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Research article

Electrophysiological evidence for attentional capture by irrelevant angry facial expressions: Naturalistic faces

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HIGHLIGHTS

- Participants were asked to judge the gender of a neutral target face.
- Angry or happy distractor faces increased reaction times.
- The P_D component suggests that angry distractors were attentionally suppressed.
- Angry distractors elicited a larger N450 component, reflecting conflict detection.
- The results support the idea that angry faces are attentionally prioritized.

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ABSTRACT

Recently, research on lateralized event related potentials (ERPs) in response to irrelevant distractors has revealed that angry but not happy schematic distractors capture spatial attention. Whether this effect occurs in the context of the natural expression of emotions is unknown. To fill this gap, observers were asked to judge the gender of a natural face surrounded by a color singleton among five other face identities. In contrast to previous studies, the similarity between the task-relevant feature (color) and the distractor features was low. On some trials, the target was displayed concurrently with an irrelevant angry or happy face. The lateralized ERPs to these distractors were measured as a marker of spatial attention. Our results revealed that angry face distractors, but not happy face distractors, triggered a P_D, which is a marker of distractor suppression. Subsequent to the P_D, angry distractors elicited a larger N450 component, which is associated with conflict detection. We conclude that threatening expressions have a high attentional priority because of their emotional value, resulting in early suppression and late conflict detection.

1. Introduction

There are few studies showing that threatening expressions, such as angry faces, capture attention when they are irrelevant to the task. However, this would be crucial evidence for the threat-capture hypothesis [1] which suggests that angry expressions grab attention automatically. Preferential attentional selection of threatening over positive expressions, called the *anger superiority effect*, has been observed in visual search only when angry faces were task-relevant [2]. This effect has been taken to support the threat-capture hypothesis, which states that threatening faces are processed faster than non-threatening faces and detected before attentional deployment [3]. However, visual search tasks in which the anger superiority effect was observed have used angry faces as targets and not as distractors. Typically, capture of attention by irrelevant distractors disrupts search, resulting in an increase in reaction times (RTs) [4]. Preferential processing of threatening stimuli would predict larger bottom-up capture by threatening than non-threatening face distractors. Studies which have required participants to search for a target in competition with an irrelevant facial expression are scarce. In previous research using natural or schematic facial expressions, increased RTs were observed for emotional distractor expressions, which was attributed to the affective significance of the distractor [5,6]. However, no difference between RTs to happy and angry distractors was established, which contradicts the threat-capture hypothesis.

Despite the lack of behavioral evidence for the threat-capture hypothesis, electrophysiological data has provided evidence in its

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favor. In this context, the N2pc has been used as a marker of spatial selective attention [7,8]. The N2pc occurs between 200 and 300 ms after stimulus onset at parietal electrodes and may be dissociated into two subcomponents [9]: a contralateral negativity, the Nt, associated with attentional selection, and a contralateral positivity, the P_D, associated with suppression of irrelevant stimuli [10]. When the distractor is shown at a lateral position and the target is on the vertical midline, the N2pc component reflects involuntary attentional capture by the distractor while the P_D reflects active attentional filtering of the distractor [11–14].

Because the N2pc and P_D constitute electrophysiological markers of attentional processing, they are useful measures for investigating the capture of attention by threatening facial expressions. For lateralized target expressions, the N2pc is larger for angry as compared to happy face targets [15,16]. Similarly, the N2pc to lateralized distractor expressions occurred in response to threatening, but not in response to happy expressions [17], which supports the threat-capture hypothesis. The N2pc to angry distractors demonstrates an early attentional deployment toward threatening emotional content, even though the stimuli were task-irrelevant.

It is currently unknown whether this effect can be generalized to conditions involving pictures of real facial expressions, rather than schematic pictures. Indeed, to be biologically relevant, the threat-capture hypothesis [1] must apply to natural faces and not only to schematic faces [18]. Evidence of attentional capture by real faces is crucial in the framework of the evolutionary relevance of threat. Threat is thought to activate a dedicated "fear module" that was forged in our phylogeny [19] before the advent of schematic drawings. Critically, the investigation of lateralized ERPs to natural angry faces as irrelevant distractors would provide information about the temporal dynamics of the activation of the fear module and its consequences on attentional and post-attentional processing.

