Short title: CONTEXTUAL CONTROL AND INFORMATIVE VALUE

Mechanisms of Contextual Control when Contexts are Informative to Solve the Task

Samuel P. León, A. Matías Gámez and Juan M. Rosas

Universidad de Jaén

Jaén, Spain

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Correspondence concerning to this article should be addressed to Samuel Parra León, Departamento de Psicología, Universidad de Jaén, 23071 Jaén, Spain. E-mail: sparra@ujaen.es.

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Abstract

An experiment was conducted using a human instrumental learning task with the goal of evaluating the mechanisms underlying the deleterious effect of context-switching on responding to an unambiguous stimulus when contexts are informative to solve the task. Participants were trained in a context-based reversal discrimination in which two discriminative stimuli (X and Y) interchange their meaning across contexts A and B. In context A, discriminative stimulus Z consistently announced that the relationship between a specific instrumental response (R1) and a specific outcome (O1) was in effect. Performance in the presence of stimulus Z was equally deteriorated when the test was conducted outside the training context, regardless of whether the test context was familiar (context B) or new (context C). This result is consistent with the idea that participants code all the information presented in an informative context as context-specific with the context playing a role akin to an occasion setter.

Key words: Attention; Context-switch effect; Discrimination; Human beings; Instrumental learning;

Resumen

Se realizó un experimento en condicionamiento instrumental humano con el objetivo de evaluar los mecanismos subyacentes al efecto de cambio de contexto sobre una clave de significado no ambiguo cuando los contextos son informativos para solucionar la tarea. Se entrenó a los participantes en una discriminación inversa basada en el contexto en la que debían discriminar entre dos claves (X e Y) que intercambiaban sus significados entre los contextos A y B. En el contexto A se presentó además el estímulo discriminativo Z anunciando consistentemente una relación entre una respuesta instrumental concreta (R1) y una consecuencia determinada (O1). La respuesta en presencia de la clave Z durante la prueba empeoró cuando la prueba se realizó fuera del contexto de entrenamiento, independientemente de si el contexto de prueba era un contexto familiar para el participante (contexto B) o un contexto nuevo (contexto C). Estos resultados son consistentes con la idea de que los participantes codifican toda la información presentada en contextos informativos como dependiente de contexto, con el contexto jugando un papel similar al de un estímulo modulador.

Palabras clave: Atención; Efecto de cambio de contexto; Discriminación; Seres humanos; Aprendizaje instrumental.

Mechanisms of contextual control when contexts are informative to solve the task

Contexts have been defined as background cues that remain present with little changes throughout the experimental session, by contrast with target stimuli that usually are of limited duration and might appear and disappear frequently throughout the learning session (e.g., Gluck & Myers, 1993). This background cues may be external stimuli such as the apparatus or the room where learning takes place (e.g., Fanselow, 2007), but also by internal states such as hormonal (e.g., Ahlers & Richardson, 1985), mood (e.g., Eich, 2007), deprivation (e.g., Davidson, 1993) or those produced by ingestion of drugs such as alcohol (e.g., Lattal, 2007) or benzodiazepines (e.g., Bouton, Kenney, & Rosengard, 1990). Finally, it has been also suggested that task related factors such as the intertrial interval in animal conditioning (e.g., Bouton & Hendrix, 2011) as well as cognitive instructions in human learning (e.g., Rosas & Callejas-Aguilera, 2006) may also play the role of contexts.

