The Quarterly Journal of Experimental Psychology

Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t716100704

Enhancing challenged students' recognition of mathematical relations through differential outcomes training

First Published on: 25 July 2006
To cite this Article: , 'Enhancing challenged students' recognition of mathematical relations through differential outcomes training', The Quarterly Journal of Experimental Psychology, 60:4, 571 - 580
To link to this article: DOI: 10.1080/17470210600820039
URL: http://dx.doi.org/10.1080/17470210600820039

THE QUARTERLY JOURNAL OF EXPERIMENTAL PSYCHOLOGY
2007, 60 (4), 571–580

Psychology Press
Taylor & Francis Group

Enhancing challenged students' recognition of mathematical relations through differential outcomes training

Angeles F. Estévez
University of Almería, Almería, Spain

Ana B. Vivas
City Liberal Studies (Affiliated Institution of the University of Sheffield), Thessaloniki, Greece

Diego Alonso
University of Almería, Almería, Spain

Paloma Marí-Beffa
University of Bangor, Bangor, UK

Luis J. Fuentes
University of Murcia, Murcia, Spain

J. Bruce Overmier
University of Minnesota, Twin Cities, MN, USA

Previous studies have reported that the differential outcomes procedure enhances learning and memory in special populations with cognitive deficits (see Goeters, Blakely, & Poling, 1992, for a review). In the present study we extend these findings to healthy adults who were asked to discriminate between the symbols " > " and " < " in mathematical statements. In Experiment 1, the performance of participants who showed difficulties in discriminating between these symbols was better (shorter response times) for the differential outcomes condition than for the nondifferential outcomes condition. In Experiment 2, the difficulty of the task was increased by using signed decimal numbers. Similar to Experiment 1, participants who initially had difficulties in discriminating between the symbols showed better performance (higher accuracy) for the differential outcomes condition than for the nondifferential outcomes condition, but only when both numbers were negative. These findings suggest that the differential outcomes procedure can be used to improve performance of challenged healthy adults on discrimination tasks with mathematical symbols and relations.

The differential outcomes effect (hereafter DOE; Peterson & Trapold, 1980) refers to increased speed of acquisition or/and terminal accuracy in a discrimination learning task when each

Correspondence should be addressed to Angeles F. Estévez, Departamento de Neurociencia y Ciencias de la Salud, Universidad de Almería, 04120 Almería, Spain. E-mail: mafernan@ual.es

This research was supported by Grant BSO2003–00930 from D.G.I., Ministerio de Ciencia y Tecnología. We thank two anonymous reviewers for their helpful comments and suggestions.

http://www.psypress.com/qjep
DOI:10.1080/17470210600820039

discriminative stimulus–response sequence is always followed by a particular outcome (i.e., type of reinforcer), relative to a condition in which no particular outcome is linked to a correct sequence. The DOE has been extensively explored since Trapold and Overmier (1972) first reported it (see Goeters, Blakely, & Poling, 1992, for a review). Thus, the DOE has been observed in different species (i.e., pigeons, rats, or dogs) and it has also been generalized to a wide range of qualitatively and quantitatively different outcomes. However, to our knowledge, very few studies have investigated this effect with humans.

Shepp (1962, 1964) was one of the first authors that suggested a possible positive effect of the differential outcomes procedure on human learning. Subsequently, four studies that explored the acquisition of two-choice conditional discriminations found the DOE in children with autism and people with mental handicap (Litt & Schreibman, 1981; Malanga & Poling, 1992; Saunders & Sailor, 1979; Shepp, 1962). More recently, Maki, Overmier, Delos, and Gutman (1995) concluded that children, ranging in age from 4 years to 5 years and 5 months, learned more readily a conditional symbolic discrimination when they were taught with the differential outcomes procedure (see also Estévez & Fuentes, 2003, for a similar study). In a more recent study, Estévez, Fuentes, Marí-Beffa, González, and Alvarez (2001) extended these findings to older children, ranging in age from 4 years and 6 months to 8 years and 6 months. The authors concluded that the DOE is not limited to early stages of development. Furthermore, Estévez et al. (2001) suggested that for the differential outcomes procedure to have an effect on performance, the task to be employed must present a challenge to children.