Therefore, we investigated attentional effects of realistic threatening distractors in a visual search task. Participants were instructed to first locate a face surrounded by a color singleton and subsequently discriminate the gender of this face. On some trials, one of the remaining faces conveyed an emotional expression. We measured the lateralized ERPs to the irrelevant distractor when the distractor was on a lateral position and the target was on the vertical midline [11–14]. Because the vertical target is equally represented in both hemispheres, the lateralized ERPs only reflect processing of the distractor. Importantly, this spatial configuration enabled us to compare attentional processing of non-threatening (happy) and threatening (angry) distractor expressions. Behaviorally, we expected to find longer RTs in the distractor-present conditions than the distractor-absent condition, but no difference between facial expressions [5,6,17]. Additionally, we analyzed the electrophysiological signal occurring irrespectively of the distractor location in the N450 time interval. This measure will allow us to evaluate post-attentional effects.

2. Materials and methods

2.1. Participants

Twenty-four University of Geneva students (five males) without any neurological or psychiatric conditions participated in this experiment. All participants reported normal or corrected-to-normal vision. One participant was rejected because fewer than 50% of his trials remained after artifact rejection, mainly due to saccadic eye movements. Two participants were excluded because they produced excessive saccades toward the target or the distractor (average horizontal EOG outside ±3 μV). Thus, the following analyses were conducted on the 21 remaining participants (three males). All participants were naive as to the purpose of the experiment. The local ethics committee of the University of Geneva had approved the study, and informed consent was obtained from participants prior to the experiment. Students received class credit in exchange for their participation.

2.2. Stimuli

The Cogent toolbox (www.vislab.ucl.ac.uk/Cogent2000) for Matlab was used to display the stimuli. As depicted in Fig. 1, six stimuli were presented at 6° of eccentricity on a black background. An oval of 1.8° horizontal by 2° vertical was shown as the contour of the faces. Faces were cropped at the hairline (see Fig. 1c) and selected from the NimStim [20] and the Karolinska Directed Emotional Faces database [KDEF; 21]. Critically, all faces with visible teeth were discarded in order to avoid any low-level capture by the resulting salient bright region [22,23]. We used 12 different identities (6 male and 6 female), each with a neutral, happy, and angry expression. In each visual search display, those identities were divided in sets of three males and three females, changing randomly every 96 trials. All pictures were gray-scale. Pictures of facial expressions are prone to low-level confounds [23]. Therefore, the contrast and the luminance histograms of the pictures were equalized using the SHINE toolbox [24], which reduces the variation of low-level perceptual features potentially influencing the lateralized ERPs.

2.3. Apparatus and procedure

Participants were seated in a comfortable chair in a dimly lit room. All stimuli were displayed on a CRT screen with a luminance of ∼7.9 cd/m^2. The target consisted of a face surrounded by an unfilled oval whose color was different from the remaining ovals. The target face varied unpredictably between green among blue and blue among green. A distractor expression was present on two-thirds of the trials as in our previous studies [for more details,see 11,12,17].

Each trial began with a gray fixation cross on a black background for a random interval between 600 and 1600 ms. Participants were instructed to report the gender of the face inside the color singleton as quickly as possible while maintaining accuracy better than 90%. Responses were given with the right hand, and participants were instructed to respond using one of two keys of a standard keyboard. Incorrect responses were indicated by visual feedback. The stimulus remained on the screen until a response was given. Before the experiment, participants completed 96 trials of the task in which they were trained to avoid moving their eyes in the direction of the target. The three male and three female identities of the practice session were not used in the main experiment. Each participant performed 12 blocks of 96 experimental trials for a total of 1152 trials. Following the experiment, participants evaluated the valence and the intensity of each face using a continuous scale (respectively −100 to +100, from highly negative to highly positive, and 0–200, from low to high intensity, rescaled to 0–100).

2.4. Electrophysiological recording and analysis

EEG signals were recorded using an actiCHamp amplifier (Brain Products, Gilching, Germany) with active Ag/AgCl electrodes sampled at 1000 Hz. Twenty-seven electrodes were fixed on the scalp, one on the outer canthi of each eye (HEOG), one above and below the right eye (VEOG), and one on each earlobe. Cz served as online reference and AFz as ground. Electrode impedance was kept below 5 kΩ for EEG and H/VEOG.