The role of background stimuli on retrieval of the information has been largely studied within the animal and human memory and learning literatures (e.g., Nelson, 2002; Paredes-Olay & Rosas, 1999; Pineño & Miller, 2004; Rosas, García-Gutiérrez, & Callejas-Aguilera, 2007; Rosas, Vila, Lugo, & López, 2001; see Bouton, 1993 for a review). As a typical illustration, when a cue is paired with an outcome in an specific background context A, and then extinction is conducted in a different, but equally familiar context B, if the organism is taken back to the original context during the test, response to the cue is renewed (ABA renewal, i.e., Bouton & Bolles, 1979; Rosas et al., 2001). This renewal is also found when acquisition and extinction are conducted within the same context, and the test is conducted in a different context (AAB renewal, i.e, Bouton & Ricker, 1994; Rosas & Callejas-Aguilera, 2006), and also when the acquisition, extinction and testing take place in three different contexts (ABC renewal, i.e., Denniston, Chang, & Miller, 2003; Pineño & Miller, 2004; Thomas, Larsen, & Ayres, 2003.). This feature has led Bouton (1993, 1994) to suggest that either inhibitory or second-learned information is more context-dependent than excitatory or first-learned information, though later it was shown that the relevant factor on context dependence of the information is the order in which such an information has been learned (e.g., Nelson, 2002, 2009; see also Bouton & Nelson, 1994; Nelson & Bouton, 1997).The reason for context-dependence of second-learned information was also advanced by Bouton (1997) when suggested that attention that the organism pays to the context may play an important role on context-dependence of the information. Specifically, Bouton (1997) pointed out that changing the meaning of a cue between acquisition and extinction renders the cue as ambiguous. It is assumed that when the cue becomes ambiguous the organism begins to pay attention to the context with the goal of disambiguate the situation, so that retrieval of the ambiguous information becomes context specific. This account perfectly fits the renewal results briefly described above. However, it cannot explain other results in the literature showing that retrieval of unambiguous information may also be context-dependent both, in human (León, Abad, & Rosas, 2010b, 2011) and non-human animals (e.g., Hall & Honey, 1990; Maes, Havermans, & Vossen, 2000).

Rosas, Callejas-Aguilera, Ramos-Álvarez, and Abad (2006; see also Rosas & Callejas-Aguilera, 2006, 2007) tried to integrate within the same explanation context-dependence of extinction and ambiguous information, and context dependence of unambiguous information. They proposed what they called the Attentional Theory of Context Processing (ATCP) as an evolution of the Theory of Interference and Forgetting proposed by Bouton (1993). As such, ATCP assumes that forgetting is mainly due to both, interference, and contextual change, regardless of whether this change is physical (e.g., Bouton & Bolles, 1979), temporal (e.g., Rosas & Bouton, 1996, 1997) or associative (e.g., García-Gutiérrez & Rosas, 2003). Following the ideas gathered by Bouton (1993), ATCP assumes that interference does not eliminate the originally learned information, but it makes it more difficult to retrieve. To which extent interfered or interfering information would be retrieved during the test would depend on the conditions under which the test is conducted, as both types of information are assumed to coexist in memory (e.g. Anderson, 1993; Mensink & Raaijmakers, 1988). Extending Bouton's (1997) idea that ambiguity in the meaning of a cue leads the organism to pay attention to the context making ambiguous information context-specific, ATCP assumes that context-switch effects on retrieval of the information depend essentially on the attention the contexts receive at the moment of training. Once participants pay attention to the contexts, all the information learned within that context becomes context-specific, regardless of whether such information is ambiguous or not (e.g., Rosas et al., 2006; Rosas & Callejas-Aguilera, 2006, 2007; c.f., Bouton, 1997).

Attention to the contexts is assumed to be drawn by different factors, such as the ambiguity of the information (Callejas-Aguilera & Rosas, 2010), experience with the contexts and the task (León et al. 2010b, 2011), the relative salience of the contexts with respect to the cues (Abad, Ramos-Álvarez, & Rosas, 2009), instructions in human participants (Callejas-Aguilera, Cubillas, & Rosas, 2011), and the informative value of the context (León, Abad, & Rosas , 2008, 2010a).

To explore the role of the informative value of the context on context-specificity of unambiguous information, León et al. (2010a) conducted an experiment in which three groups of participants were trained within a human instrumental conditioning situation in which they had to discriminate between two stimuli (X and Y) that signaled which of two specific instrumental responses was followed by one of two distinctive outcomes within a specific context A (X: R1-O1 and Y: R2-O2). Within context A, participants were trained with a different target cue (Z) in the presence of which response R1 was followed by Outcome 1 (Z: R1-O1). Cue Z was not trained in context B. The informative value of the context was modified across groups by changing the experience participants had in an alternative context B with cues X and Y. In group Informative (I) discrimination between X and Y was reversed across contexts, so that attending to the contexts was necessary to solve the discrimination –participants were trained with X: R2-O2 and Y: R1-O1 in context B. In the two other groups the contexts were not informative to solve the discrimination. In group NI1 (non informative 1) the discrimination between X and Y was kept the same across contexts A and B (X: R1-O1 and Y: R2-O2), while in group NI2 two different discriminative stimuli (F3 and F4) were used in context B. Once discriminative training was finished, a test with the target cue Z was conducted in extinction in the same context in which that stimulus was trained (contexts A), and in the alternative context (context B). León et al. (2010a) found that responding to Z was lower in context B than in context A in the Informative group, while no differences across contexts were found in both groups NI1 and NI2 (see also Preston, Dickinson, & Mackintosh, 1986).

