Spatial attention increases performance but not subjective confidence in a discrimination task

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Selective attention to a target yields faster and more accurate responses. Faster response times, in turn, are usually associated with increased subjective confidence. Could the decrease in reaction time in the presence of attention therefore simply reflect a shift toward more confident responses? We here addressed the extent to which attention modulates accuracy, processing speed, and confidence independently. To probe the effect of spatial attention on performance, we used two attentional manipulations of a visual orientation discrimination task. We demonstrate that spatial attention significantly increases accuracy, whereas subjective confidence measures reveal overconfidence in non-attended stimuli. At constant confidence levels, reaction times showed a significant decrease (by 15–49%, corresponding to 100–250 ms). This dissociation of objective performance and subjective confidence suggests that attention and awareness, as measured by confidence, are distinct, albeit related, phenomena.

Keywords: spatial attention, awareness, reaction times, confidence

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Introduction

More than a century of research has quantified the ample, objective benefits accrued to attended objects, or events (Pashler, Johnston, & Ruthruff, 2001; Posner & Petersen, 1990; Treisman, 2006). In contrast, much less is known about the direct influence of attention on subjective confidence in one's perceptual decisions. Confidence is considered to be intrinsically linked to stimulus awareness as an index of subjective perception (Kunimoto, Miller, & Pashler, 2001; Szczepanowski & Pessoa, 2007): Awareness of a stimulus allows the observer to have higher confidence in his or her judgment of the stimulus (Kunimoto et al., 2001) and increases their willingness to wager high on their decision (Koch & Preuschoff, 2007; Persaud, McLeod, & Cowey, 2007). Such subjective confidence measures vary in a predictable manner with the performance of human (Kolb & Braun, 1995; Morgan, Mason, & Solomon, 1997) and non-human subjects (Shields, Smith, Guttmannova, & Washburn, 2005; Smith et al., 1995). The debate whether subjective measures, such as confidence ratings, capture awareness better than objective performance metrics has been ongoing since the early days of empirical psychophysics (Merikle, Smilek, & Eastwood, 2001; Peirce & Jastrow, 1884; Szczepanowski & Pessoa, 2007). The dissociation between subjective measures of confidence and objective performance is most evident in two extreme clinical examples, blindsight and Anton's blindness (Anton-Babinski syndrome): In the former, patients perform visual tasks well above chance despite being reportedly unaware of their percepts (Stoerig & Cowey, 2007; Weiskrantz, 2004). In the latter, the reverse occurs, patients claim to see, although objective measures confirm their blindness (e.g., Roos, Tuite, Below, & Pascuzzi, 1990). For normal observers, however, the relation between subjective confidence measures and performance has received surprisingly little

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investigation, in particular with respect to their modulation by attention. This is remarkable, as the speed of perceptual processes, probed via reaction time, is influenced not only by confidence but also by attention: Unless external stopping rules are used (Vickers, Smith, Burt, & Brown, 1985), reaction time and confidence rating are intrinsically linked in an inverse relationship (Audley, 1960; Baranski & Petrusic, 1998; Henmon, 1911), up to the point that sometimes reaction times are substituted as measure of confidence. However, equating reaction time with confidence is problematic as attention influences reaction times (Posner, 1980). If spatial attention is directed toward the location of a target, reaction times at the attended location are faster than at unattended locations. Therefore, reaction time, confidence ratings, and attention all appear to be related, yet the nature of relationship is not known. Specifically, since reaction times are slower in the absence of attention, the attention-related increase in reaction time could simply reflect a shift toward less confident responses. Surprisingly, hardly any studies have directly addressed the three-way interaction between objective, subjective performance, and attention. One notable exception was the demonstration of a reaction time decrease in the presence of spatial attention without awareness in one blindsight subject (Kentridge, Heywood, & Weiskrantz, 2004). Here we address the threefold relation between attention, reaction time, and confidence in normal observers. We employed an orientation discrimination task, while manipulating the distribution of spatial attention using a classic cueing paradigm in a single stimulus environment (Experiment 1) and a precue–postcue paradigm in a dual-stimulus environment (Experiment 2). In both settings, observers rate the confidence of their response.

Experiment 1

Materials and methods

Volunteers were recruited from the Caltech campus and gave written informed consent. They had normal or corrected-to-normal eyesight. Experiments were approved by the Institutional Review Board. Nine volunteers, naive to the purpose of the experiment, participated. They were instructed to make two decisions on whether a grating was tilted toward the left or the right while also rating their subjective confidence in this decision by pushing one of six buttons on a computer keyboard: the grating tilted leftward, high confidence (for analysis coded as 3); left, medium confidence (coded as 2); left, low confidence (1); right, low confidence (1); right, medium confidence (2); and right, high confidence (3).

Each trial began with the participant fixating an arrow pointing either upward or downward (Figure 1). Stimuli were presented on a 20-in. CRT monitor (resolution 1024*768 pixel; refresh rate 120 Hz) located 80 cm from the subjects. Eye movements were monitored online at 1000 Hz using an Eyelink 1000 (SR Research, Osgoode, Canada) eye-tracking device, and the stimulus presentation was started after participants continuously fixated on the arrow for 500 ms. When participants did not properly fixate on the arrow for 500 ms, the trial was aborted and restarted. Participants were instructed to respond quickly and accurately reflecting their orientation judgment and the confidence level.