Using BrainVision Analyzer 2.1 (Brain Products, Gilching, Germany), data were filtered with a zero phase-shift, low-pass But-

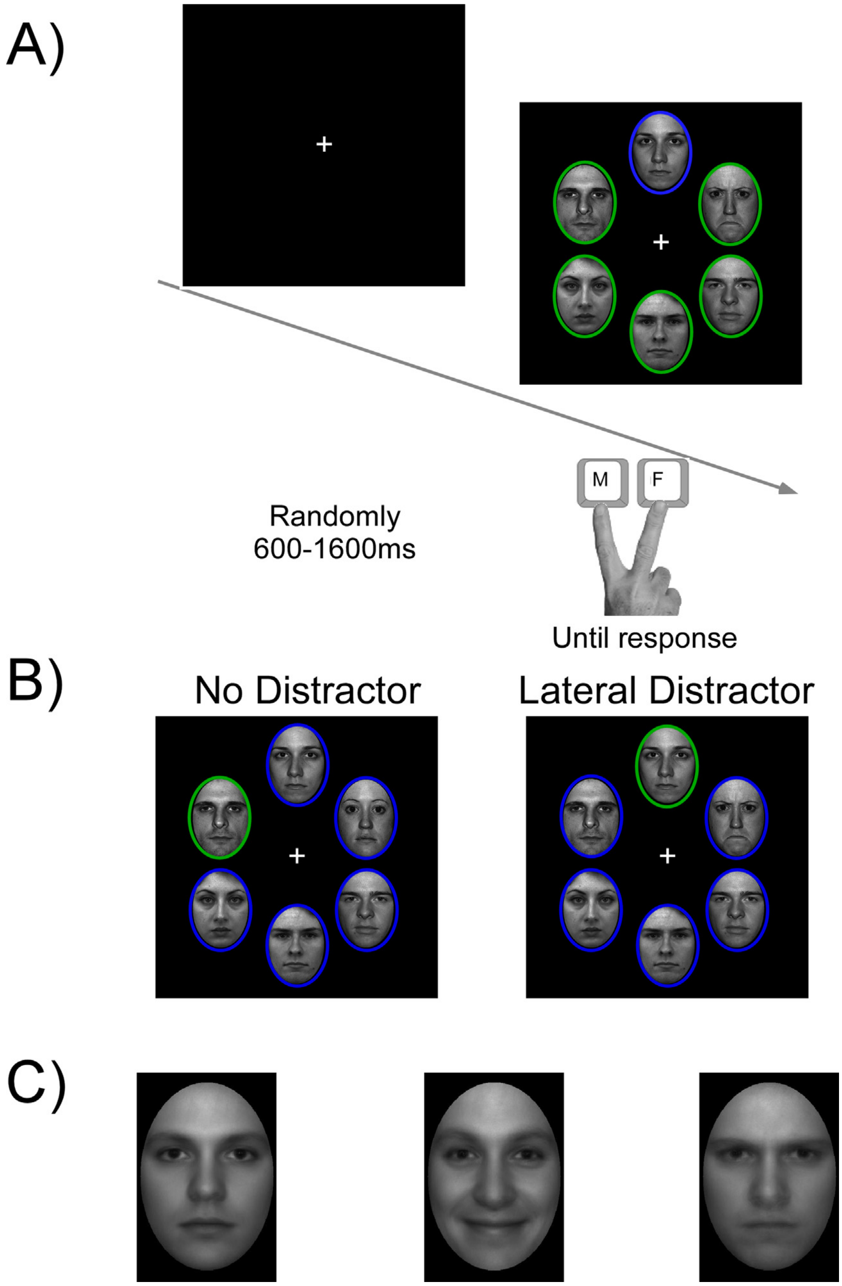

Fig. 1. Paradigm, visual search display and sample stimuli.
(A) Six faces were displayed on a virtual circle. In two-thirds of the trials, an irrelevant distractor (angry or happy face) was shown in competition with the target. Participants were required to press one of two buttons (M – male or F – female) to indicate the gender of the target face, which was surrounded by a different color. (B) Illustrations of the condition with a target and no distractor (left panel) and the condition with a target at midline and a lateral distractor (right panel; here, an angry distractor is shown). Some additional filler conditions were added but not reported here (for detailed information: see Burra et al., 2016). (C) The average image of all facial expressions (6 male/6 female). The facial expressions were easily recognized. All stimuli were aligned and selected to be typical neutral, happy, and angry expressions (shown from left to right, respectively).