León et al. (2010a) explained their results by suggesting that the informative value of the contexts led participants to pay attention to them in group Informative, so that retrieval of Z became context-specific. However, there is an alternative explanation of these results that cannot be discarded by the data reported by León et al. (2010a). To give contexts informative value the meaning of cues X and Y was reversed across contexts in group I. This kind of treatment could have led participants to learn a specific rule such as “The meaning of the cues is reversed across contexts A and B” (see for instance, Pineño & Miller, 2004). Additionally, the results reported by León et al.

(2010a) are ambiguous with respect to the mechanism through which the context exerted its control on behavior. Their design ruled out the possibility of context controlling behavior through direct associations with the outcome as predicted by elemental models of conditioning such as Rescorla and Wagner's (1972; see, Abad, Ramos-Álvarez, & Rosas, 2009; Callejas-Aguilera, Cubillas, & Rosas, 2011; León et al., 2011), given that the relationship between the two contexts used in the experiment and the outcomes was kept constant. However, their design did not allow to distinguish whether the contexts played the role of occasion setters (e.g., Bouton & Swartzentruber, 1986; Callejas-Aguilera & Rosas, 2010) or they formed a configure with discriminative stimuli to control behavior (e.g., Pearce, 1987, 2002; see Moreno-Fernández, Abad, Ramos-Álvarez, & Rosas, 2011).

The main goals of the experiment reported here were, first, to differentiate between an explanation of context-switch effects reported by León et al. (2010a) in terms of the informative value of the context leading participants to pay attention to them, as the authors suggested, and in terms of participants learning a rule to solve the problem; and second, to try to evaluate whether the context exert its control through a configural or a hierarchical mechanism in this situation. The task was the same human instrumental task used by León et al. (2010a, b). The design was also identical with two exceptions: Control group NI2 was dropped from the study as no differences between the two control groups used by León et al. (2010a) were reported, and the test was conducted within-subjects with Z being presented in the two contexts of training, A (Same) and B (Different), and in a new context C. In agreement with the results of León et al. (2010a) we expected to find a decrease in performance to Z when the discriminative stimulus is tested in context B but only in the group in which the context was informative to solve the task (group I). No differences were expected in the non-informative group, as contexts should be irrelevant to solve the task (see León et al., 2008, 2010a). The key question in this experiment is what happens when the test is conducted within a new context (C). If reversing the discrimination across contexts led participants to code all the information as context-specific in group I, then the context-switch effect should appear equally in an unfamiliar context. Alternatively, if participants learned to reverse the meaning of all the cues across contexts A and B, conducting the test in a new context should have weaker effects on performance than conducting the test within the familiar context in which the meaning of the discrimination was reversed. Finally, if contextual control were exerted by contexts being part of configurations that acted as discriminative stimuli, then the test in a new context should produce a generalization decrement greater than the test conducted in the alternative but familiar context, given that the latter one would have been involved in different configurations that also played the role of discriminative stimuli.

It should be noted that a traditional configural approach such as the one proposed by Pearce (1987, 1994, 2002) would expect the same results in the control group, given that the configure is assumed to be established automatically including everything that is present within the sensory buffer (Pearce, 1987). However, Darby and Pearce (1995) raised the idea that only attended stimuli will be part of the configural stimulus that controls behavior, and that attention to the contexts may be determined by whether those contexts are informative to solve the discrimination (see, Preston et al., 1986). As contexts are not informative to solve the task in group NI, contexts are not expected to be attended, neither they are expected to be part of the configure controlling behavior and no context-switch effects would be expected in group NI.

Method

Participants

Seventy-two undergraduates at the University of Jaén (approximately 65% were women) participated for course credit. They were between 18 and 28 years old and had no previous experience with this task.

Apparatus and stimuli

Participants were trained individually in five adjacent isolated cubicles. Each cubicle had a Pentium PC on which the task was presented. The procedure was implemented using the program SuperLab Pro (Cedrus Corporation) software. The task was identical that León et al. (2010a, b), based in a task used by Gámez & Rosas (2005, 2007).

