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# The Influence of Endogenous and Exogenous Spatial Attention on Decision Confidence

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# 1. Summaries

## 1.1. English Summary

How much we trust our own decisions, knowledge or perceptions influences our behavior in many everyday situations. Normally the confidence we have in our decisions is rather accurate, but under certain circumstances the subjective evaluation of a decision and its objective quality can differ heavily. Subjectively over- or underestimating the quality of decisions can lead to disadvantageous behavior. Little is known about how this feeling of confidence about a decision is generated. Is it computed automatically with the decision or does it arise in a different process?

This thesis is based on a publication that contributed to the investigation of this question by comparing the influence of two different forms of spatial attention on decision confidence. Visual spatial attention is a cognitive mechanism that serves to select parts of the visual field, leading to more accurate decisions about the attended items. It can be either voluntarily controlled (endogenous) or reflexively driven by external events (exogenous). In an orientation-matching task participants performed better in both attentional conditions than in a control condition without directed attention. Additionally, we found that only endogenous, but not exogenous attention led the subjects to overestimate the quality of their performance. The possible implications of this “relative overconfidence” were discussed with respect to the theoretical framework of spatial attention and decision confidence. The present findings support the idea that decision confidence is generated in a distinct metacognitive process. Possible ideas for further neurophysiological research are proposed. The thesis concludes with an attempt to integrate the discussion into a broader context of medical research on certain neuropsychiatric symptoms and conditions.

## 1.2. Deutsche Zusammenfassung

Wie sehr wir unserem eigenen Wissen, unseren eigenen Wahrnehmungen oder Entscheidungen vertrauen, beeinflusst unser Verhalten in vielen Alltagssituationen. Normalerweise ist dieses Vertrauen in die eigene Entscheidung einigermaßen angemessen, unter bestimmten Voraussetzungen jedoch können die subjektive Bewertung einer Entscheidung und deren tatsächlich objektivierbare Qualität erheblich voneinander abweichen. Die Qualität einer Entscheidung subjektiv zu über- oder unterschätzen kann zu sehr unvorteilhaftem Verhalten führen. Aber wie entsteht dieses Gefühl zu einer Entscheidung überhaupt? Wird es automatisch in einem gemeinsamen Prozess - zusammen mit der Entscheidung selbst - berechnet oder entsteht es in einem getrennten Prozess?

Diese Dissertation basiert auf einer Veröffentlichung, die zur Beantwortung dieser Frage beitrug, indem sie den Einfluss von zwei verschiedenen Formen räumlicher Aufmerksamkeit auf das Vertrauen in die eigene Entscheidung verglich. Räumliche Aufmerksamkeit ist ein kognitiver Mechanismus, der es ermöglicht, genauere Entscheidungen über jene Teile des Blickfeldes zu treffen, denen die Aufmerksamkeit gewidmet wird. Eine der beiden Formen wird willentlich kontrolliert (endogene räumliche Aufmerksamkeit), die andere wird unwillkürlich von äußeren Reizen gesteuert (exogene räumliche Aufmerksamkeit). In einer Orientierungsangleichungsaufgabe zeigten Probanden unter beiden Aufmerksamkeitsbedingungen bessere Leistungen als unter der Kontrollbedingung ohne gerichtete Aufmerksamkeit. Zusätzlich konnte gezeigt werden, dass die Probanden die Qualität ihrer Leistung nur in der endogenen, nicht aber in der exogenen Aufmerksamkeitsbedingung überschätzten. Mögliche Folgerungen aus diesem „relativen Übervertrauen“ werden im Rahmen des theoretischen Hintergrundes der räumlichen Aufmerksamkeit und des Vertrauens in die eigene Entscheidung diskutiert. Weiterhin wird diskutiert, inwiefern die Ergebnisse dafür sprechen, dass das Vertrauen in die eigene Entscheidung in einem eigenen, metakognitiven Prozess bestimmt wird. Mögliche Ideen für weitergehende Forschung in der Neurophysiologie werden diskutiert. Und schließlich werden die Befunde in einen

größeren Zusammenhang mit bestimmten neuropsychiatrischen Symptomen und Krankheiten gestellt.