terworth filter (40 Hz with 24 dB/oct.). We used the same artifact rejection criteria as in our prior study [17]. On average, 15% of the trials were discarded. Epochs started 100 ms before the onset of the display and ended 600 ms after, for a total time window of 700 ms. When necessary, we corrected for the non-sphericity of the data in the ANOVA using the Greenhouse-Geisser correction of the degrees of freedom. All following statistical tests were two-tailed.

The N2pc/P_D was measured time-locked to the search display at electrodes PO7/PO8, where the signal was maximal during the 285–325 ms time period. Additionally, we measured ERPs at frontal sites in the time window from 320 to 460 ms, which corresponds to the N450.

3. Results

3.1. Valence and intensity rating

Median scores of valence and intensity per facial expressions were analyzed in a one-way, repeated-measures ANOVA (emotional expression: neutral, angry, and happy). The mean valence scores are shown in Fig. 2 (left). Angry faces were rated as more negative (−56) than neutral (−3) and happy (+52) faces, $F(2,40) = 116.42$, $p < 0.001$. In absolute terms, valence scores were not different for angry and happy faces (56 vs. 52), $t(20) = -0.69$, $p = 0.49$. Moreover, the same ANOVA on the emotional intensity

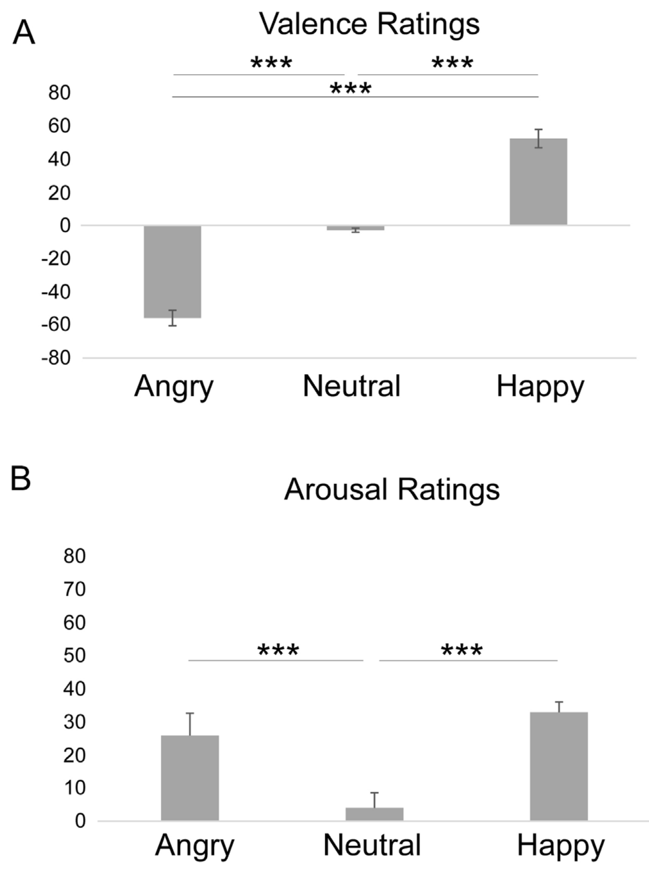

Fig. 2. Mean ratings of the picture set.
(A) Mean valence rating. (B) Mean emotional intensity (arousal) ratings. Error bars show the between-subjects standard error of the mean. *** = $p < 0.001$.

rating revealed that angry (25) and happy (32) faces were rated as more intense than neutral faces (3), $F(2,40) = 19.91$, $p < 0.001$. Critically, the difference between the intensity ratings for happy and angry faces did not reach significance, as displayed in Fig. 2 (right). Overall, angry and happy faces were balanced regarding valence and intensity.