Participants played a computer game in which they had to defend Andalusia from air and land attacks. The task is presented in Figure 1. The main screen presented a black viewscreen simulating participant's control panel. On top of the screen there were four rectangles that could be coloured. Red, navy blue, and green colours were counterbalanced as discriminative stimuli X, Y, and Z. Grey, light blue, yellow, and brown colours were used as fillers F1, F2, F3, and F4, respectively. Contexts were presented within the viewing area of the viewer. Scenes of different beaches of Andalusia, Puerto Banús (urban beach), Tarifa (natural beach), and Cabo de Gata (Natural beach with a few buildings) were counterbalanced as contexts A, B and C. The two attackers were a plane and a tank. The plane was presented in the sky, at the top right area of the context, while the tank was presented on the sand, at the bottom left area of the context. Both attackers could appear in one of two different positions within their respective areas on the context so that it would give the impression of movement to the participant. Position of the attacker changed across trials and whenever the attacker was destroyed. The instrumental response was clicking on either the plane or the tank (R1 and R2, counterbalanced). Destruction of the tank and the plane was counterbalanced as outcomes 1 and 2 (O1 and O2) across participants.

Procedure

All participants gave their informed consent to participate in the experiment. The instructions and all necessary information were presented on the computer screen. Participants interacted with the computer using the mouse (left button). Instructions were presented in five screens using a black Times New Roman 26 bold font against a light yellow background to emulate the appearance of an old document. To advance the instruction screens the participants had to click on a button labelled as “next” placed on the right bottom of the screen. Each participant was initially asked to read the following instructions (in Spanish):

> (Screen 1) Andalusia is being attacked. Different parts of Andalusia are being assaulted by land and air. You are placed in the only bunker able to face up the attackers. Your work consists of defending Andalusia. Use the mouse to throw missiles to the targets. You should destroy the attackers before they take over Andalusia. (Screen 2) The monitor represents the bunker’s viewer, and the different attackers you should face will appear on it. Your technology and weapons are older than theirs, so you will need to shoot several times to destroy them. To shoot, click with the left button of the mouse while the pointer is on top of the target. (Screen 3) On top of the viewer there are several sensors. Each of those sensors will indicate that <u>only one</u> of the attackers is within your shooting range and can be destroyed by you. If the sensors are off, none of the attackers will be within the shooting range. (Screen 4) The battle begins! Remember that you can destroy only one attacker at any given time, so you will have to discover which one is currently within the shooting range. Remember not to waste the ammunition on the attackers

that are beyond the shooting range. Call the experimenter if you have any doubts. Otherwise, click with the mouse to begin. GOOD LUCK!

Participants were randomly assigned to groups I and NI upon their arrival to the laboratory. The experiment was conducted in two phases (see design on Table 1).

Discrimination training. Two training blocks were conducted in each context. Four trials of each discriminative stimulus were presented in each block, leading to a total of 8 trials per block and context. Trials within each block were randomly presented. The change of contexts was announced by a screen with the sentence "Your detachment has been posted to… (name of the beach where the battle continued)". This screen was presented for 2000 msec. The order in which those training blocks with each context were presented to participants was counterbalanced within and across participants (ABBA or BAAB). Each trial was divided in pre and stimulus periods (see Figure 1). During the Pre period, the tank and the plane were presented without the discriminative stimulus for 4 s (see top panel of Figure 1). Responding during this period was not reinforced. During the Stimulus period, the tank and the plane were presented accompanied by the relevant discriminative stimuli, depending on the trial (see middle panel of Figure 1). Correct responses were reinforced under a VI reinforcement schedule in which the availability of reinforcers oscillated randomly between 1 and 3 s. Once the reinforcer was available the trial continued until the participant gave the correct response. Participants were forced to choose the correct response to end the trial.

Each participant received X: R1-O1, Y: R2-O2 and Z: R1-O1 trials in context A. Groups differed on the treatment participants received in context B. In group I, discrimination between X and Y was reversed (X: R2-O2, Y: R1-O1). In Group NI discrimination between X and Y was kept identical across contexts A and B. Fillers were included to equate outcome experience across groups and contexts. Participants received F2: R2-O2 trials in Context A, and F1: R1-O1 and F2: R2-O2 trials in Context B.

Test. All participants received a trial with Z in each context (A, B and C). No reinforcement was available during test trials. Before the test trial the screen informing about the context was presented. The order of presentation of the contexts was counterbalanced across participants (ABC, CAB or BCA).