Other research has shown that the differential outcomes procedure might be effective in improving learning and memory in neuropsychological patients. For instance, Joseph, Overmier, and Thompson (1997) reported that adults with Prader–Willi syndrome learned concepts and complex equivalence relations significantly better when their correct responses were followed by differential outcomes than when they were followed by nondifferential outcomes. Also, patients with alcohol-induced amnesia showed significantly better delayed face recognition when a differential outcomes procedure was employed (Hochhalter, Sweeney, Bakke, Holub, & Overmier, 2000).

Although the DOE is a robust phenomenon that can be generalized to different populations with cognitive deficits, only one study has investigated the differential outcomes procedure in healthy adults in order to aid teaching (Miller, Waugh, & Chambers, 2002). In this study, university students showed improved learning (fewer trials were needed) of Japanese kanji characters when a differential outcomes procedure was employed, although they did not exhibit a better terminal accuracy.

This finding suggests that the differential outcomes procedure could be employed as an effective teaching method in order to enhance learning and memory in healthy adults. However, before this procedure can be proven useful in educational settings, there must be established: (a) the generality of the DOE to different tasks and different healthy populations and, (b) the boundary conditions of this effect. Given the scarce number of studies on the DOE involving adults without mental cognitive deficits, the purpose of this study was to further explore this effect with undergraduate students. Participants performed a discrimination task of the mathematical relation "greater than" and "less than", symbolized with " $>$ " and " $<$ ", respectively. Although, this might appear as a simple task, some undergraduate students consider it challenging.

EXPERIMENT 1

In the present experiment participants had to decide whether the symbols " $>$ " and " $<$ " were used correctly in a mathematical statement. We were interested in participants who, despite knowing the formal rule (when to use the symbol " $>$ " or the symbol " $<$ "), showed high response times and/or high percentage of errors when they had to apply it under time pressure conditions. Given that this mathematical rule is taught during high school in the Spanish educational system, we assumed that participants were already acquainted with it. Consequently, the purpose of the study was not to test whether the differential outcomes procedure would improve learning of the discrimination between these two symbols, but rather whether it would influence their actual recognition of the correct use of the rule in a concrete mathematical relation.

Method

Participants

A total of 60 undergraduate students from the University of Almería (Spain), ranging in age from 19 years to 30 years, participated in the experiment. They received course credits for their participation. All of them had normal or corrected-to-normal vision.

Stimuli and materials

The stimuli consisted of mathematical relations expressed between 2 three-digit numbers (with two digits after the decimal point) connected by the mathematical symbol " $>$ " or " $<$ ". On a third of the trials, all digits in the two numbers were different (i.e., $3.27 > 2.89$), on another third, only the two decimals changed (i.e., $1.91 < 1.88$), and on the remaining trials only the last decimal differed from the rest (i.e., $6.37 > 6.39$). On half of the trials the relationship between the two decimal numbers, indicated by the symbols " $>$ " or " $<$ ", was correct; on the remaining half this relation was incorrect. Stimuli were presented in white on a dark background on a colour monitor (VGA) of an IBM/PC compatible computer. Each digit was 3 mm wide and 5 mm high, and the total width of the mathematical statement was approximately 3.5 cm. The MEL program (Schneider, 1988) controlled the presentation of the stimuli as well as collection of the reaction time (RT) and accuracy data.

Experiment 1 used only positive numbers on both sides of the mathematical relation, which was judged by teachers as a relatively easy task.

Procedure

The experiment consisted of two phases—an initial practice phase and a discrimination training phase—which lasted approximately 5 and 15 minutes, respectively.

The initial practice phase consisted of 18 trials. No response feedback or outcomes were administered during this phase. First of all, each participant read the following instructions (translated from Spanish into English here) that appeared on the computer's screen:

> Welcome to the experiment. The symbols " $>$ " and " $<$ " have a mathematical meaning but I don't remember now which of them means "less than" and which "greater than". Next some mathematical statements will appear using these symbols; some of them will be correct and the others will be incorrect. You have either to press the key "J" if you consider that the relation is correct or to press the key "K" if you think that it is incorrect. Remember that you have to respond as accurately and as quickly as possible. When you are ready please press the space bar to begin.