The stimulus, a sinusoidal grating (patch size of 5°, 8 cycles per patch; minimum luminance 0.001 cd/m^2, maximum luminance 26 cd/m^2; background screen 13 cd/m^2),

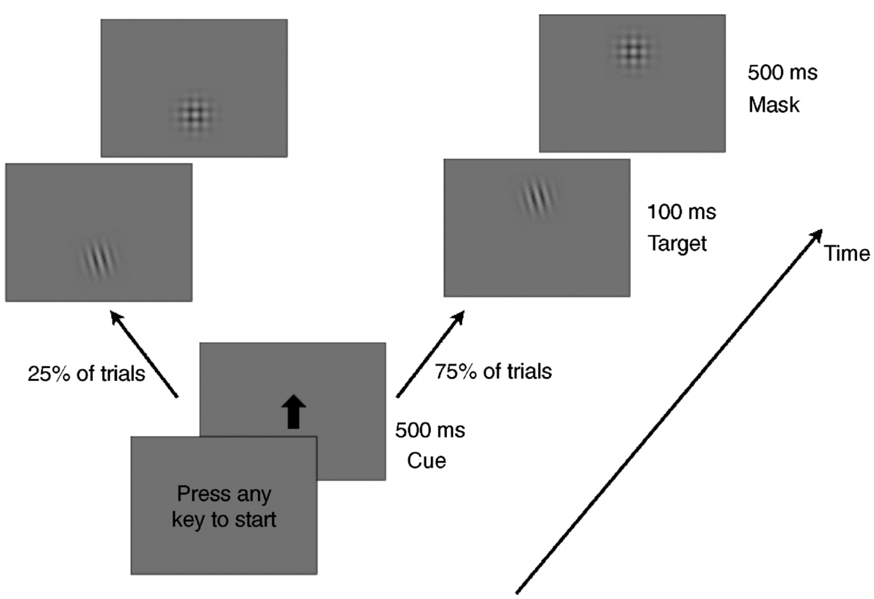

Figure 1. Experiment 1: Time course of the paradigm: Subjects had to indicate whether the patch, appearing either at a cued or a non-cued location, was tilted to the left or to the right and their confidence in this judgment.

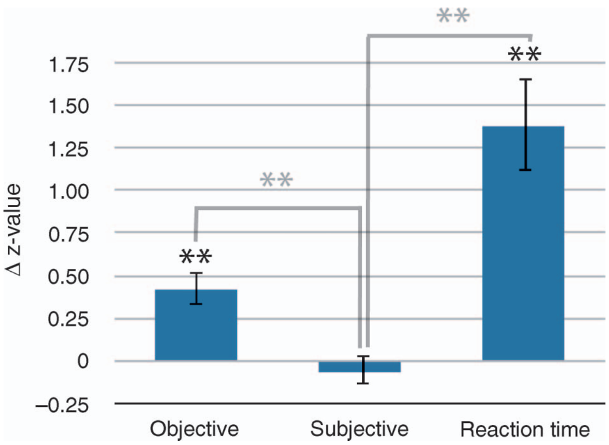

Figure 2. Experiment 1: Attention-related change in z-standardized objective and subjective measures of performance and reaction time: High attention leads to a significant increase in objective measures of performance (p = 0.002) and to a significant decrease in re-action time (p = 0.002), but not to a significant change in subjective measures of performance (p = 0.467). Changes in objective measures and reaction times are significantly larger than the one in subjective measures (p = 0.002 and p = 0.006 respectively).

was tilted toward the left or right by one of six difficulty levels (0.5°, 1°, 2°, 4°, 8°, 16°). The grating was presented for 100 ms either 5° above or below the center of the arrow, then masked by a plaid, consisting of vertical and horizontal sinusoidal gratings for 500 ms. The range of difficulty levels was adjusted in pilot studies by varying the orientation of the grating away from the vertical to let participants use the whole range from "very confident" to "guessed" responses. Participants performed an initial training block (96 trials) to stabilize performance. For the 6 following experimental blocks (96 trials each), the arrow correctly indicated the location of the subsequent target in 75% of the trials (high attention condition) and incorrectly in 25% of the trials (low attention condition). Data from one participant and data of one block of a second participant were excluded as eye position during stimulus presentation was two standard deviations out of the range of all other data (>2° of visual angle).

