
Differential	2354	152.66	2342	141.80	2452	150.69	2472	149.70	n.s.	<.05
Non-differential	2293	141.33	2324	131.28	2424	139.52	2326	138.59		
Experiment 1b										
Differential	2576	115.70	2514	126.85	2661	131.53	2641	153.42	< .05	< .01
Non-differential	2859	115.70	2874	126.85	2993	131.53	3133	153.42		

[a] This column shows the ANOVA results for the factors of Outcomes and Delay. The interaction was never significant.

4. Discussion

The results showed, to our knowledge for the first time, that the differential outcomes procedure improves delayed face recognition in healthy adults (Experiment 1b). That is, participants who received differential outcomes following their correct response were faster than those who received non-differential outcomes.

On the other hand, the differential outcomes effect was observed neither in the accuracy data nor in the latency data in Experiment 1a. Similar results were found in previous studies when the task used was simple and subjects could easily solve it (Estévez et al., 2001;2007; Legge & Spetch, 2009). According with this, when the difficulty of the task was increased (Experiment 1b) we observed the effect when correct RTs were analyzed. The lack of effect with accuracy data in this experiment might also be accounted for by a modulation of the differential outcomes effect by task difficulty. In fact, in a prior study, Estévez et al. (2007) argued that RT is a sensitive measure to observe the differential outcomes effect when the task is relatively easy and that this effect is evidenced with accuracy data when a more difficult task is employed. It is possible that the task used in the present experiment was still too easy for participants and therefore, we could have obtained a ceiling effect with accuracy data. To explore this hypothesis, in Experiment 2 we decided to assess the differential outcomes effect in adults performing a more difficult version of the tasks used in Experiments 1a and 1b.

5. Experiments 2a and 2b

In Experiment 2a the difficulty of the facial recognition task was increased by changing the order of the sample and the comparison stimuli used in the previous experiments, so that in the current experiment subjects had to keep six photographs in memory instead of only one. Each trial began with the set of six photographs, and after the delay interval, a single photograph of a man's face was presented. The participants had to decide whether the face they were seeing was among the six faces they saw previously. Experiment 2b also included the distraction task used in Experiment 1b. Although the two experiments were run at different times, all procedural details were identical.

6. Method

6.1. Participants

Forty-four and thirty-two undergraduate students from the University of Almería (Spain) participated in Experiments 2a (M age = 21.3, SD = 3.6) and 2b (M age = 21.1, SD = 5.23), respectively. They received course credits for their participation and the chance to win one of the six prizes that were raffled off at the end of the experiment. They had no previous task experience.

6.2. Stimuli and materials

The stimuli and materials were identical to that of previous experiments.

6.3. Procedure

The procedure was similar to that used in Experiments 1a and 1b except that now six faces serving as sample stimuli appeared on the screen for 4 s. After a delay interval of 5, 10, 25 or 32 s (randomly selected), a face serving as comparison stimulus was presented. This stimulus lasted until the participant responded or until 10 s elapsed, whichever occurred first. The participants had to decide whether the face they were seeing was or was not previously presented as a sample stimulus. As in the previous experiments participants were asked to respond as quickly and accurately as possible.

In Experiment 2b, the six faces were followed by a three-digit number that appeared on the centre of the screen for one second (see Fig. 2). As in Experiment 1b, participants were instructed to count backwards aloud by threes until the presentation of the comparison face.

7. Results

Accuracy and latency data were analyzed through a 4×2 mixed ANOVA with Delay (5, 10, 25, and 32 s) as the within-subjects factor and Outcomes (differential vs. non-differential) as the between-subjects factor. Table 2 shows the mean percentage of correct choices and the mean of the median correct RTs in the task as a function of Outcomes and Delay in both experiments (2a and 2b).

7.1. Experiment 2a

Results showed a significant main effect of Outcomes when percentages of correct responses were analyzed [$F(1, 42) = 5.96$, $p < 0.05$]. That is, participants assigned to the differential outcomes treatment showed better performance than those in the non-differential outcomes condition (70% and 65% accuracy, respectively).