On each trial, a central fixation point (an asterisk) appeared during 500 ms. After an interval of 500 ms the target display (the mathematical statement) was presented. The target stimuli were presented during 10 s or until a response was made. The participants responded by pressing one of two keys, "J" when the inequality was correct and "K" when it was incorrect (for half of the participants the inverse key−response mapping was employed). No response outcomes were administered during this phase.

The discrimination training phase consisted of 72 trials. On half of the trials, the statements were correct and incorrect on the remaining half of trials. In this phase, correct responses were followed by positive feedback. The instructions were as follows:

> Now, you have to decide again whether the mathematical statements presented on the screen are correct or not. If you believe that it is correct press the key "J", otherwise press the key "K". When you make a correct response either the word "GREAT" will appear on the screen or a brief melody will sound. When you make an incorrect response neither the word nor the melody will appear. Remember that you have to respond as accurately and as quickly as possible. When you are ready please press the space bar to begin.

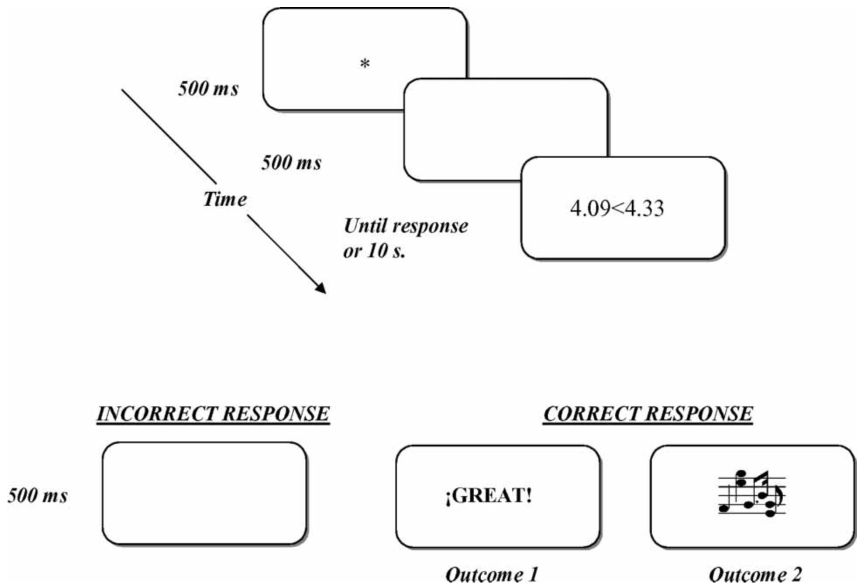

Figure 1. *An example of the task used in Experiments 1 and 2.*

Figure 1 shows the sequence of events and the time intervals used in this phase. The main difference with the practice phase was that in this phase correct responses were followed by two different outcomes: the word "GREAT" that appeared in the middle of the screen during 500 ms, or a melody that was presented for 500 ms. If the response was incorrect, the following trial began after an interval of 500 ms.

Participants were randomly assigned to one of the two experimental groups. Participants in the experimental group (differential outcomes condition) received differential outcomes for correct discriminations: The word "GREAT" followed correct responses to the symbol " $<$ ", and the melody followed correct response to the symbol " $>$ ". For instance, a response "correct" to the inequality $2.47 < 2.49$ and a response "incorrect" to the inequality $5.27 < 5.22$ were followed by the word "GREAT". Participants in the control condition (nondifferential outcomes condition) did not receive differential outcomes. That is, although they were rewarded for each correct response, either the word or the melody followed correct responses in a random fashion.