We analyzed percentage correct as determined by classic forced-choice measures, mean confidence for correct responses and reaction time for correct responses of high, medium, and low confidence. Furthermore, to allow comparison of the attention-related change in different measures of objective performance (% correct responses), confidence and reaction times, we z-transformed all measures to a common mean (0) and standard deviation (1) (z-standardization). Accuracy for the orientation discrimination (Wickens, 2001) was determined by calculating the area under the ROC curve for this objective measure ($AUC_{objective}$). We defined a response as "Hit" when a left tilted stimulus was judged as left and as "False Alarm" when a left tilted stimulus was judged as right (ROC analysis for objective measure; Galvin, Podd, Drga, & Whitmore, 2003; Kunimoto et al., 2001). We constructed an ROC curve with two inflection points from the confidence data: Correct responses with higher confidence were regarded as "Hit" and incorrect responses with higher confidence were regarded as "False alarm" (Galvin et al., 2003; Kunimoto et al., 2001; Szczepanowski & Pessoa, 2007). We denote the area under this ROC curve as $AUC_{subjective}$. Statistics on all AUC values were performed on logit-transformed AUC values ($\log(p / (1 - p))$). For easy interpretation, we report inverse transformed values. Comparisons between high and low attention conditions are paired t tests.

Results

Correct responses showed the classic effect of increased performance in the presence of spatial attention: an increase from 73.7 ± 3.3% (mean ± standard error of mean) in the low attention to 77.4 ± 2.8% correct performance in the high attention-condition (p = 0.002). This effect is also reflected in the area under the ROC curve, $AUC_{objective}$, which increased significantly (p = 0.004) from 0.74 ± 0.04 to 0.77 ± 0.03 when switching from low to high attention

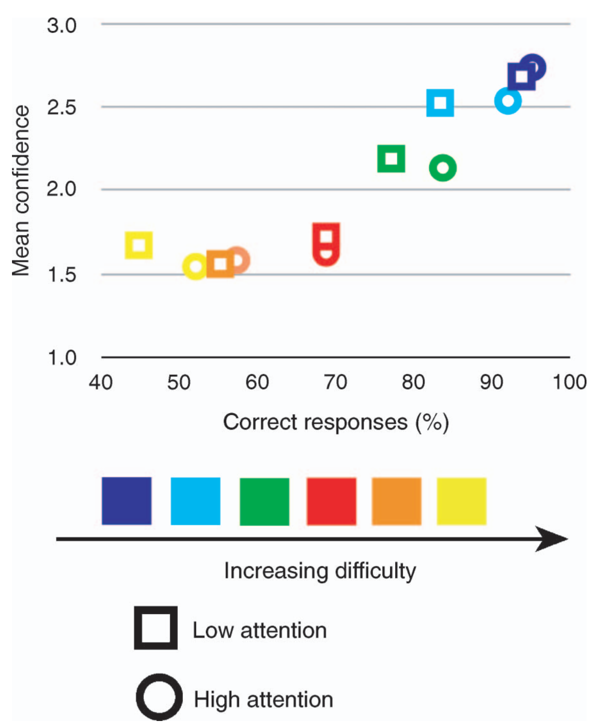

Figure 3. Experiment 1: Correlation between performance (% correct responses) and confidence over the six different difficulty levels: Mean confidence and mean percentage of correct responses, averaged over 8 subjects, for each individual difficulty level (0.5°, 1°, 2°, 4°, 8°, 16°) are correlated under both low (r = 0.93; p = 0.007) and high attention (r = 0.92; p = 0.007) load.

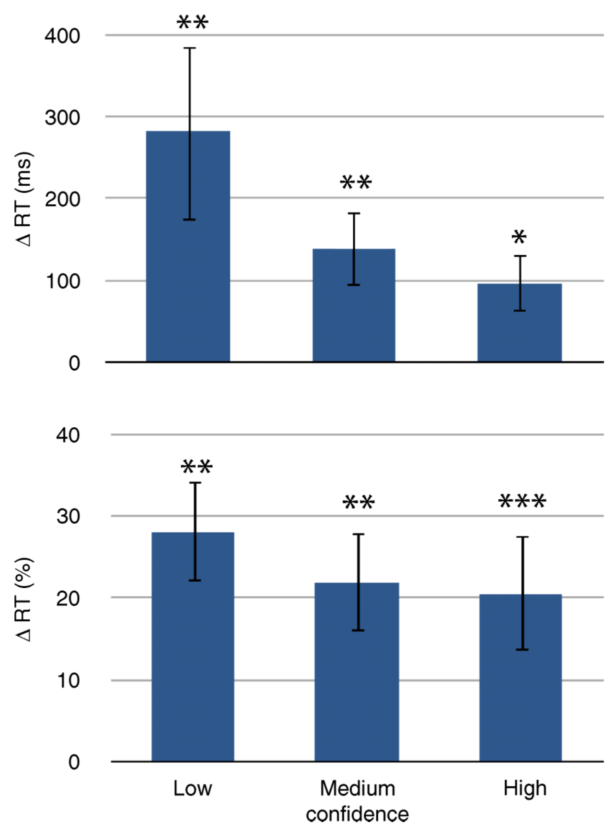

Figure 4. Experiment 1: Increase in RT for confidence judgments for $n = 8$ subjects (similar levels of confidence) for the low spatial attention condition as the absolute difference with low and high attention condition in milliseconds (top) and as RT percentage relative to the condition under high attention (bottom). [* depicts $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; error bars depict standard error of mean].

conditions. On the contrary, there was no significant difference ($p = 0.462$) in the mean confidence for the correct decision under low- and high-attention conditions (Table 2). Equally, $AUC_{subjective}$ did not increase significantly (Table 3).