The main effect of Delay was also significant for both accuracy [$F(3, 126) = 7.76$, $p < 0.001$] and RT [$F(2.6, 110.5) = 5.58$, $p < 0.01$]. Participants

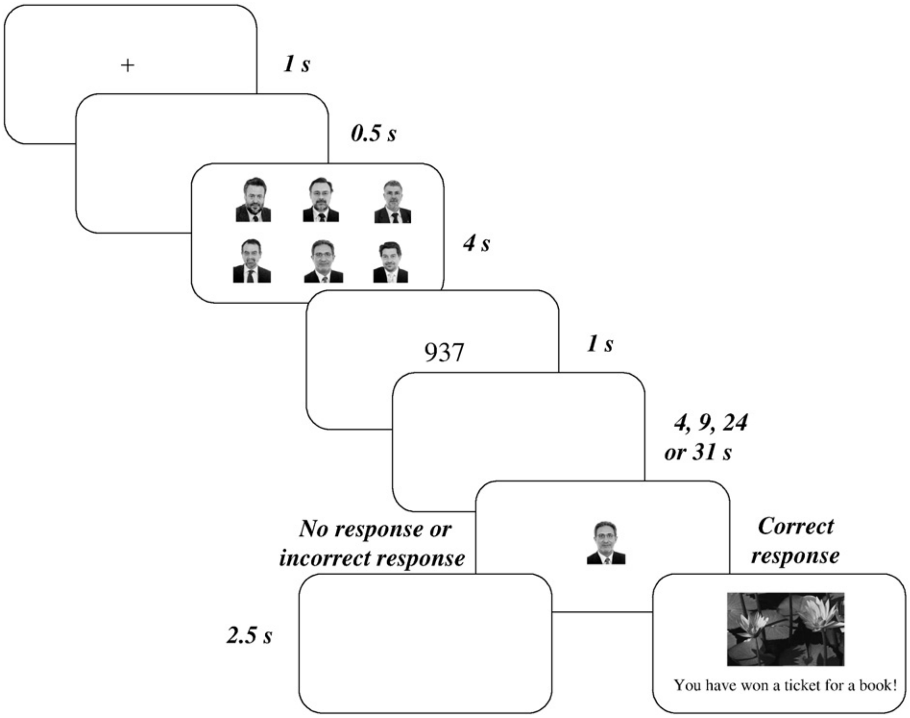

Fig. 2. Stimuli sequence (from left to right) used in Experiment 2b.

were less accurate and their RTs were slower for the higher delays (69%, 73%, 65% and 64%; 1181 ms, 1189 ms 1262 ms and 1234 ms, in 5 s, 10 s, 25 s and 32 s, respectively). No other effects, nor their interaction, reached statistical significance [ps>0.05].

7.2. Experiment 2b

Results from this experiment were very similar to those obtained in Experiment 2a. The main effect of Delay was significant with accuracy data [F(2.3, 70,1) = 3.07, $p<0.05$], in line with results of the previous experiments. The main effect of Outcomes was also significant when accuracy data were analyzed [F(1, 30) = 5.24, $p<0.05$], reflecting the DOE (65% and 59% in the differential and non-differential outcomes condition, respectively). No other effects, nor their interaction, reached statistical significance [ps>0.05].

8. Discussion

Unlike Experiment 1b, the differential outcomes effect was now evident with accuracy data. The analysis showed that face recognition memory performance of healthy adults was more accurate when they received differential outcomes following their correct responses. These results, along with those obtained in the previous experiments, also suggest that task difficulty is an important variable to take into

Table 2
Mean percentages of correct responses, standard error of the mean (SE) and mean median correct RTs (in milliseconds) obtained by participants in the task as a function of Delay (5, 10, 25 and 32 s) and Outcomes (differential and non-differential) in Experiments 2a and 2b. n.s. = non-significant.

	5 s delay		10 s delay		25 s delay		32 s delay		Factors[a]	
	M	SE	M	SE	M	SE	M	SE	Outcomes	delay
Correct responses										
Experiment 2a										
Differential	72	2.04	76	2.04	68	2.67	66	2.06	<.05	<.001
Non-differential	67	2.13	70	2.14	62	2.79	62	2.16		
Experiment 2b										
Differential	67	3.46	67	2.57	62	2.53	64	2.50	< .05	< .05
Non-differential	61	3.46	63	2.57	54	2.53	58	2.50		
Reaction times										
Experiment 2a										
Differential	1193	55.10	1220	57.40	1283	63.96	1257	61.58	n.s.	<.01
Non-differential	1170	57.67	1158	60.07	1241	66.94	1211	64.45		
Experiment 2b										
Differential	1491	103.99	1501	92.77	1561	101.42	1588	110.20	n.s.	n.s.
Non-differential	1569	103.99	1466	92.77	1603	101.42	1604	110.20		

[a] This column shows the ANOVA results for the factors of Outcomes and Delay. The interaction was never significant.

account when exploring the effects of differential outcomes training procedures in humans.

It is worth noting that RTs increased from Experiment 1a to Experiment 1b, along with task difficulty. However, in the present experiments, in which the difficulty was even higher, RTs and accuracy went down. This result can be explained in terms of the characteristics of the task being used. As in the previous experiments, participants had to perform a "yes/no" recognition task. However, only one comparison stimulus was now presented instead of six, decreasing the time required to process the information and, therefore, to make a response.