3.2. Behavior

A one-way, repeated-measure ANOVA (distractor type: absent, happy, angry) revealed that RTs were longer for trials with happy (853 ms) and angry (851 ms) distractors compared to distractor-absent trials (837 ms), $F(2,40) = 11.04$, $p < 0.001$ (see Fig. 2). However, the mean RT in the two distractor conditions were not significantly different ($p = 0.82$). Proportion of correct responses as a function of distractor type was also analyzed via a one-way, repeated-measure ANOVA, but no significant effect was observed. Overall, the mean proportion of correct responses was 0.89.

3.3. Lateralized ERP components

A one-way, repeated-measures ANOVA (distractor type: absent, angry, happy) on the lateralized ERPs from 285 to 325 ms showed a significant effect, $F(2,40) = 35.31$, $p < 0.001$ (see Fig. 3). Critically, the voltage difference occurring in response to the angry expression (0.38 μV) was significantly more positive than the voltage occurring in response to the happy expression (−0.11 μV), $t(20) = 2.29$, $p = 0.033$ (paired t-test).

Independent-samples t-tests comparing the mean voltage difference to zero confirmed a significant N2pc to the target when the distractor was absent (−2.21 μV), $t(20) = 6.05$, $p < 0.001$. Further, we found a significant P_D in response to the angry distractor, $t(20) = 2.39$, $p = 0.027$, and no significant voltage difference in response to the happy distractor, $p = 0.304$.

3.4. Non-lateralized visual ERP components

A 3 (electrodes: F3, Fz, F4) x 3 (distractor type: absent, angry, happy) on the voltage from 320 to 460 ms revealed that the N450 component was larger at Fz (−2.03 μV) than at F3 (−0.83 μV) or F4 (−0.64 μV), $F(2,40) = 17.59$, $p < 0.001$. Critically, the N450 was larger to angry (−1.47 μV) than to happy (−1.01 μV) distractor expressions or when the distractor was absent (−1.02 μV), $F(2,40) = 3.98$, $p = 0.026$ (see Fig. 4). The differences angry-happy and angry-neutral were confirmed by paired t-test, $ts(20) > 2.13$, $ps < 0.05$. The interaction failed to reach significance, $p = 0.845$.

4. Discussion

In this study, we measured the impact of threatening distractors on visual search. Importantly, the present study used real faces to support the relevance of the threat-detection hypothesis in natural settings. As in prior studies, RTs were longer in the presence of emotional distractor expressions, but no difference between angry and happy distractors was observed [5,6,17]. However, our electrophysiological data allowed us to unveil the greater attentional engagement by angry distractors, in line with recent ERP data showing attentional capture by angry distractor expressions [17]. Importantly, the P_D component occurred to angry, but not to happy distractor expressions.

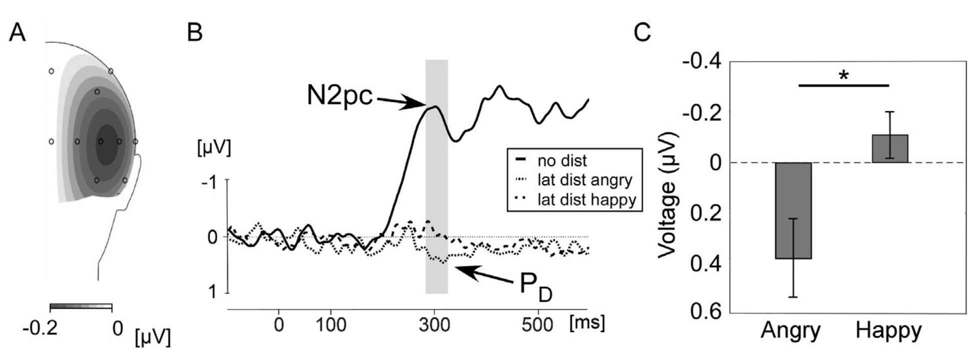

Fig. 3. Lateralized event-related potentials.
(A) The scalp topography of the N2pc, with the maximal of amplitude at PO7/PO8. (B) The difference wave of contralateral–ipsilateral activity at PO7/PO8 electrodes for each condition. The gray area indicates the analysis window, around the peak of the N2pc to the target, from 285 to 325 ms. (C) Mean amplitudes of angry and happy distractor conditions. Error bars show the between-subjects standard error of the mean. * = $p < 0.05$.