Results

To explore whether the participants showed different performance in the two outcome conditions (differential vs. nondifferential), correct RTs and percentage of correct responses from the discrimination-training phase were submitted to a one-way analysis of variance (ANOVA) with outcomes (differential and nondifferential) as the between-subjects factor. The performance in the initial practice phase was also analysed in order to check for individual differences in recognizing the correct application of the mathematical rule. The results from this phase were used to assign participants to one of two groups: (a) "low performers", whose performance was below the mean percentage of correct responses (85%) and whose response latency was above the mean of RTs (2828 ms), and (b) "high performers", whose performance was above the mean percentage of correct responses and whose response latency was below the mean of RTs. We refer to the first group as "participants with difficulties to discriminate" and to the second group as "participants without difficulties to discriminate". Following this criterion 13 participants in total were classified as "with difficulties" (6 from the control group and 7 from the experimental group), whereas 16 participants in total were classified as "without difficulties" (9 from the control group and 7 from the experimental group). Table 1 shows the percentage of correct choices and the mean RTs, for both groups, as a function of outcomes in the discrimination training phase.

Accuracy data

Percentages of correct responses from the discrimination training phase were submitted to a 2 × 2 ANOVA with outcomes (differential and nondifferential) and group (participants with difficulties to discriminate and those without difficulties to discriminate) as the between-subjects factors. The main effect of group was significant, $F(1, 25) = 7.92$, $p < .01$. That is, participants without difficulties to discriminate showed a higher percentage of correct responses than those with difficulties to discriminate (92% and 85%, respectively). Neither the effect of outcomes nor its interaction with group reached statistical significance (ps > .05). Thus, the DOE was not observed when accuracy data were analysed.

Latency data

Correct response times from the discrimination training phase were submitted to a 2 × 2 ANOVA with outcomes (differential and nondifferential) and group (participants with difficulties to discriminate and those without difficulties to discriminate) as the between-subjects factors. Results showed significant main effects of outcomes, $F(1, 25) = 7.16$, $p < .05$, and group, $F(1, 25) = 4.64$, $p < .05$. Most important, the outcomes by group interaction was also significant, $F(1, 25) = 4.31$, $p < .05$. The analysis of the interaction revealed a significant main effect of outcomes for participants with difficulties to discriminate, $F(1, 11) = 8.89$, $p < .05$, but not for the group without difficulties to discriminate ($F < 1$). That is, participants with difficulties to discriminate between the mathematical symbols " > " and " < ", who received differential outcomes following their correct response, were faster than those who received nondifferential outcomes (2,131 ms and 3,232 ms, respectively). No other effects were significant (ps > .05).

Table 1. *Correct responses and median correct reaction times obtained by participants with or without difficulties to discriminate in the discrimination training phase as a function of the outcomes condition in Experiment 1*

		With difficulties	*Without difficulties*
CR[a]	DO	85 (8.4)	92 (4.9)
	NDO	85 (8.2)	91 (4.8)
RT[b]	DO	2,131 (570.92)	2,113 (757.16)
	NDO	3,232 (760.91)	2,252 (393.69)

Note: CR = correct responses. RT = reaction time. DO = differential outcomes. NDO = nondifferential outcomes. Means are shown, with standard deviations are in parentheses.
[a]In percentages. [b]In ms.

Discussion

This experiment investigated whether the differential outcomes procedure would influence performance of healthy adults in a discrimination task with mathematical symbols (" > " and " < "). The results showed that this procedure improved performance, as evidenced by faster RTs, of those participants who initially showed difficulties in discriminating between the two symbols. As predicted, the performance of those participants who knew well the correct use of the mathematical symbols was not influenced by the use of the differential outcomes procedure.

Although prior studies have reported the DOE with accuracy data, in the present study the effect was evidenced only with RT data (a 1,101 ms effect for the group of participants with difficulties to discriminate). The lack of effect with accuracy data might be accounted for in terms of task difficulty. Given that the teachers judged the task with positive numbers as being relatively easy, we could have obtained a ceiling effect with the accuracy data (in fact, the overall average percentage of correct response was 88%). This hypothesis is supported by previous studies that reported a modulation of the DOE by task difficulty in children (Estévez et al., 2001) and animals (e.g., Brodigan & Peterson, 1976; Peterson, Linwick, & Overmier, 1987). The present study suggests that task difficulty may also modulate the differential outcomes–accuracy effect in adults. In order to test this hypothesis, in the second experiment participants were asked to perform a more difficult version of the task used in Experiment 1.