9. General discussion

The general focus of this study was to extend the differential outcomes methodology to healthy adults performing a facial recognition memory task. The present results demonstrate, to our knowledge for the first time, that delayed face recognition performance of adults is improved (faster response times in Experiment 1b and higher accuracy in Experiments 2a and 2b) when differential outcomes are employed, as compared to non-differential outcomes. As expected, participants were less accurate and slower in their correct responses at the longer delays (25 and 32 second delay conditions) in all four experiments. However, the delay never interacted with reward contingency indicating that the DOP enhanced performance equally at all delay intervals.

The present results are of interest to researchers studying the DOE in both animals and humans. First, our study shows that the differential outcomes training can enhance short-term memory performance and extends its beneficial effect to normally functioning adults. Second, the present findings also adds to those obtained in previous studies reporting a modulation of the differential outcomes effect by task difficulty in animals (e.g., Brodigan & Peterson, 1976; Peterson, Linwick, & Overmier, 1987), children (Estévez et al., 2001) and adults (Estévez et al., 2007; Legge & Spetch, 2009). In Experiment 1a, participants did not benefit from the differential outcomes training because the task was very easy. Although in Experiment 1b task difficulty was increased with the distraction condition, a ceiling effect was also obtained with correct responses. However, correct RTs were increased. Thus, it might be that the differential outcomes methodology exerted its beneficial effects by only decreasing participants' latencies. In Experiments 2a and 2b, participants were asked to perform a more difficult version of the previous tasks. It has been demonstrated that recognition accuracy decreases when a difficult or more demanding task is used (e.g., Hicks & Marsh, 2000; Malmberg, 2008). Accordingly, in these two experiments participants did not attain a high level of performance. Given that the instructions used in the present study emphasized accuracy (participants were told the more accurate they were, the more raffle tickets they would win and the better chance they would have of winning one of the prizes), we believe they adopted a strategy that maximized the probability of a correct response irrespective of response latencies. That is, when the requirements of the task changed (e.g., a very difficult task was used), participants might have implemented a strategy that emphasized accuracy rather than speed (see Malmberg, 2008 for a review about efficiency and recognition memory). We think that the arrangement of specific response outcomes affected performance by helping participants achieve their goal, namely, to obtain the best possible overall accuracy.

This hypothesis fits well with both the expectancy theory (Trapold & Overmier, 1972) and the more recent two-memory systems model (Savage & Ramos, 2009; see below) proposed as explanations of the DOE. When differential outcomes are arranged, the representation of the unique reward (or prospective memory) is maintained throughout the delay interval. We consider that this information will affect delayed recognition performance by improving accuracy and/or latency depending mostly on both the demands of the task (which might be increased, for example, by using a distractor task or by having longer delays intervals) and the goals of the participant (which might be modulated by instructions). Although the present results are consistent with this hypothesis, further investigation is needed to test it. In particular, future studies might explore whether facilitative effects of differential outcomes on recognition memory are observed in accuracy or latency measures when instructions emphasizes either to respond as accurately as possible or to respond as fast as possible.

9.1. Explaining the DOE

The recognition memory task used in this study included delays ranging from 5 to 32 s between the presentation of the discriminative stimulus and the choice alternatives. In such a delayed response paradigm, it has been proposed that when non-differential outcomes are arranged, there is only one source of information that can guide correct choice behavior, the retrospective recall of the particular discriminative stimulus (a cholinergic-dependent memory system). By contrast, there is a different memory process that can be used to solve the task when training under differential outcomes procedures, the prospective memory of what the upcoming reward will be (a glutaminergic-dependent memory system) (e.g., Overmier, Savage, & Sweeney, 1999; Ramirez, Buzzetti, & Savage, 2005; Savage, 2001; Savage & Parsons, 1997). Such prospective memory (or reward expectancy) elicited by the discriminative stimulus is thus critical to the enhancement of choice behavior observed in the differential outcomes condition.

Basic research with laboratory animals has demonstrated that different brain regions are recruited when differential and non-differential outcomes are employed (for a review, see Savage & Ramos, 2009). As Ramirez and Savage (2007) showed, the basolateral amygdala and the orbitofrontal cortex, respectively, are critical for the development and maintenance of reward expectancies produced by the DOP. On the other hand, when trained with the non-differential outcomes procedure, the animal must rely on remembering the sample stimulus to solve the task and the hippocampus is mainly required for this process (Savage, Buzzetti, & Ramirez, 2004).