Dependent variable and statistical analysis

Total mouse clicks on each target were recorded separately and transformed to percentage of correct responses, taking the appropriate response to the present target as a reference. Responding was evaluated by analysis of variance (ANOVA). The rejection criterion was set at $p < .05$, and effect sizes were reported using partial eta-squared (η_p^2). Bonferroni correction was used for Post hoc pair-wise comparisons.

Results

Discriminative training

To simplify the presentation of the secondary data, discrimination between cues X and Y was pooled across cues and contexts. The right panel of Figure 2 shows the mean percentage of correct responses across the 8 trials of discrimination training between X and Y in contexts A and B in Group I and Group NI. Percentage of correct responses was high from the very beginning of training, increasing towards the end, without differences between groups I and NI. A 2 (Group) x 8 (Trials) ANOVA confirmed these impressions, showing a main effect of Trials, F (7, 490) = 19.95 (*MSe* = 97.38), $\eta_p^{2\,=}$ .22, but not main effect of Group neither Group x Trial interaction, larger F (1, 70) = 1.41 (*MSe* = 1157.59). So, reversing X-Y discrimination between contexts did not seem to affect the speed of the discrimination as group Informative performed at the same level than group No Informative. This result is not entirely surprising, as participants were forced to give a correct response to end any given trial during training, something that should have make discriminations easier for participants.

The right hand of Figure 2 presents mean percentage of correct responses to the key discriminative stimulus Z throughout the 8 trials of training in context A in groups I and NI. Note that discrimination proceeded quickly and, most importantly, without any appreciable difference across groups. A 2 (Groups) x 8 (Trial) ANOVA found a significant main effect of Trial, F (7, 490) = 5.04 (MSe = 310.21), $\eta_p^{2 =}$ .06. Most important, neither the main effect of group, nor the group x trial interaction were significant, $Fs < 1$.

Test

The most interesting results came from the test phase. Figure 3 depicts the mean percentage of correct responses to Z during the extinction trial conducted in the training context (A), in the alternative context (B), and in a new context (C) in group I (left) and group NI (right). As the test was conducted in extinction, correct responses are defined as the responses that were correct during training. The change in the context seemed to reduce responding to Z outside the training context in group I, regardless of whether the change in the context implied to go to the alternative context of training, or to a new context. No context switch effects seem to appear in group NI. A 2 (Group) x 3 (Context) ANOVA found significant main effects of Group, F (1, 70) = 13.07 (MSe = 734.74), $\eta_p^{2 =}$ .15, and Context, F (7, 490) = 7.10 (MSe = 310.21), $\eta_p^{2 =}$ .09. Most important, the Group x Context interaction was significant, F (2, 140) = 3.20 (MSe = 448.11), $\eta_p^{2 =}$ .04.

Analysis focused on exploring the Group x Context interaction found that the simple effect of Context was significant in group I, F (2, 70) = 11.79 (MSe = 372.33),

$\eta_p^{2} =$ .25, but not in NI, $F < 1$. Planed post hoc comparison conducted on group I found that performance in contexts B and C was lower than in context A ($ps \geq 0.002$), but not differences were found between contexts B and C.

Discussion

Learning about a discriminative stimulus that was a consistent predictor of the relationship between an instrumental response and an outcome was found to be context dependent when training was conducted within a context that was informative to solve an alternative discrimination (group I), but not when training was conducted within a non-informative context (group NI). Additionally, this context-switch effect was found regardless of whether the test was conducted in a different, but familiar context, our in an entirely new context.

These results replicate and extend those reported by León et al. (2010a, see also León et al., 2008). These authors reported context-dependence of performance to a discriminative stimulus that was trained within an informative context. As the test was conduced only in context B, results reported by León et al. (2010a) could reflect both, participants coding cue Z as context dependent because the informative value of the context led participants to pay attention to the context, or because participants learned a rule that involved reversing the meaning of the discriminative stimuli across contexts (e.g., Pineño & Miller, 2004). The fact that context-switch effects appeared in the unfamiliar context and that they were of the same size than the context-switch effect reported within the familiar context strongly suggest that participants did not solve the discrimination by using a general rule such as “the meaning of the cues is reversed across contexts A and B”.