EXPERIMENT 2

In Experiment 2, the difficulty of the task was increased by changing the sign (positive or negative) of the two decimal numbers connected by either the symbol " > " or the symbol " < ". It was expected that challenged participants would now show the DOE with both accuracy and latency data, whereas the performance of participants without difficulties would continue to be unaffected by the differential outcomes procedure.

Method

Participants

A total of 46 undergraduate students from the University of Almería participated for partial fulfilment of a course requirement. All of them had normal or corrected-to-normal vision.

Stimuli and materials

The materials and the stimuli were identical to those used in Experiment 1, except that the two decimal numbers could be positive or negative. This manipulation resulted in four sign conditions: (a) positive–positive (PP; i.e., $+5.26 > +5.29$); (b) negative–negative (NN; i.e., $-1.72 > -1.49$); (c) positive–negative (PN; i.e., $+8.53 < -6.75$); and (d) negative–positive (NP; i.e., $-3.58 < +3.62$).

Procedure

The design was identical to that of Experiment 1, except that there were two additional trials in the initial practice phase, resulting in a total of 20 trials (5 trials per condition), and 24 additional trials in the discrimination training phase, making a total of 96 trials (24 trials per condition). As in the previous experiment, in the differential outcomes condition the word "GREAT" followed correct responses to the symbol " < ", and a melody followed correct responses to the symbol " > ". In the nondifferential outcomes condition, either of the two possible outcomes randomly followed correct responses.

Results

As in the previous experiment, participants were assigned to one of two groups, with or without difficulties to discriminate between the symbols " < " and " > ", depending on whether their performance would be below or above the overall mean of correct responses and RTs in the initial practice phase (80% and 3,458 ms, respectively). Following this criterion, a total of 11 participants was assigned to the group "with difficulties" (6 from the nondifferential outcomes control group and 5 from the differential outcomes experimental group), and a total of 16 participants was included in the second group "without difficulty" (10 from the control group and 6 from the experimental group). Table 2 shows the percentage of correct choices and the mean RTs for both groups, as a function of outcomes and sign, in the discrimination training phase.

Accuracy data

Percentages of correct responses from the discrimination training phase were submitted to a mixed ANOVA with outcomes (differential and nondifferential) and group (participants with difficulties to discriminate and those without difficulties to discriminate) as the between-subjects factors and sign (NN, NP, PN, and PP) as the within-subjects factor. The main effect of sign was significant, $F(3, 69) = 24.10$, $p < .001$. Fisher's LSD comparisons showed significant differences between the NN (78%) and the other three conditions, NP, PN, and PP (90%, 95%, and 90%, respectively; ps $< .001$); and between the PN and the other three conditions (ps $< .05$). Most important, the results showed a significant outcomes × group × sign interaction, $F(3, 69) = 2.95$, $p < .05$. In order to analyse this interaction two separate mixed ANOVAs were conducted for each group with outcomes (differential and nondifferential) as the between-subjects

Table 2. *Correct responses and median correct reaction times obtained by participants with or without difficulties to discriminate in the discrimination training phase as a function of the outcomes and sign conditions in Experiment 2*

		With difficulties				*Without difficulties*			
		NN	*NP*	*PN*	*PP*	*NN*	*NP*	*PN*	*PP*
CR[a]	DO	86 (2.7)	93 (7.6)	98 (3.6)	91 (5.7)	82 (13.9)	93 (3.1)	98 (2.2)	90 (10.2)
	NDO	61 (21.9)	85 (19.3)	89 (12.7)	90 (16.5)	81 (9.5)	89 (9.6)	94 (4.9)	90 (9.5)
RT[b]	DO	3,721 (1,397.4)	2,813 (1,491.6)	2,606 (998.5)	3,081 (1,244.6)	3,829 (709.7)	2,549 (558.1)	2,497 (585.7)	2,925 (478.9)
	NDO	3,303 (1,487.4)	2,536 (987.5)	2,870 (765.1)	3,267 (831.9)	3,415 (999.5)	2,213 (843.4)	2,308 (944.3)	2,682 (791.2)

Notes: CR = correct responses. RT = reaction time. DO = differential outcomes. NDO = nondifferential outcomes. NN = negative–negative; NP = negative–positive; PN = positive–negative; PP = positive–positive. Means are shown, with standard deviations are in parentheses.
[a]In percentages. [b]In ms.

