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Psychological Science 2009 20: 1313
DOI: 10.1111/j.1467-9280.2009.02443.x

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Short Report

The Unconscious Eye Opener

Pupil Dilation Reveals Strategic Recruitment of Resources Upon Presentation of Subliminal Reward Cues

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Recent research suggests that reward cues, in the absence of awareness, can enhance people's investment of physical resources (Aarts, Custers, & Marien, 2008; Pessiglione et al., 2007). Pessiglione et al., for example, showed that participants spent more physical effort in a demanding force task when they could gain a high-value coin (a pound) than when they could gain a low-value coin (a penny), even when the coins were presented subliminally (i.e., below the threshold of awareness). One explanation for this intriguing finding is that subliminal reward information is processed strategically—that the costs (i.e., the required effort) and benefits (i.e., the value of the reward) of an action are weighed against each other. However, such a weighing process would require higher control functions (Cohen, Heller, & Ranganath, 2005) that are typically thought to operate only on information available to consciousness (Baars, 2002). Another explanation is that the prime directly boosts resources. From this perspective, the effects of subliminal rewards can be explained in terms of low-level, reflex-like responses to primes (Bargh, 2006). Here, we challenge the latter perspective by examining the interaction of reward value and task demands. We aim to show that resources are not directly recruited in reaction to high-reward cues, but instead are recruited strategically—only when the task requires it, and regardless of whether or not the cues enter conscious awareness.

In a computerized experiment, we employed an on-line, physiological index: pupil dilation. Because the pupil dilates with sympathetic activity and constricts with parasympathetic activity (Steinhauer, Siegle, Condray, & Pless, 2004), pupil size is an accurate and unobtrusive measure of the resources invested in a task. Ruling out potential alternative explanations, such as anxiety, research demonstrates that pupil dilation increases when tasks require more resources, either because of variations within or between tasks (Kahneman, 1973) or because of individual differences in, for example, cognitive ability (Ahern & Beatty, 1979). These findings demonstrate that the amount of resources individuals need to mobilize for a task can be reliably indexed by changes in their pupil size.

If subliminal reward cues input into the strategic processes involved in resource recruitment, the effects of rewards on pupil dilation should occur when the task is demanding (here, recall of five digits), but not when the task is undemanding (recall of three digits), as undemanding tasks can be completed routinely and do not require many resources. It is important to note that this interactive effect of reward and demand on recruitment of resources is expected to occur regardless of whether the reward is processed consciously or nonconsciously.

METHOD

Fifteen participants (mean age = 21 years) performed a digit-retention task in which they could earn a coin (1 or 50 euro cents, or c) presented on the computer screen by correctly recalling a subsequent series of digits. They were told that the coin would sometimes be "difficult to perceive." Accordingly, in half of the trials, the coin was presented supraliminally (i.e., was consciously perceivable); in the other half, the coin was presented subliminally (Pessiglione et al., 2007). The number of random digits to be recalled also varied (three vs. five). If participants responded correctly (mean accuracy = 96.9%) on the digit task, they received the coin.

Each trial in the digit-retention task featured a fixation cross (4,000 ms), followed by a premask (400 ms), the coin stimulus (17[1] or 300 ms), and a postmask (583 or 300 ms; total duration of the masks and coin was always 1,000 ms). Next, participants saw another cross (2,000 ms), after which the number of upcoming digits was announced (e.g., "3 digits"; 2,000 ms). Then, another fixation cross was shown, and after 3,000 ms the digits were presented aurally (1 per second). After 4,000 ms (retention in-

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[1]Subliminality was tested in a separate signal detection task with different participants. After inspection of the coin pictures, 15 participants were presented with 24 coins, in the same manner as in the 17-ms-duration condition. After each postmask, they were asked to indicate the value of the coin (1 or 50 c). Participants performed no better than chance in discriminating between the coins, p = .51, $t(14)$ = 0.425, p_{rep} = .62.

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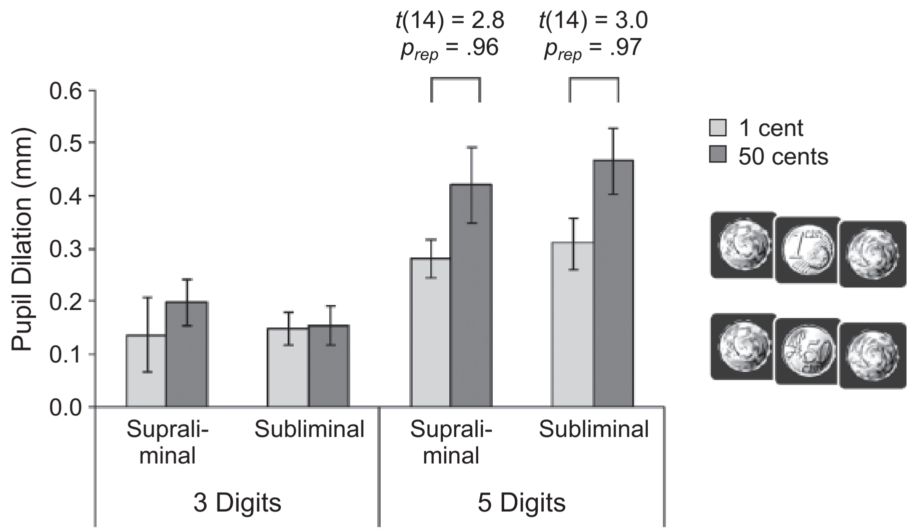