Note that if participants were using a general rule, responding would be expected to be reduced also when tested in the new context. However, proposing the use of this type of rules in this experiment has to deal with two problems. The first problem is that participants did not reverse their performance to Z when the context is changed, regardless of whether the change of context involves going to the familiar context in which X-Y discrimination is reversed, or going to the new context C. Their performance is around chance, while using a reversing rule would have led to incorrect responses outnumber correct responses. The second problem is that establishing such a rational rule would have to ignore some evidence against it that is presented during training. As our design involved a filler cue (F2), that kept its meaning across contexts A and B, the use of a general rule could have been prevented (see García-Gutiérrez & Rosas, 2003). These results seem to be better explained by an automatic process in which the informative value of the contexts keep attention to them high, so that all the information learned within those contexts is coded together with the context in which such an information is learned (Rosas et al., 2006). Once the information is coded within a specific context, any context change should produce a decrease in performance, regardless of whether such a context change involves going to a familiar or to an unfamiliar context.

Conducting the test only in the familiar context B, as León et al. (2010a) did, allowed for an additional ambiguity in the interpretation of the results. As stated in the introduction, the results obtained in context B could be due to contexts exerting a function of modulators of the discriminative stimulus-response-outcome relationship (e.g., Bouton & Swartzentruber, 1986; see Holland, 1992) or to contexts becoming part of a configure that involved each specific discriminative stimulus (e.g., Pearce, 1987). The present experiment solved this confound by testing the discriminative stimulus in an entirely new context. Contrarily to context B, the new context C had not been involved in any previous configuration related with any of the responses or outcomes used in this experiment, and thus cannot receive generalized associative strength from any other configure. So, responding from this perspective should be lower in context C than in context B, an idea that the data do not support. Accordingly, the results of this experiment are better explained as the context playing a role of an occasion setter (e.g., Holland, 1992) rather than establishing direct associations with the response or the outcome either by itself or as part of a configure. Note that this conclusion does not imply that the discriminative stimuli used in this experiment played the role of occasion setters as well. They might control behaviour by establishing which response will be followed by which reinforcer at any given time, or just forming a configure that announce which reinforcer will be available at any given time. However, exploring this issue goes beyond the scope of the research reported here, and do not affect the conclusion that the role of the contexts in this experimental situation is better understood if contexts played the role of occasion setters, as stated above.

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Table 1

Experimental design

Group	Training	Test
I	A: **X:R1-O1**, **Y:R2-O2**, F2:R2-O2, **Z:R1-O1** B: **X:R2-O2, Y:R1-O1**, F2:R2-O2, F1:R1-O1	A: Z:R1/R2-NO B: Z:R1/R2-NO C: Z:R1/R2-NO
NI	A: **X:R1-O1**, **Y:R2-O2**, F2:R2-O2, **Z:R1-O1** B: **X:R1-O1, Y:R2-O2**, F2:R2-O2, F1:R1-O1	

Note. Contexts A, B and C: beaches of Puerto Banús, Cabo de Gata and Tarifa, counterbalanced. Discriminative stimuli X, Y, and Z: red, Navy blue, and green, counterbalanced. Discriminative stimuli F1, F2, F3, and F4: grey, light blue, yellow and brown, respectively. R1 and R2: clicking on the plane or the tank, counterbalanced. O1 and O2: plane or tank destruction, counterbalanced. NO: No outcome. Target treatments are presented in bold font.