In order to directly compare subjective and objective performance measures, i.e., confidence ratings and percentage correct responses, as well as reaction times, we z-transformed these 3 types of data. Z-transformed fraction of correct responses increased from −0.21 ± 0.39 to 0.21 ± 0.32 ($p = 0.002$; Figure 2). The difference in z-transformed confidence between the low (0.03 ± 0.34) and the high (-0.03 ± 0.39) attention did not reach significance ($p = 0.467$; Figure 2). The influence of attention on z-transformed performance was larger than on z-transformed confidence ($p = 0.001$).

Does this simply reflect an overall lack of awareness about performance? To test whether participants adjust their confidence according to performance, we computed the correlation between performance and mean confidence separately for the different tilt angles (Figure 3), corresponding to different difficulty levels. In Experiment 1, the correlation between mean confidence and performance over these six difficulty levels was significant within different attentional conditions, both under low ($r = 0.93$; $p = 0.007$) and high attention ($r = 0.92$; $p = 0.007$). Thus, while subjects adjust their confidence according to stimulus-induced changes in performance, they fail to do so for attention-induced changes in performance.

The lack of a clear difference in mean confidence for attended and unattended correct responses cannot be easily explained by an overall lack in awareness of performance. Thus, the fact that confidence is kept nearly constant between attention-induced changes in performance indicates an overconfidence in judgments in the (near) absence of attention relative to the confidence in judgments to attended stimuli.

How does the attentional manipulation influence reaction time (RT)? RT shows the classic effect (Posner, 1980) of decreasing in the high (0.577 ± 0.180 s for correct responses) compared to the low attention condition (0.735 ± 0.040 s) ($p = 0.002$; see also Figure 2). The lack of a clear difference in overall confidence makes it unlikely that this increase in RT can be solely explained by a shift toward less confident responses. Indeed, the influence of attention onto z-standardized RT is significantly larger than on z-standardized confidence judgments ($p = 0.006$; Figure 2). To confirm an increase of RT without a change in confidence we computed reaction times for each level of confidence separately. Within similar levels of confidence, the RT for correct responses to non-attended stimuli increased by 100–230 ms (corresponding to a 20–28% increase relative to the 75% condition; $0.02 < p < 0.002$; Figure 4).

Thus, attention boosts objective measures of perception (performance, $AUC_{objective}$ and RT) but not subjective measure (confidence in decision and $AUC_{subjective}$) (Tables 1, 2, and 3) indicating a relative overconfidence when judging non-attended stimuli.

A potential confound can arise from the instruction given to the participants to respond “as fast and as

	Experiment 1	Experiment 2, single response	Experiment 2, dual response
High attention	77.4 ± 2.8	78.0 ± 2.6	76.9 ± 2.9
Low attention	73.7 ± 3.3	68.3 ± 3.3	70.3 ± 2.8
p-value of comparison	−0.002	<0.001	<0.001

Table 1. Comparison of performance levels.

	Experiment 1	Experiment 2, single response	Experiment 2, dual response
High attention	2.09 ± 0.12	2.37 ± 0.14	2.29 ± 0.11
Low attention	2.11 ± 0.11	2.19 ± 0.13	2.20 ± 0.07
p-value of comparison	0.462	0.033	0.132

Table 2. Comparison of mean confidence levels.

accurate as possible.” As participants have to make two decisions (the orientation discrimination and a meta-decision about the confidence they have in this decision), it is possible that confidence ratings require longer processing times and are therefore less accurate given the speedy response paradigm. Signal detection theory commonly uses one-response schemes (Wickens, 2001), whereas classic paradigms are not speeded. In fact, in many studies investigating confidence judgments, two responses are made, one after another (Kunimoto et al., 2001; Szczepanowski & Pessoa, 2007). Therefore, in a second experiment, we directly compared the effects of making a single complex versus two simpler decisions in series. For this, we employed a postcueing paradigm Gorea and Sagi (2001) to investigate the effects of top-down attention. This technique allowed us to more efficiently collect data for attended versus unattended stimuli in equal numbers. Furthermore, in Experiment 1, the low attention condition was three times less frequent in the high attention condition. This might create an additional bias the precue–postcue paradigm avoids (Gorea & Sagi, 2001).

Experiment 2

Materials and methods

Nine volunteers, naive to the purpose of the experiment, participated in Experiment 2. They were instructed to decide whether a grating was tilted toward the left or right. Each volunteer participated in two versions of the experiment on two different days. In one version (one-response condition), participants indicated their decision about the orientation judgment and rated their subjective confidence with a six alternative choice confidence scale, as in Experiment 1. In another version (two-response condition), participants first indicated their orientation judgment (left–right) and then rated their confidence about this decision on a three alternative choice scale (high, medium, and low confidence), as in the traditional experiment with confidence rating. The order of the conditions was randomized over all participants. Each trial began with the participant fixating on a cross (Figure 5). Eye movements were monitored online as above, and the cue presentation was started after participants continuously fixated on the fixation cross for 500 ms. When participants failed to fixate properly, the trial was aborted and restarted, as in Experiment 1.