Fig. 1. Maximum increase in pupil diameter as a function of level of reward (1 vs. 50 euro cents), presentation of the reward display (supraliminal vs. subliminal), and number of digits to be retained (three vs. five). Error bars represent standard errors of the mean. Significant differences between corresponding high- and low-reward conditions are marked (other paired *t*s < 1). On the right, the sequence of premask, coin, and postmask is depicted for each reward condition.

terval), a sound cued participants to verbally report the digits. Subsequently, feedback about performance on the trial (incorrect or correct, 1 or 50 c; 2,000 ms) and the cumulative earnings (1,500 ms) were displayed.

During 48 trials (6 for each condition of the $2 \times 2 \times 2$ within-subjects design), pupil size was recorded using a Tobii 1750 infrared eye tracker sampling at 50 Hz (Tobii Technology, Falls Church, VA). Raw pupil data were corrected for artifacts and filtered (Kuchinke, Võ, Hofmann, & Jacobs, 2007). Task-evoked pupillary responses were calculated to index the amount of resources recruited in each condition (Beatty & Lucero-Wagoner, 2000). Average pupil size in the 1,000 ms preceding the trial served as a baseline.[2]

RESULTS

Pupil responses were submitted to a 2 (reward) × 2 (reward-presentation duration) × 2 (number of digits) repeated measures analysis of variance, which revealed that the mean increment in pupil diameter was greater in the five-digit (0.37 mm) than in the three-digit (0.16 mm) condition, $F(1, 14) = 29.56$, $p_{rep} > .99$, $\eta^2 = .68$. Mean pupil dilation also proved greater in the high-reward (0.31 mm) than in the low-reward (0.22 mm) condition, $F(1, 14) = 6.85$, $p_{rep} = .95$, $\eta^2 = .33$. Crucially, a Reward × Number of Digits interaction was found, $F(1, 14) = 4.74$, $p_{rep} = .92$, $\eta^2 = .25$, indicating that the effect of reward was present in the five-digit, but not the three-digit, condition. This effect was not qualified by a three-way interaction, nor were there any effects of reward-stimulus duration, all Fs < 1; thus, subliminal and supraliminal rewards affected pupil size in the same way (see Fig. 1).

DISCUSSION

Pupil-dilation data indicated that valuable (compared with nonvaluable) rewards led to recruitment of more resources, but only when obtaining the reward required considerable mental effort. This pattern was identical for supraliminal and subliminal reward cues. This indicates that awareness of a reward is not a necessary condition for strategic resource recruitment to take place. These findings are in line with recent research suggesting that the unconscious has flexible and adaptive capabilities (Hassin, Uleman, & Bargh, 2005; Wilson, 2002). More generally, whereas analyses of costs (required effort) and benefits (value of rewards) are usually thought to require consciousness, our findings suggest that such strategic processes can occur outside of awareness—and these processes show in the eyes.

Acknowledgments—This manuscript was supported by grants from the Netherlands Organization for Scientific Research (NWO; VENI 451-06-014, VICI 452-02-047). We thank Lorenz van Doornen for his valuable input.

[2]We conducted a pilot study to validate pupil dilation as a measure of resource deployment in our specific digit-retention task. In this preliminary study, 15 participants (who did not take part in the main study) retained three or five digits on each trial. Peak pupil dilation was greater in the five-digit condition ($M = 0.48$ mm) than in the three-digit condition ($M = 0.18$ mm), $t(14) = 3.84$, $p_{rep} = .99$. If retaining five digits requires more resources than retaining three digits, then pupil size should have declined more slowly in the 4-s retention interval in the former condition. Indeed, during the retention interval, pupil size declined with time, but this decline was significantly slower in the five-digit condition, $r(199) = -.87$, than in the three-digit condition, $r(199) = -.95$, p_{rep} of the difference > .99 (Meng, Rosenthal, & Rubin, 1992). These results validate the idea that pupil dilation reliably indexes the amount of mental resources deployed in our task.

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(Received 12/10/08; Revision accepted 3/22/09)

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