factor and sign (NN, NP, PN, and PP) as the within-subjects factor. For the group with difficulties, the results showed a significant main effect of sign, $F(3, 27) = 18.35$, $p < .001$. The interaction between outcomes and sign was also significant, $F(3, 27) = 5.94$, $p < .01$. This interaction was mainly due to a significant DOE (a significant outcomes effect) for the NN condition, $F(1, 9) = 6.52$, $p < .05$, whereas this effect did not reach statistical significance for the other three conditions, PP, PN, and NP (ps > .05).

For the group without difficulties, the results showed a significant main effect of sign, $F(3, 42) = 8.28$, $p < .001$. Fisher's LSD comparisons showed significant differences between the NN (81%) and the other three conditions, NP (91%), PN (96%), and PP (90%) conditions ($p < .001$), and between the PN and the other three conditions. No other effects, nor their interaction, reached statistical significance (ps > .05).

Latency data

Correct response times from the practice and the discrimination training phases were submitted to a mixed ANOVA with outcomes (differential and nondifferential) and group (participants with difficulties to discriminate and those without difficulties to discriminate) as the between-subjects factors and sign (NN, NP, PN, and PP) as the within-subjects factor. Results showed a significant main effect of sign, $F(3, 69) = 26.87$, $p < .001$. Post hoc analyses (Fisher's LSD) revealed significant differences between the NN condition (3,567 ms) and the other three conditions, NP, PN, and PP (2,528 ms, 2,570 ms, and 2,989 ms, respectively; ps < .001). There were also significant differences between the PP condition and the NN, NP, and PN conditions ($p < .001$), but there were no differences between the last two conditions (ps > .05). That is, RTs were slowest in the NN condition, intermediate in the PP condition, and shortest in the NP and PN conditions. No other effects reached statistical significance (ps > .05).

Discussion

Experiment 2 was designed to explore the DOE in healthy adults using a relatively difficult task. Similar to Experiment 1, challenged university students exhibited the DOE in a discrimination task, but unlike Experiment 1, the effect was only evident with accuracy data. Specifically, the group with difficulties to discriminate showed higher accuracy for the differential outcomes condition than for the nondifferential outcomes condition, only for the most difficult trials (when both numbers were negative). The present findings suggest that task difficulty is an important variable to take into account when exploring the effects of differential outcomes training procedures in humans.

GENERAL DISCUSSION

In the present study, undergraduate students from the University of Almería were rewarded when they discriminated correctly the use of the mathematical symbols “ $>$ ” and “ $<$ ”. The rewards consisted of the word “Great” for correct responses to the symbol “ $>$ ” and a brief melody for correct responses to the symbol “ $<$ ” (differential outcomes condition). A control group received also the same rewards for their correct responses, but each reward was not linked to a particular stimulus (nondifferential outcomes condition). Here we demonstrate that the performance of challenged participants—those who initially did not discriminate well the correct use of the symbols—is improved (faster response times in Experiment 1 and higher accuracy in Experiment 2) when differential outcomes are employed, as compared to nondifferential outcomes. Importantly, participants who initially showed a good knowledge of the use of the mathematical symbols did not benefit from the differential outcomes procedure (group without difficulties in Experiments 1 and 2). Furthermore, task difficulty appeared to modulate the DOE for the group of challenged students; thus, when the task was relatively easy the DOE was found only with RTs data (Experiment 1), whereas it was only found with accuracy data when a more difficult task was employed (NN condition in Experiment 2).

The present findings suggest (a) that the differential outcomes procedure can be effectively used to improve performance in challenged but high-functioning healthy adults, and (b) that response time is a sensitive measure to observe the DOE. The latter is important since previous research has shown the DOE only with accuracy data (Estévez et al., 2001; Maki et al., 1995). Finally, they also suggest that task difficulty is an important factor to take into account because it can affect differentially response times and accuracy.

