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# The paradoxical conditioning effect of the human pupil might be evaluative in nature

Ferdinand Pittino*, Katrin M. Kliegl, Anke Huckauf

*General Psychology, Institute of Psychology and Education, Ulm University, Ulm, Germany*

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ABSTRACT

Conditioning the human pupillary response with variations in brightness (brightness vs. darkness) as an unconditioned stimulus (UCS) has yielded contradictory findings (see Voigt, 1968). In the current study, we conditioned Landolt Rings with bright and dark monitor backgrounds (UCS). Before conditioning, the Landolt Rings were rated equally neutral and moderately arousing and resulted in comparable pupillary changes. After conditioning, the Landolt Ring conditioned with a bright background was rated more arousing and more negative and resulted in a larger pupillary dilation than the Landolt Ring conditioned with a dark background. Hence, although it is well known that pupil size decreases with increasing brightness, we found larger pupil sizes for the stimulus conditioned with a bright monitor background. The paradoxical pupil effects are discussed with regard to the contribution of the evaluative change (evaluative conditioning) in the formation of the conditioned pupillary reaction. Further, the possibility of a conditioned compensatory reaction is discussed.

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## 1. Introduction

The pupil is mainly responsive to changes in brightness, since its primary function is to regulate the amount of light hitting the retina. However, research indicated that pupil size also reflects cognitive processes (e.g. Laeng, Sirois, & Gredeback, 2012; Wierda, van Rijn, Taatgen, & Martens, 2012). For example, Wierda et al. (2012) were able to show that the pupillary signal offers information about attentional processes in an attentional blink task.

The pupil is innervated by the sympathetic and parasympathetic nervous systems and is therefore influenced by changes in affective arousal (e.g. Ehlers, Strauch, Georgi, & Huckauf, 2016; Partala & Surakka, 2003). Partala and Surakka (2003) demonstrated that the pupil is more dilated in response to positive and negative stimuli than to neutral ones. The authors conclude that the larger pupil is caused by the higher arousal of these affective stimuli, which resembles sympathetic activation.

To summarize these advances in pupillometry, pupil size is not solely determined by brightness conditions but is also regulated by cognitive and arousal-related processes. In this study, we present a paradoxical effect in conditioning the human pupillary response, which may help to deepen our understanding of factors affecting human pupil control.

One method to shape autonomic processes (e.g. like salivation or pupillary movements) consists in classical conditioning. In the basic paradigm, a neutral stimulus (NS; e.g. a bell) only causing an orienting response, is repeatedly paired with an

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* Corresponding author at: General Psychology, Institute of Psychology and Education, Ulm University, Albert-Einstein-Allee 47, 89069 Ulm, Germany.
*E-mail address:* ferdinand.pittino@uni-ulm.de (F. Pittino).

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unconditioned stimulus (UCS; e.g. food) which elicits an unconditioned response (e.g. salivation). After repeated pairings, the now conditioned stimulus (CS, e.g. bell) also shows the conditioned response (e.g. salivation; for an overview see Domjan & Grau, 2015). Despite the long history of research on conditioning and the validity of the concept regarding various dependent variables (e.g. eyeblink conditioning; Cason, 1922a), there is still an ongoing controversy concerning the conditioning of the human pupillary response.

The first experiments conducted by Watson (1916), Cason (1922b), or Baker (1938) showed successful conditioning of the pupil using variations in brightness as the UCS. These studies found that the CS paired with brightness ($\mathrm{CS}_{\mathrm{bright}}$) resulted in pupillary constriction whereas the one paired with darkness ($\mathrm{CS}_{\mathrm{dark}}$) elicited pupillary dilation. However, further attempts to replicate this effect showed mixed and contradictory results (e.g. Hilgard, Dutton, & Helmick, 1949; Kugelmass, Hakerem, & Mantgiaris, 1969; Young, 1954, 1958). For example, the study carried out by Kugelmass et al. (1969) even showed pupillary dilation in response to a tone that was conditioned with brightness. The authors were not able to provide a comprehensive explanation for this paradoxical conditioning effect and therefore encouraged future research to focus on the contribution of sympathetic factors (like e.g. emotional arousal) in the formation of the conditioned reaction.