After 500-ms fixation in 50% of the trials, a precue was presented for 500 ms pointing either upward or downward at the stimulus location (high attention condition). Two sinusoidal gratings were presented, one (the target) at the location indicated by the precue and the other one (the distractor) at the opposite location. The precue was 100% valid; thus, after the arrow, participants could focus their attention on the target and disregard the distractor. In the remaining 50% of the trials, two precue arrows were presented instead of the unambiguous single one (Figure 5), indicating that participants had to wait for the postcue to know the location of the target. Thus, in these trials, participants did not know at the time of stimulus presentation the respective locations of the target and the distractor and therefore had to split their attention between both locations. In the following, we call this the low attention condition.

Both target and distractor were similar to those in Experiment 1 with the exception of orientation angles (1°, 2°, 4°, 8°, 10°, 16°). Gratings were presented 3.5° above and below the fixated location for 100 ms, then masked by a plaid for 250 ms. A postcue was presented for 500 ms pointing either upward or downward indicating the target location. In the precue trials, this information was merely a repetition of the precue information. Participants performed an initial training block (96 trials) to stabilize performance followed by 5 experimental blocks (96 trials

	Experiment 1		Experiment 2, single response		Experiment 2, dual response	
	Objective	Subjective	Objective	Subjective	Objective	Subjective
High attention	0.77 ± 0.03	0.73 ± 0.03	0.78 ± 0.03	0.74 ± 0.03	0.77 ± 0.03	0.71 ± 0.03
Low attention	0.74 ± 0.04	0.70 ± 0.03	0.69 ± 0.03	0.65 ± 0.03	0.71 ± 0.03	0.67 ± 0.04
p-value	0.004	0.124	<0.001	0.023	0.004	0.034

Table 3. Comparison of area under the ROC curve (AUC) for objective and subjective measures.

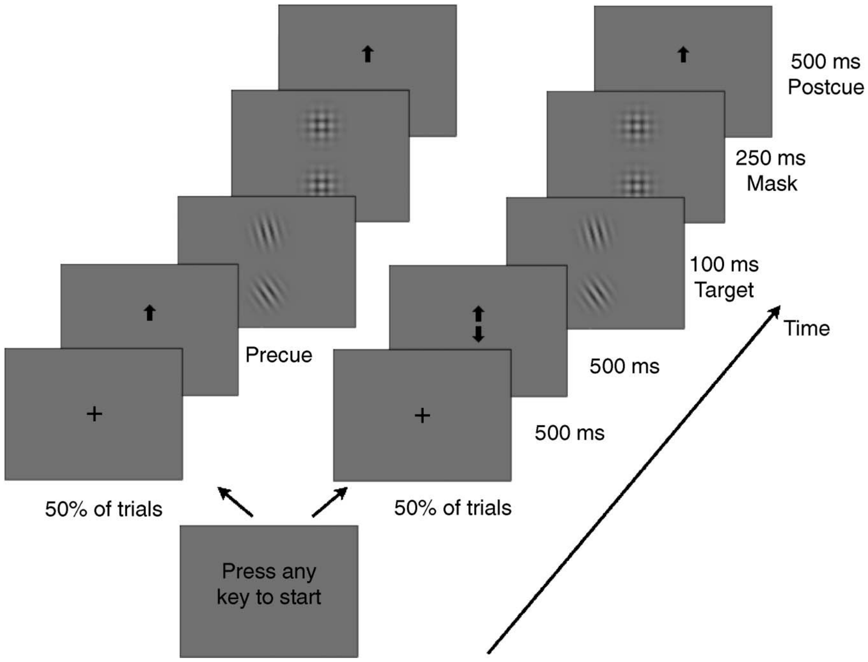

Figure 5. Experiment 2: Time course of the precue-postcue-paradigm: Subjects had to indicate whether the target was tilted to the left or the right and their confidence in this judgment. The target location was indicated either by a precue (high attention) or a postcue (low attention condition); the confidence judgment was either given at the same time as the confidence judgment (1 response condition) or sequentially (2 response condition).

each). Data from two subjects were excluded as their performance did not exceed 54% correct for precue or postcue condition.

Results

As expected, performance increased significantly with attention in both conditions; from 68.3 ± 3.3% correct responses to 78.0 ± 2.6% for the one-response experiment ($p < 0.001$; Table 1) and from 70.3 ± 2.8% to 76.9 ± 2.9% in the two-response condition ($p < 0.001$, Table 1). For the one-response condition, the difference between the mean confidence for correct decisions increased from 2.19 ± 0.13 to 2.37 ± 0.14 with attention (a significant difference at $p = 0.033$; Table 2). $AUC_{objective}$ increased from 0.69 ± 0.03 to 0.78 ± 0.03 with attention ($p < 0.001$), while confidence rose significantly ($p = 0.023$) from 0.65 ± 0.03 to 0.74 ± 0.04 (Table 3). *Z*-transformed objective measures of performance (percentage of correct responses) increased from −0.54 ± 0.96 to 0.54 ± 0.76 with attention ($p < 0.001$; Figure 6). The difference in *z*-transformed confidence between low (0.51 ± 0.76) and high (0.89 ± 0.76) attention was significant ($p = 0.033$). The influence of attention on *z*-transformed percentage correct responses was still larger than on *z*-transformed confidence ratings ($p = 0.007$).