# 2. Theoretical Background

## 2.1. Introduction

### 2.1.1. Confidence

Every day we make a multitude of decisions. Each decision is associated with a feeling of how good or bad that decision was. The same applies to knowledge that we have or information that we perceive. This sensation influences the way we make decisions in many everyday situations. For example, if you think you see a deer running in front of your car you have to decide whether you are confident enough in your perception to brake and risk being rear ended. It is very important to estimate accurately the quality of the knowledge or evidence to make a decision that maximizes one's potential benefit. This has made confidence a subject of extensive research.

What is the definition of confidence, especially as opposed to uncertainty? Pouget et al. [1] argue that uncertainty refers to all probability distributions in neural circuits which are not choice-dependent, while confidence on the other hand is choice-dependent and reflects the subject’s estimation of the probability to be right given the sensory evidence. However, decisions can be made in very different contexts. In perceptual decisions we decide for example which of two presented lines is longer [2], while in general knowledge tasks we decide which answer is correct [3,4]. But also many everyday actions include a decision, for example when choosing between different food items[5]. We can report a feeling of confidence about all of these types of decisions. It has been shown that, in general, confidence correlates with the objectively assessed probability to be right [6,7], but different types of decisions can distort this correlation [3]. This is not the only factor affecting confidence: Task difficulty, or rather the performance level, influences confidence ratings. Subjects tend to be overconfident when the task is difficult (and their performance poor) and underconfident when the task is easy (and their performance good) [7,8]. Moreover, feedback on performance and confidence enhances the accuracy with which subjects rate their confidence [9]. In addition to these factors, individuals differ in the way they use confidence measures [10]. Research on cognitive awareness in humans has shown that performance and confidence sometimes can differ heavily [11]. An extreme example is “blindsight” where patients with lesions in the visual cortex report that stimuli are not visible and they were only guessing, while performing clearly above chance level in visual tasks [12,13]. On the contrary, patients with Anton's Syndrome claim they can see while an objective assessment shows their functional blindness [14,15].

The number of factors that can lead to an inaccurate subjective evaluation of a choice and the size of this inaccuracy might suggest that confidence results from a process which is distinct from the decision process itself. However, there is still a debate in research on decision confidence about the "nature" of confidence. It is unclear whether decision confidence arises automatically with every decision in the same process, and can therefore be read out directly from the perceived evidence, or whether it is generated by a distinct, metacognitive process.

Metacognition has been described as a higher-level control and monitoring mechanism of one's perception or memory [16], and is often just explained as "thinking about thinking"[17]. In the case of decision confidence this would mean that one does not just report a certain confidence value that was automatically computed together with the decision. It would rather mean that there is a second, distinct process where you "think" about how good your performance was. If this is really the case this second process could possibly also take other information into account in addition to the physical evidence. Therefore, the most important evidence in favor of a distinct process for confidence are the many above-mentioned factors that affect decision confidence but not the actual performance.

Most of the evidence in favor of a simple read-out process comes from animal research. In 2008 Kepecs et al.[18] argued that confidence is an inherent part of every decision. They found neurons in the rat orbitofrontal cortex that corresponded to confidence behavior. The rats had to perform an odor discrimination task. The authors used the rats' willingness to wait for reward as a measure of confidence in their decision. They were able to show that corresponding to the rats' behavior, neurons fired in a way that could be predicted by simple confidence models that only take sensory evidence into account. Therefore, the authors argued that decision confidence is a simple process that comes with every decision and does not require a higher-level process. Similarly, Kiani & Shadlen [19] found neurons in the lateral intraparietal sulcus (LIP) of monkeys that represented both information about the decision itself and also the confidence in this decision. They argued that this finding provides evidence for a “low-level explanation” for decision confidence, ruling out the need for a metacognitive explanation. If this applies to humans, then giving a confidence rating would only be a simple read-out of this inherent feature of the decision.