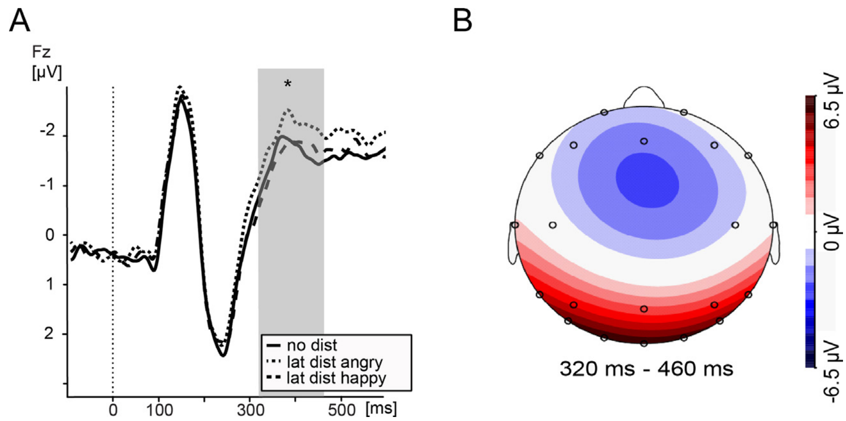

Fig. 4. Event-related potentials (non-lateralized).
(A) The N450 at electrode Fz where the component was at its maximum. (B) Scalp topography. This component was larger in the lateral angry distractor condition than in the lateral happy and no distractor condition. The gray area indicates the analysis interval from 320 to 460 ms. * = $p < 0.05$.

The P_D component reflects the active suppression of salient-but-irrelevant stimuli that compete for attentional selection [9,25,26]. Previous research suggested that suppression occurs after an attend-to-me signal is generated by a salient stimulus [27]. Therefore, the presence of the P_D component suggests that angry distractors were more salient than happy distractors and had to be suppressed in order to assure successful target selection. Critically, we excluded that low-level [18,23] or emotional intensity (i.e. arousal) [28,29] differences between the expressions affected attentional priority. Consequently, our data suggest that attentional suppression is related to the negative valence and threatening character of angry expressions [3,16][i.e.,3,16].

In our previous study [17], we observed an N2pc to angry and no lateralized ERP to happy distractor expressions. The important difference to the present study is that target-nontarget similarity was lower in the present study than in the previous study. In Burra et al. (2016), participants judged the orientation of the only tilted nose in the search array. However, the tilted nose was similar to the tilted eyebrows of the nontarget stimuli, resulting in high target-nontarget similarity. In contrast, search for the target face in the present study was based on color and it was easy to locate the odd-colored circle in the display because it was highly salient (i.e., low target-nontarget similarity). In research involving geometrical shapes, we have demonstrated that attentional capture by salient distractors occurs when target-nontarget similarity was high, whereas attentional suppression occurred when target-nontarget similarity was low (Barras and Kerzel, Submitted). The same may apply to the occurrence of attentional capture in Burra et al. (2016) and attentional suppression in the present study. The important point is that both capture and suppression indicate that threatening emotional expressions are salient and engage attention.

Furthermore, late non-lateralized ERPs (the N450) suggest that threatening expressions result in conflict processing. Typically, the N450 is a large negativity peaking around 400–500 ms after onset, mostly at fronto-central scalp regions. In the present study, this component was larger with angry distractors. Presumably, the N450 is associated with conflict detection and may be the correlate of the amount of resources devoted to cognitive control [30]. For instance, it is sensitive to Stroop-like conflicts between irrelevant word meaning and color [i.e.,31,32]. Furthermore, a more pronounced N450 occurred in response to incongruent trials in an affective Stroop task [33] where a word was incongruent with a facial expression [34] or an emotional prosody [35]. It is likely that the active suppression of an irrelevant distractor in our task might have elicited this conflict signal to inform the brain of a likely threat. In summary, the N450 allows for the detection of a conflict in the achievement of the task [36] to assure accurate gender categorization.

In conclusion, the results of this study provide evidence for the influence of a salient threatening distractor on spatial attention and on later conflict processing. Results indicated that the human attentional system conveys high attentional priority to natural angry faces even when irrelevant to the task. These results support the threat-capture hypothesis [1], substantiating its validity in naturalistic situations.

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