For the two-response condition, the difference between the mean confidence did not significantly differ between the two attention conditions ($p = 0.132$; Table 2). $AUC_{objective}$ increased significantly ($p = 0.004$) from 0.71 ± 0.03 to 0.77 ± 0.03, as did $AUC_{subjective}$ (from 0.67 ± 0.04 to 0.71 ± 0.04 with $p = 0.034$; Table 3). *Z*-transformed objective measures of performance increased from −0.41 ± 0.92 in the low attention to

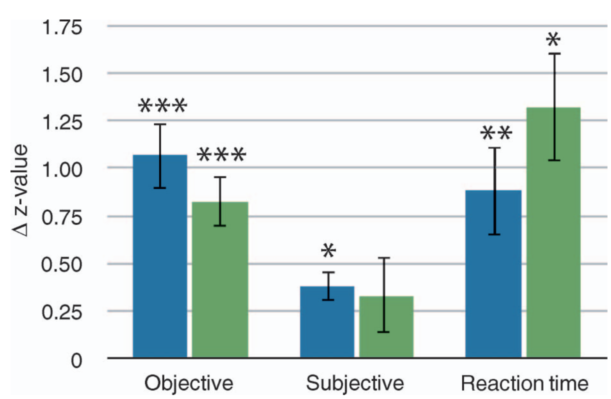

Figure 6. Experiment 2: Attention-related change in z-standardized objective and subjective measures of performance and reaction time in the one response condition (blue) and the two-response condition (green): High attention leads to a significant increase in objective measures of performance ($p < 0.001$ for both conditions) and a significant decrease in RT ($p = 0.026$ and $p = 0.008$ respectively), but only a significant change in subjective measures of performance in the one response condition ($p = 0.033$). Changes inobjective measures and RT are significantly larger than the ones in subjective measures ($p = 0.024$ and $p = 0.030$ for the one response condition and $p = 0.007$ and $p = 0.008$ for the two response condition).

0.41 ± 0.96 in the high attention condition ($p < 0.001$). The difference in z-transformed confidence between the low (−0.15 ± 0.70) and high (0.18 ± 1.05) was not significant ($p = 0.132$). The influence of attention on z-transformed percentage correct responses was larger than on z-transformed confidence ratings ($p = 0.024$; Figure 6).

Again, confidence increases more or less linearly with performance (Figure 7), both in the one-response condition under low ($r = 0.98$; $p < 0.001$) and high attention ($r = 0.99$; $p < 0.001$) as well as in the two-response condition under low ($r = 0.99$; $p < 0.001$) and high attention ($r = 0.99$; $p < 0.001$).

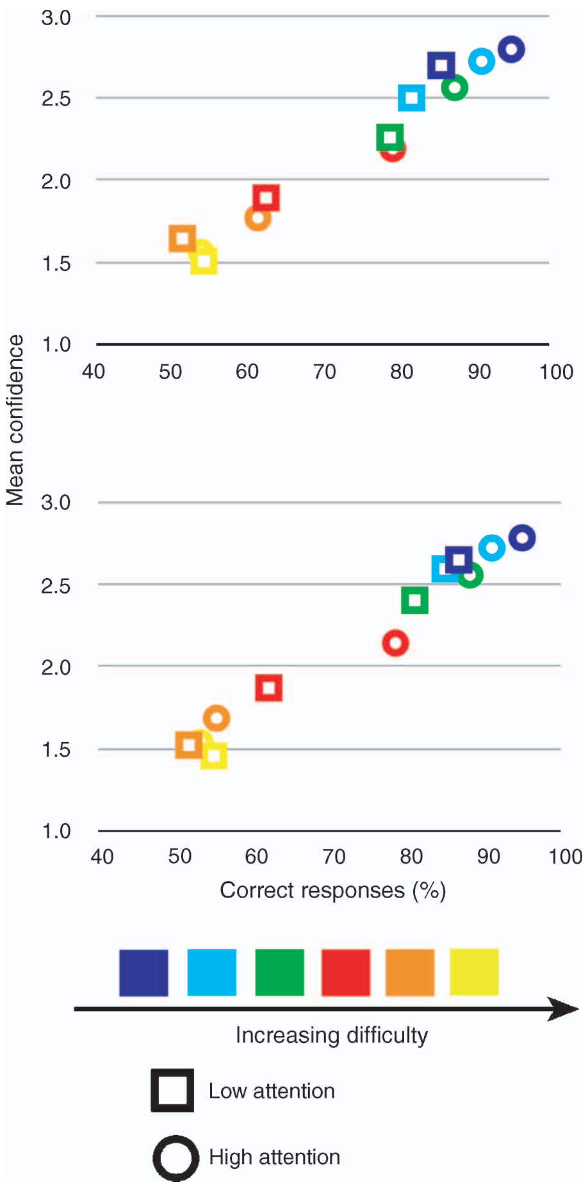

Figure 7. Experiment 2: Correlation between performance (% correct responses) and mean confidence over the six different difficulty levels: Mean confidence and mean percentage of correct responses, averaged over 7 subjects, for each individual difficulty level (1°, 2°, 4°, 8°, 10°, 16°) show a high correlation for the one-response condition (top) under low ($r = 0.98$; $p < 0.001$) and high attention ($r = 0.99$; $p < 0.001$) and for the two- response condition (bottom) under low ($r = 0.99$; $p < 0.001$) and high attention ($r = 0.99$; $p < 0.001$).