This model has also been supported by some human research on the DOE. If the DOP is in fact more resistant to cholinergic alterations (see Savage, 2001; Savage & Parsons, 1997; Savage & Ramos, 2009 for animal evidence), this procedure might help to overcome memory deficits on those populations in which the cholinergic system is deteriorated, as in normal aging (v.g., Schliebs & Arendt, 2006). Recently, López-Crespo et al. (2009) demonstrated that aged people trained with the DOP did not show the delay-related decline observed in a delayed facial recognition task when non-differential outcomes were used. In fact, their performance increased to the level shown by younger adults. Similarly, we have also obtained in our laboratory (in preparation) that patients with Alzheimer's disease showed better delayed face recognition when each face to be remembered was paired with its own outcome.

Additional support for the two-memory systems model comes from a recent event-related functional magnetic resonance imaging (fMRI) study with healthy adults who were training in delayed perceptual discrimination tasks under differential and non-differential outcomes procedures (Mok, Thomas, Lungu, & Overmier, 2009). As in previous animal studies (e.g., Savage et al., 2004) results showed greater hippocampal activation when non-differential outcomes were arranged suggesting that the hippocampus plays a role in mediating retrospective rather than prospective memory. In contrast, under differential outcomes, the angular gyrus of the posterior parietal cortex was activated suggesting that this region mediates prospective processing. Brain regions related to sensory-specific cortices also increased delay-period activity, producing a perceptual representation about what the anticipated outcome would look like. Mok et al. (2009) suggested that the involvement of the brain reward system (e.g., the basolateral amygdala and the orbitofrontal cortex in rats; Savage et al., 2004) or the sensory-specific cortices (e.g., supplementary and frontal eye fields, posterior cerebellum and left dorsolateral prefrontal cortex in humans; Mok et al., 2009) in prospection depends on the outcomes being used (hedonic vs. sensory-perceptual events as, for example, pictures).

Based on the data we have reviewed thus far, it appears clear that there are two neurochemical and neuroanatomical distinct memory systems that are preferently activated by differential and non-differential outcomes procedures and that they might easily account for the results obtained in the present study.

9.2. Differential outcomes and human face recognition memory

A relevant finding from this study for face recognition researchers is that the arrangement of differential outcomes after each correct response emission changes delayed face recognition performance in humans. An interesting question is how current neural models of human face recognition memory can explain this empirical finding. The study of the role of the brain in face perception and recognition is currently a very active field (e.g., Hofer et al., 2001; Posamentier & Abdi, 2003). Functional imaging studies have shown that performing short-term memory tasks similar to those used in the present study activates several different areas of the cortex, including the fusiform face area and the ventral prefrontal cortex (e.g., Druzgal & D'Esposito, 2001,2003; Ranganah & D'Esposito, 2001; for a model of familiar face recognition see also Gobbini & Haxby, 2007). We hypothesise that these areas will be activated under both differential and non-differential outcomes conditions when using a delayed facial recognition task. However, we also expect that different brain regions (perhaps those proposed by Mok et al., 2009) will be recruited depending on the type of information (prospective vs. retrospective) being actively maintained during the delay. For instance, different brain regions are activated during the delay period depending on whether the task requires the temporary maintenance of retrospective (e.g., past sensory events) or prospective (e.g., representations of anticipated action and preparatory set) codes (Curtis, Rao, & D'Esposito, 2004, reviewed in D'Esposito, 2010).

Finally, it is also worth noting that in the present study a set of distractor faces were used as comparison (Experiments 1a and 1b) or sample stimuli (Experiments 2a and 2b). Thus, participants had to select the relevant face among irrelevant distracting faces during encoding or retrieval of target faces, two memory functions anatomically dissociated which can be differentially affected by a variety of factors, such as brain damage or disease (e.g., Bernstein, Beig, Siegenthaler, & Grady, 2002; Hofer et al., 2001). Interestingly, the DOP enhanced delayed face recognition performance under both conditions. This suggests that the DOP does not affect selective processing, but the way an association between a sample stimulus and its unique outcome is maintained in memory.

10. Conclusions

In summary, the current research demonstrated the usefulness of the DOP on a delayed facial recognition task performed by healthy adults. This novel finding can be of interest to both researchers exploring the DOE and those studying face recognition. Important directions for future work will be to further explore the neural mechanisms underlying the DOE in humans or the effect of using specific outcomes on different memory functions. Taken together, the present results, along with those obtained by Hochhalter et al. (2000) with amnesic patients, and by López-Crespo et al. (2009) with aged people, also suggest the potential of specific outcomes training as a therapeutic technique to facilitate short-term memory performance in humans. Future research should investigate the usefulness of the DOP for different populations and for different types of memory tasks in more applied settings.

Supplementary materials related to this article can be found online at doi:10.1016/j.actpsy.2010.11.001.

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