An important difference between the present and other studies is that while in earlier studies (see Estévez et al., 2001) a particular stimulus–response mapping (the correct choice of a unique comparison stimulus) was associated with a specific outcome in a delayed matching-to-sample task, in the present study only the discriminative stimulus (the symbols “ $<$ ” and “ $>$ ”) was associated with a particular outcome. That is, the mapping response-key (the keys J and K were used for correct and incorrect responses, respectively, regardless of the symbol) was not linked to a particular outcome (i.e., correct responses using the key “J” could be followed by either the word or the melody if the statement included the symbol “ $<$ ” or “ $>$ ”, respectively). According to the expectancy theory—the theoretical account of the DOE that has received more support—establishing a discriminative stimulus–outcome association is a *sufficient* condition for DOE to be observed (Trapold, 1970; Trapold & Overmier, 1972). In contrast, the backward association account places the emphasis on the response–outcome associations (Rescorla, 1992, 1994; Rescorla & Colwill, 1989). Like the expectancy theory, it recognizes the involvement of differential discriminative stimulus–outcome associations in performance. Unlike the expectancy theory, the differential and bidirectional response–outcome associations are seen as the source of the DOE. Because the response–outcome associations were not differential in these experiments, only the unique discriminative stimulus–outcome associations could have contributed to the enhanced performance observed, for the group of participants with difficulties to discriminate between the mathematical symbols “ $>$ ” and “ $<$ ”, when differential outcomes were arranged. Thus, the results obtained in the present study support the expectancy theory, and they are consistent with those from other studies (DeLong & Wasserman, 1981; Edwards, Jagielo, Zentall, & Hogan, 1982; Estévez, Overmier, & Fuentes, 2003; Kruse, Overmier, Konz, & Rokke, 1983; Peterson, 1984; Williams, Butler, & Overmier, 1990).

In recent years there has been some debate over the generality of the DOE. Several authors have suggested that the validity of the differential outcomes procedure could be limited to early developmental stages and to people with cognitive deficits

(Goeters et al., 1992; Maki et al., 1995). That is, as soon as the person would be able to use more sophisticated learning strategies such as verbal rules, the DOE would disappear. Our study suggests that this is not the case and that the differential outcomes procedure may be a useful tool in order to improve performance in healthy adults when they perform difficult symbolic discriminations. Furthermore, our findings are in agreement with the results of Miller et al. (2002). They found the DOE in a group of university students who had to learn to associate Japanese kanji characters with their corresponding English meaning. It is worth noting that in their experiment, all participants showed a high terminal accuracy, which indicates a ceiling effect. We think that the correcting feedback supplied after the incorrect responses probably also contributed to the learning observed and may have masked the contribution of differential outcomes to terminal accuracy.

To conclude, the present findings contribute to the existing literature on the DOE in elucidating what are the boundary conditions of this effect in healthy adults without cognitive deficits. Moreover, the positive effect of the differential outcomes procedure on the performance of a group of students, in a simple discrimination task with mathematical relations, stimulates its future applications in other nonexperimental settings. Thus, future research should investigate the adequacy of the differential outcomes procedure in more ecologically valid educational settings such as schools.

Original manuscript received 28 April 2005
Accepted revision received 2 May 2006
First published online 25 July 2006

REFERENCES

Brodigan, D. L., & Peterson, G. B. (1976). Two-choice conditional discrimination performance of pigeons as a function of reward expectancy, prechoice delay, and domesticity. *Animal Learning & Behavior*, *4*, 121–124.

DeLong, R. E., & Wasserman, E. A. (1981). Effects of differential reinforcement expectancies on successive matching-to-sample performance in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes*, *7*, 394–412.

Edwards, C. A., Jagielo, J. A., Zentall, T. R., & Hogan, D. E. (1982). Acquired equivalence and distinctiveness in matching to sample by pigeons: Mediation by reinforcer-specific expectancies. *Journal of Experimental Psychology: Animal Behavior Processes*, *8*, 244–259.

Estévez, A. F., & Fuentes, L. J. (2003). Differential outcomes effect in four-year-old children. *Psicológica*, *24*, 159–167.

Estévez, A. F., Fuentes, L. J., Mari-Beffa, P., González, C., & Alvarez, D. (2001). The differential outcomes effect as useful tool to improve conditional discrimination learning in children. *Learning and Motivation*, *1*, 48–64.