Based on the contradictory findings, Voigt (1968) inferred that neither dilation nor constriction of the pupillary response can be conditioned using brightness as the UCS. This failure would have important implications for theories of conditioning. Hilgard et al. (1949, p. 689) stated "Unless satisfactory pupillary conditioning can be obtained, classical conditioning theory will have to be revised. It is important that the negative results should not be allowed to stand until every effort has been made to discover more favorable conditions."

Nevertheless, there have been studies successfully showing that conditioning the human pupillary response is possible. Reinhard and Lachnit (2002) found a conditioned dilation response to the CS paired with an aversive electric shock and to the CS paired with reaction time tasks.

Therefore, conditioning of the human pupil seems to be possible. Taking this fact into consideration, it is surprising that brightness, being the stimulation to which the pupil is primarily responsive and which causes massive pupillary changes (Bremner, 2012), has yielded mixed results in conditioning experiments. To our knowledge, no further study using brightness to condition the human pupil has been published since the work of Kugelmass et al. (1969).

Our study took up on this unresolved controversy. We applied changes in brightness (brightness vs. darkness) as the UCS. Because pupil size decreases with increasing brightness, we expected to find smaller pupil sizes for the $\mathrm{CS}_{\mathrm{bright}}$ in comparison to the $\mathrm{CS}_{\mathrm{dark}}$, replicating previous results (Baker, 1938; Cason, 1922b; Watson, 1916). As the pupil is not solely responsive to changes in brightness, but also to valence and arousal, we additionally assessed evaluative changes towards the CS. This was done to further assess the contribution of sympathetic factors in conditioning the human pupillary response (Kugelmass et al., 1969).

## 2. Methods

### 2.1. Participants

Sixteen female students of Ulm University ($M_{age} = 22.00$, $SD_{\mathrm{age}} = 2.90$) participated in this experiment in exchange for partial fulfillment of course credit or as a courtesy to the examiners. All subjects were naïve about the hypotheses and the purpose of the experiment and had normal or corrected to normal-vision. They all read and signed a written consent form, which was based on the guidelines of the German Research Foundation (DFG).

### 2.2. Apparatus and stimuli

The experiment was implemented using PsychoPy (Version 1.81.02; Peirce, 2007) and was run on a Windows XP computer. The stimuli were presented on a BenQ G2200WT LCD Monitor (1680 × 1050 px, 60 Hz refresh rate) which was stationed approximately 60 cm from the participant. An iView $\mathrm{X}^{\mathrm{TM}}$ Hi-Speed eye-tracker with a sampling-rate of 500 Hz (SensoMotoric Instruments, Teltow Germany) was used to monitor the pupil size of the participants.

We used a dark (black; 0.19 lx, 0.2 $\mathrm{cd/m^2}$) and a bright monitor background (white; 40 lx, 115.4 $\mathrm{cd/m^2}$) as the UCSs. In order to achieve the biggest pupillary change, the UCSs were presented in full-screen-mode. The other stimuli were presented on a homogenous grey screen (18.4 lx, 34.1 $\mathrm{cd/m^2}$).

Two Landolt Rings with opposite gap positions (either left vs. right; up vs. down) were chosen as the CSs. A Landolt Ring is characterized by a diameter five times larger than its stroke width and gap opening size (EN ISO 8596; see Fig. 1 for an illustration of a Landolt Ring). The assignment of the gap position to the UCS was balanced across participants. Throughout the experiment, the Landolt Rings were presented centrally with a size of 3° (resulting in 17.8 lx).

The four corners of a black 3.2° square served as a fixation cue in order to orient the spatial attention to the location of the following CS presentation throughout conditioning. This stimulus was chosen in order to minimize interference from possible afterimages, as it does not overlap with the Landolt Rings (Kliegl, Watrin, & Huckauf, 2015).

For baseline measurement of the pupil, an isosceles triangle was presented centrally with a size of 3°. The triangle consisted of the same number of black pixels as the Landolt Ring, in order to create a baseline-stimulus that was identical to the Landolt Rings in brightness and also resembled a common geometrical figure.

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