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SUPPLEMENTARY INFORMATION

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Behavioural evidence for parallel outcome-sensitive and outcome-insensitive Pavlovian learning systems in humans

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Supplementary Methods

Materials

Stimuli: The fractal images used as CSs were selected based on two pilot studies (n = 28; n = 33) to be as neutral as possible on a pleasantness scale and as different as possible in terms of shape and colour. The selected fractal images were preprocessed with Matlab to have similar level of luminosity. The assignment of the images to particular Pavlovian cue conditions (e.g., CS+ L, CS+ R, CS-) was fully counterbalanced across participants.

Reaction times: For the four experiments, the reaction times were recorded through a keyboard using Psychtoolbox 3.0, implemented on Matlab. Before analysis the reaction time were log transformed and adjusted to account for linear trends independently of the trial type and changes in reaction time related to switching responses from one side of the screen to the other[9].

Procedure

Experiment 1

Pavlovian conditioning: Participants were asked to press on the "1" keyboard with the cue fractal image appeared on the upped side of the screen and the "2" keyboard when the cue fractal image appeared on the lower side of the screen and to press on the "6" key when the food outcome appeared on the left side of the screen and the "7" key when the food outcome appeared on the right side of the screen as quickly and accurately as possible. They were informed that the key-pressing task was a measure of their sustained attention independent of the cue-outcome contingencies. At the end of each session, participants were asked to provide ratings of the

perceived pleasantness of each image used as the cues on a visual analogue scale going from 0 (not pleasant at all) to 100 (extremely pleasant).

Experiment 2

Pavlovian conditioning: As in Experiment 1 participants were asked to press on the keys to detect the side of food outcome delivery, and at the end of each session they were asked to provide ratings of their perceived pleasantness for each one of the stimuli used as cues.

Experiment 3

Pavlovian Instrumental Conflict task: As in Experiment 1 and 2, participants were asked to make one of two key-presses to detect the side of food outcome delivery, and at the end of each session they were asked to provide ratings of their perceived pleasantness for each one of the images used as cues.

Experiment 4

Pavlovian conditioning: As in Experiment 1, 2, and 3, participants were asked to press on the keys to detect the side of the food outcome delivery, and at the end of each session, they were asked to provide ratings of their perceived pleasantness for each one of the stimuli used as cues.

Supplementary Notes

Experiment 1

Reaction times and Ratings: As complementary measures of Pavlovian conditioning, we also analyzed the reaction times to detect the side of the outcome delivery and the pleasantness ratings of the fractal images used as CSs. A planned contrast revealed that the CS+ L and the CS+ R were rated as more pleasant than the CS-, $F(1,39) = 11.00$, $p = .002$, $\eta^2_p = .220$, 90% CI [.055, .384]. The corrected reaction times to detect the side of the food outcome delivery were significantly longer if the side of the outcome was different than the one that was the most often predicted by the CS, $F(1,38) = 18.81$, $p < .001$, $\eta^2_p = .331$, 90% CI [.133, .486].

Experiment 2

Reaction times and Ratings: As complementary measures of Pavlovian conditioning, we also analysed the reaction times to detect the side of the outcome delivery and the pleasantness ratings of the fractal images used as CSs. As in Experiment 1, a planned contrast revealed that the CSs+ L and the CSs+ R were rated as more pleasant compared to the CS-, $F(1,19) = 21.09$, $p < .001$, $\eta^2_p = .526$, 90% CI [.229, .674]. We also replicated the findings of Experiment 1 for the log-transformed reaction times to detect the side of the food outcome delivery, which were adjusted to account for linear trends and switch costs. Results showed that participants had significantly longer reaction times if the side of the outcome was different than the one that was the most often predicted by the CS, $F(1,19) = 21.92$, $p < .001$, $\eta^2_p = .536$, 90% CI [.240, .681]. Moreover, reaction times to detect the side on the food outcome delivery were also significantly longer when the outcome identity (i.e., sweet or savoury) was different than the one that was the most often predicted by the CS $F(1,19) = 15.89$, $p < .001$, $\eta^2_p = .456$, 90% CI [.159, 624].

Experiment 3

Reaction times and Ratings: As complementary measures of Pavlovian learning we also analysed the reaction times to detect the side of the outcome delivery and the pleasantness ratings of the fractal images used as cues during the learning sessions. The reaction times to detect the side of the food outcome delivery were log-transformed and adjusted to account for linear trends and switch costs. Results showed that they were significantly longer if the side of the outcome was different than the one that was the most often predicted by the cue $F(1,41) = 39.75$, $p < .001$, $\eta^2_p =$ .492, 90% CI [.298, .614]. A series of planned comparisons revealed that the congruent cue was evaluated as being more pleasant than the incongruent cue ($F(1,41) = 5.88$, $p = .020$, $\eta^2_p = .125$, 90% CI [.011, .282]) and the CS- cue ($F(1,41) = 9.01$, $p = .005$, $\eta^2_p = .180$, 90% CI [.035, .341]), which did not significantly differ from each other ($F(1,41) = 3.01$, $p = .091$, $\eta^2 = .068$, 90 % CI [.000, .212]).

Experiment 4

Reaction times and Ratings: As complementary measures of Pavlovian conditioning, we also analysed the reaction times to detect the side of the outcome delivery and the pleasantness ratings of the fractal images used as CSs. We replicated the findings of Experiment 1 and 2 for the log-transformed reaction times to detect the side of the food outcome delivery, which were adjusted to account for linear trends and switch costs. Results showed that participants had significantly longer reaction times if the side of the food outcome was different than the one that was the most often predicted by the CS, $F(1,32) = 16.60$ $p < .001$ $\eta^2_p = .342$, 90% CI [.125, .505]. A series of planned comparisons revealed that the CS+ were evaluated as being more pleasant than the CS control ($F(1,32) = 23.80$, $p < .001$, $\eta^2_p = .427$, 90% CI [.201, 574]) and the CS- ($F(1,32) = 5.82$, $p = .022$, $\eta^2_p = .154$, 90% CI [.013, .332]). The CS- ($M = 52.75$, $SD = 13.25$) was

descriptively evaluated as being more pleasant than the CS control (M = 47.16, SD = 9.52), though this difference did not reach significance, ($F(1,32) = 4.09$, $p = .051$, $\eta^2_p = .113$, 90% CI [.000, .288]). We compared the liking ratings of the CS- across Experiment 1, 2 and 4 in a one-way ANOVA with Experiment (1, 2 or 3) as a fixed factor, which revealed a main effect of Experiment $F(2,90) = 6.49$, $p = .002$, $\eta^2_p = .126$, 90% CI [.030, .224]: in Experiment 4, the CS- was rated as being more pleasant (M = 52.75, SD = 13.25) than in Experiment 1 (M = 46.37, SD = 15.48) and Experiment 2 (M = 37.02, SD = 18.34). This suggests that the presence of a control condition with a video of the experimenter's hand not delivering the reward increased the perceived value of the CS- condition where no videos were displayed, i.e. that the presence of the CS control condition generated a contrast effect which modulated the value of the CS-. This effect might have also been reflected in the pupil dilation effect at the onset of the CS-, which in Experiment 4 did not significantly differ from the CS+ ($F(1,32) = .007$, $p = .935$, $\eta^2_p = .000$, 90% CI [.000, .015]) nor the CS control ($F(1,32) = 2.28$, $p = .140$, $\eta^2_p = .067$, 90% CI [.000, .229]).