The significant correlation between performance and confidence judgments indicate that the larger influence of attention on objective over subjective measures is not solely due to an overall lack in awareness of performance, again indicating an overconfidence when judging in the (near) absence of attention relative to the confidence in judgment to attended stimuli.

Reaction times decrease under high attention in the one response condition (0.809 ± 0.490 s for correct responses under low and 0.581 ± 0.374 s under high attention; $p = 0.008$) as well as the two response condition (0.635 ± 0.280 s under low and 0.455 ± 0.101 s under high attention; $p = 0.029$). In both conditions, the influence of attention on z-standardized RT was larger than on z-standardized confidence judgments ($p = 0.030$ in the one-response condition and $p = 0.008$ in the two-response condition). To test the influence of confidence on reaction times, we again computed RT for each level of confidence separately. For similar levels of confidence, RT for non-attended stimuli increase by 130–176 ms in the one-response condition, corresponding to a 17–49% increase in RT relative to the high attention condition ($0.030 > p > 0.004$; see Figure 8) and by 125–223 ms in the two-response condition, corresponding to a 20–42% increase in RT relative to the high attention condition ($0.032 > p > 0.003$; see Figure 8).

Measures of performance did not differ between the one-response and the two-response conditions (for percentage correct responses in the high attention condition, $p = 0.597$, and in the low attention condition $p = 0.414$; for $AUC_{objective}$ in the high attention $p = 0.614$, and $p = 0.388$ in the low attention condition). Equally, measures of confidence did not differ between response conditions (for mean confidence in the high attention condition $p = 0.851$, and $p = 0.397$ for the low attention condition; for $AUC_{subjective}$ in the high attention $p = 0.192$, and $p = 0.350$ in the low-attention condition). Likewise, the difference in RT did not reach significance for each confidence level and attentional manipulation (for the high attention $0.313 > p > 0.189$ and for the low attention condition $0.475 > p > 0.155$).

Whether participants responded by giving the orientation judgment and the confidence judgment at the same time (one-response condition) or sequentially (two-response condition), neither objective nor subjective measures were affected significantly. Yet the influence of attention on RT for similar levels of confidence remains strong. The attentional manipulation in Experiment 2 strongly changes objective measures of performance (percentage correct responses and $AUC_{objective}$) (Tables 1 and 3) but has a much weaker influence on $AUC_{subjective}$ (Table 3) and on confidence level (Table 2). Z-standardized analysis confirms this stronger influence of attention on objective than on subjective measures. As

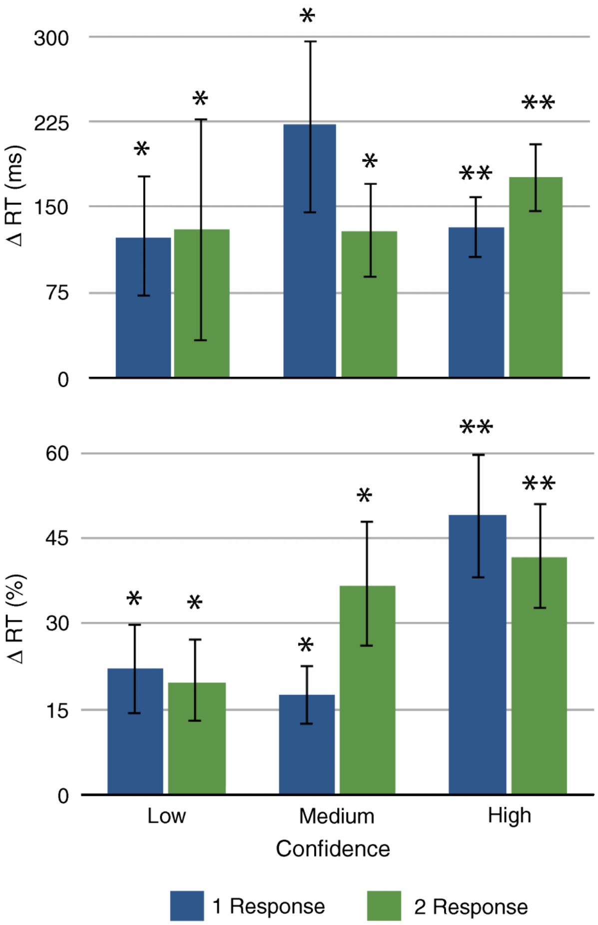

Figure 8. Experiment 2: Increase in RT for confidence judgments for n = 7 subjects (similar levels of confidence) under reduced spatial attention as the absolute difference between condition with low and high attention condition in milliseconds (left) and as RT percentage relative to the condition under high attention (right). [* depicts $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; error bars depict standard error of mean].