Figure 1

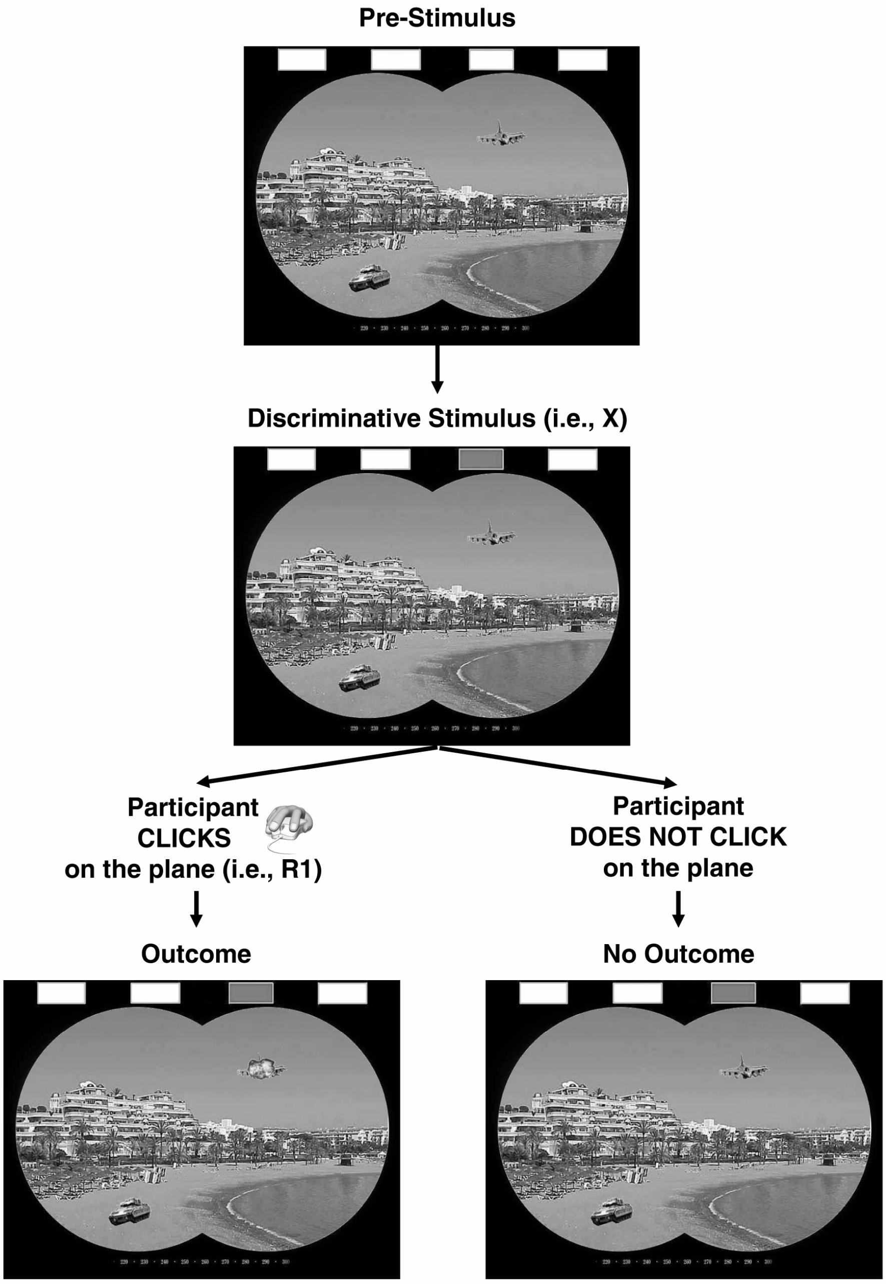

Figure 1. Example of trial. The top section presents the Pre-stimulus period. Plane and tank are presented on the context (the beach of Puerto Banús in this case) but no response is reinforced. The middle section presents the Stimulus period. Discriminative stimulus lights on and responding in the correct attacker produces reinforcement, while not responding or responding in the alternate attacker does not lead to reinforcement (bottom).