Estévez, A. F., Overmier, J. B., & Fuentes, L. J. (2003). Differential outcomes effect in children: Demonstration and mechanisms. *Learning and Motivation*, *34*, 148–167.

Goeters, S., Blakely, F., & Poling, A. (1992). The differential outcomes effect. *The Psychological Record*, *42*, 389–411.

Hochhalter, A. K., Sweeney, W. A., Bakke, B. L., Holub, R. J., & Overmier, J. B. (2000). Improving face recognition in alcohol dementia. *Clinical Gerontologist*, *22*, 3–18.

Joseph, B., Overmier, J. B., & Thompson, T. (1997). Food and nonfood related differential outcomes in equivalence learning by adults with Prader–Willi syndrome. *American Journal on Mental Retardation*, *4*, 374–386.

Kruse, J. M., Overmier, J. B., Konz, W. A., & Rokke, E. (1983). Pavlovian CS effects upon instrumental choice behavior are reinforcer specific. *Learning and Motivation*, *14*, 165–181.

Litt, M. D., & Schreibman, L. (1981). Stimulus-specific reinforcement in the acquisition of receptive labels by autistic children. *Analysis and Intervention in Developmental Disabilities*, *1*, 171–186.

Maki, P., Overmier, J. B., Delos, S., & Gutman, A. J. (1995). Expectancies as factors influencing conditional discrimination performance of children. *The Psychological Record*, *45*, 45–71.

Malanga, P., & Poling, A. (1992). Letter recognition by adults with mental handicaps: Improving performance through differential outcomes. *Developmental Disabilities Bulletin*, *20*, 39–48.

Miller, O. T., Waugh, K. M., & Chambers, K. (2002). Differential outcomes effect: Increased accuracy in adults learning kanji with stimulus specific rewards. *The Psychological Record*, *52*, 315–324.

Peterson, G. B. (1984). How expectancies guide behavior. In H. L. Roitblat, T. G. Bever, & H. S. Terrace (Eds.), *Animal cognition*. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Peterson, G. B., Linwick, D., & Overmier, J. B. (1987). On the comparative efficacy of memories and expectancies as cues for choice behavior in pigeons. *Learning and Motivation*, *18*, 1–20.

Peterson, G. B., & Trapold, M. A. (1980). Effects of altering outcome expectancies on pigeons' delayed conditional discrimination performance. *Learning and Motivation*, *11*, 267–288.

Rescorla, R. R. (1992). Response–outcome versus outcome–response associations in instrumental learning. *Animal Learning & Behavior*, *20*, 223–232.

Rescorla, R. R. (1994). Transfer of instrumental control mediated by a devalued outcome. *Animal Learning & Behavior*, *22*, 27–33.

Rescorla, R. R., & Colwill, R. M. (1989). Associations with anticipated and obtained outcomes in instrumental training. *Animal Learning & Behavior*, *17*, 291–303.

Saunders, R., & Sailor, W. (1979). A comparison of three strategies of reinforcement on two-choice learning problems with severely retarded children. *AAESPH Review*, *4*, 323–333.

Schneider, W. (1988). MicroExperimental Laboratory: An integrated system for IBM PC compatibles. *Behavior Research Methods, Instruments and Computers, 20*, 206–217.

Shepp, B. E. (1962). Some cue properties of anticipated rewards in discrimination learning of retardates. *Journal of Comparative and Physiological Psychology*, *55*, 856–859.

Shepp, B. E. (1964). Some cue properties of rewards in simultaneous object-discriminations of retardes. *Child Development*, *35*, 587–592.

Trapold, M.A. (1970). Are expectancies based upon different positive reinforcing events discriminably different? *Learning and Motivation, 1*, 129–140.

Trapold, M. A., & Overmier, J. B. (1972). The second learning process in instrumental learning. In A. A. Black & W. F. Prokasy (Eds.), *Classical conditioning: Current research and theory*. New York: Appleton-Century-Crofts.

Williams, D. A., Butler, M. M., & Overmier, J. B. (1990). Expectancies of reinforcer location and quality as cues for a conditional discrimination in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes*, *16*, 172–178.