confidence is a good predictor of performance within a constant attentional condition, this reflects a relative overconfidence in non-attended judgments. Furthermore, if the influence of attention on subjective measures was just weaker albeit closely related to the one on objective measures, we would expect a relationship between the attentional shift in both $AUC_{objective}$ and $AUC_{subjective}$. That is, participants who show a weak influence of attention on $AUC_{objective}$ also should show a weak influence of attention on the corresponding subjective measure. We did not find such a positive correlation between the individual attentional shift in either AUC (Experiment 1: $r = -0.35$; $p = 0.367$; Experiment 2 (one response): $r = -0.14$; $p = 0.765$; Experiment 2 (two responses): $r = -0.27$; $p = 0.556$; population analysis over all 3 experiments: $r = 0.13$; $p = 0.550$). Hence, the influence of attention on subjective performance cannot be merely attributed to the shift in objective performance.

Discussion

We investigated the influence of attention on both subjective confidence and objective performance measures using two different attentional manipulations. No matter whether the manipulations of attention resulted in a weak (Experiment 1) or in a substantial (Experiment 2) difference in performance, confidence levels for attended and unattended stimuli showed (nearly) no changes. This argues against the hypothesis that withdrawing attention from a stimulus location primarily decreases confidence. There is no evident difference between confidence for attended and less or non-attended stimuli. As this negative result does not reflect the actual performance difference between attentional conditions, it may either be interpreted as overconfidence in unattended stimuli or as a lack of confidence in attended stimuli. In contrast, within one attentional condition, stimulus-induced changes in performance were accurately reflected in confidence measures.

Even under presumably constant attention conditions, objective and subjective measures can be dissociated under certain conditions, for example, in a metacontrast masking paradigm at certain SOAs (Lau & Passingham, 2006). Similarly, for different difficulty levels easy decisions tend to lead to underconfidence and difficult decisions to overconfidence (Baranski & Petrusic, 1994, 1999; but see Olsson & Winman, 1996). In its most straightforward interpretation, this somewhat counterintuitive result is a consequence of a combination of a floor and a ceiling effect: Underconfidence for easy conditions results from some residual subjective uncertainty at (near-)perfect performance, while even at guessing levels observers occasionally report being very confident of their decision (Baranski & Petrusic, 1999). In line with such data, in our paradigm observers are more likely to be overconfident, when less attention is allocated to a stimulus location. Changes of confidence levels are smaller than changes in actual performance with and without attention. This effect reaches significance only for the largest performance difference (Experiment 2, one-response condition), apparently reflecting observers' tendency to keep overall confidence more constant than the actual performance might suggest. ROC measures for subjective confidence ($AUC_{subjective}$) similarly show an influence of attentional manipulation only for large shifts in objective measures (Experiment 2), but not weak ones (Experiment 1). Without direct correlation between both measures on an individual level, this provides more evidence for a dissociation between objective and subjective measures of performance. The weak influence of attentional manipulation on confidence suggests that directing attention to a target may not affect the way some of its attributes are consciously experienced. Using solely objective measures, previous studies provided contradictory evidence: Selective attention does not affect perceived brightness of stimuli (Prinzmetal, Nwachuku, Bodanski, Blumenfeld, & Shimizu, 1997) or color appearance (Blaser, Sperling, & Lu, 1999), but exogenous transient attention increases the apparent contrast of a stimulus (Carrasco, Ling, & Read, 2004). This discrepancy illuminates the need to integrate different measures of performance, both objective and subjective ones, into attention research. Only then the extent to which these results rely on the exact measure or on the experimental methodology used to manipulate attention can be assessed.

The lack of difference between the one- and the two-response condition argues against the view that decisions about confidence are reached substantially later in time than the perceptual decision itself (Baranski & Petrusic, 1998). Actually, the only significant difference between confidence levels is found in a one-response condition ruling out the possibility that the lack of change in confidence is a consequence of the subject's response in the one-response condition preceding a subsequent meta-decision about confidence. Instead, the subjective feeling of confidence may be present and accessed at the time of the decision.

In contrast to the weak or altogether absent influence of attention on the overall level of confidence, we find substantial differences in reaction times for similar levels of subjective confidence. This implies that reaction times cannot be used as a measure of awareness as assayed by confidence without controlling for the effects of attention: For different amounts of spatial attention, substantially different levels of reaction time are associated with similar levels of confidence. The importance of carefully controlling attentional effects in studies of awareness has already been highlighted (Macknik & Martinez-Conde, 2007). Interestingly, a possible dissociation between reaction times and confidence-related measures has been reported in rats in an olfactory perceptual discrimination task (Uchida, Kepecs, & Mainen, 2006; Uchida & Mainen, 2003). Our study shows that the decrease in reaction time in the presence of attention is in general unrelated to the aspect of conscious awareness that is probed by confidence measures. Hence, the reaction time disadvantage in the near absence of spatial attention cannot be explained by a shift toward lower confidence but instead reveals a signature of an attentional mechanism not related to stimulus awareness. This further buttresses the claim that attention and awareness are distinct, although related, processes (Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006; Koch & Tsuchiya, 2007; Macknik & Martinez-Conde, 2004; Merikle et al., 2001).

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