Figure 2

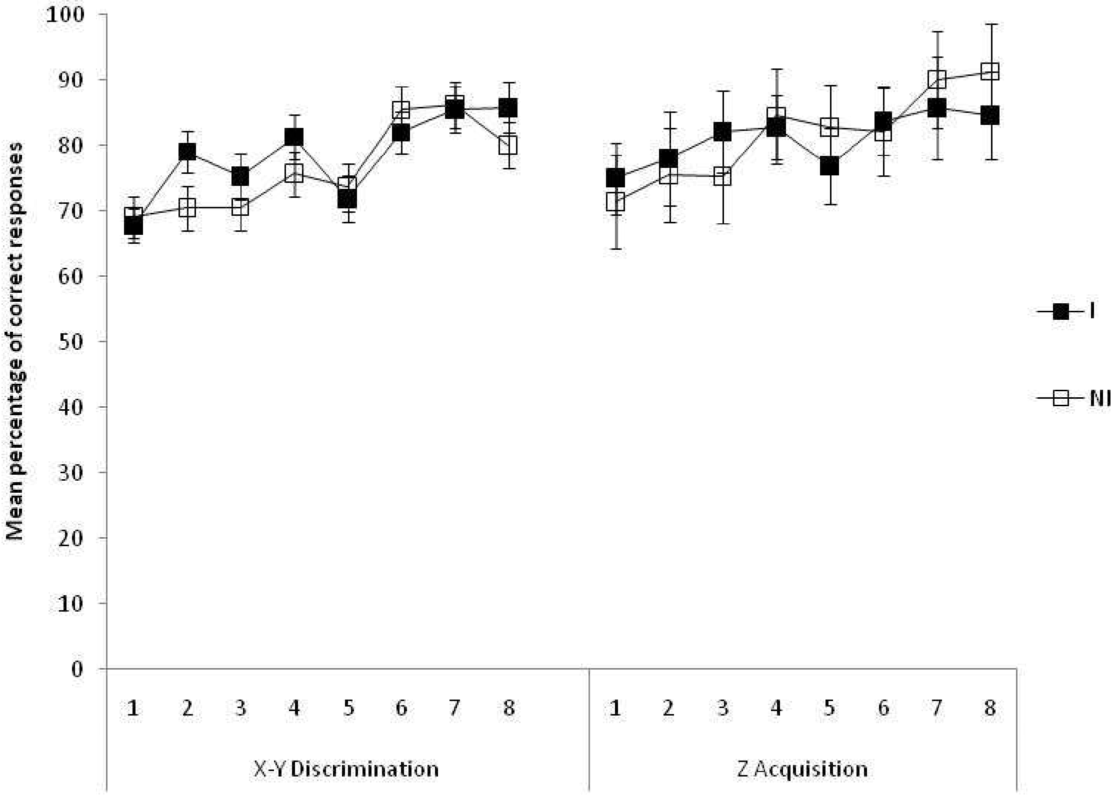

Figure 2. Mean percentage of correct responses during the X-Y discrimination (left panel), and during acquisition of Z (right panel) throughout the 8-training trials in groups I and NI. Error bars denote standard errors of the mean.

Figure 3

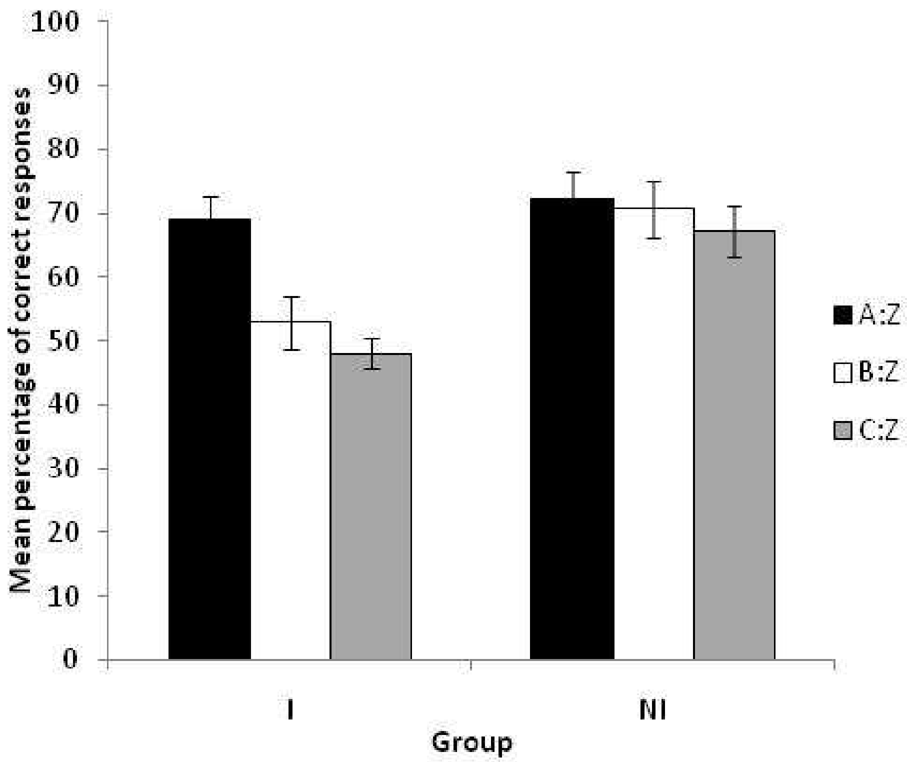

Figure 3. Mean correct responses per minute given to Z during the tree test trials in groups I and NI. A, B and C were the different contexts in test. Error bars denote standard errors of the mean.