Modelling studies also claim that confidence can be read out directly from the sensory evidence on which the perceptual decision was based. Indeed it has been shown that manipulating the evidence influences confidence ratings [20]. These computational models provide a strikingly accurate fit for behavioral decision and confidence in perceptual tasks (for example, see [11]). While this does not necessarily mean that confidence ratings are a strict statistical read-out of the perceived sensory evidence, it implies that the mental computation of confidence takes only sensory evidence into account.

The present study offered a novel approach to distinguish between the two alternative conceptions using a spatial attention paradigm in human psychophysics in which attention was either reflexive, i.e. controlled by an external stimulus, or purposefully controlled by the observer. This allowed us to compare the effects of bottom-up versus top-down-driven processing on decision confidence using the same basic task. This made it technically relatively easy to possibly link confidence to higher or lower level neural processes.

### 2.1.2. Spatial attention

At any moment, our brain has to deal with a huge amount of sensory information. Not only does it have to recognize what we are perceiving, but it also has to decide which of this information is relevant. Visual spatial attention selects specific locations in the visual field and prioritizes the processing of information at these locations. This can be achieved by directly looking at that specific location, object or person. This is called overt spatial attention, as opposed to covert attention where the focus of attention is independent of visual fixation. Both forms of attention improve the processing of information in the attended part of the visual field compared with information in unattended parts[22–25]. For example, attention facilitates the detection of sinusoidal gratings when presented at low contrast levels [26], and improves performance in orientation discrimination tasks, where subjects have to decide whether such a grating was tilted to the left or right or whether it was horizontally or vertically oriented [27,28].

Research on covert spatial attention has typically used paradigms in which cues guide the orienting of attention and some reaction task has to be performed on stimuli appearing either in attended or unattended parts of the visual field. One can differentiate two types of cues: central cues are presented in the center of a display, whereas peripheral cues are presented at or near the stimulus location. The former guide voluntarily controlled (endogenous or top-down attention), while the latter elicit reflexive (exogenous or bottom-up) attention[29–31].

The effects of spatial attention have been investigated also in various other tasks such as letter discrimination[25] or motion discrimination [32]. The underlying mechanisms [33,34] and corresponding neural networks [35–37] have been studied extensively. However, the question of how spatial attention affects confidence has received little interest. To the author's knowledge only two studies have addressed this question so far [38,39]. Both were limited to endogenous attention and found contradictory results. The present study compared the two forms of attention to test whether decision confidence represents a higher cognitive process that should be more affected by endogenous attention, or whether it rather reflects a low level sensory process. In the latter case we expected either no difference between both types of attention or a stronger effect of exogenous attention.

## 2.2. Contribution of the study

The present study investigated the influence of the two different forms of spatial attention on both objective performance and subjective confidence in a perceptual decision task. This was done using an orientation matching paradigm. Differentiation between endogenous and exogenous attention was ensured using the well-documented difference in stimulus onset asynchrony (SOA) between cue and test stimulus: Endogenous attention is most effective at 300-500 ms after a cue, whereas the corresponding time window for exogenous attention ranges from about 90-120 ms [29,30,40,41]. Performance was measured as the accuracy with which subjects could reproduce the orientation of a visual stimulus (a sinusoidal grating). Confidence was measured with a visual analogue scale (VAS).

How might this study contribute to determining whether decision confidence arises from the same process as the decision itself or from a distinct process? First, in order to make any statement about confidence, both forms of attention need to have a comparable effect on the decision process itself. It can be assumed that this is the case if the following two criteria are met:

1. Both endogenous and exogenous attention enhance task performance.
2. The increase in performance is of comparable size for both forms of attention.

Second, if these preconditions are met, the following hypotheses and corresponding predictions can be formulated and tested:

1. Hypothesis: Decision and decision confidence are distinct processes. Prediction: The effects of endogenous and exogenous attention differ.
   Explanation: If either endogenous or exogenous attention affect confidence in a way that cannot solely be explained by the attentional effect on performance in the task, this would argue in favor of a second process for confidence which would be selectively influenced by only one of the two forms of attention.
2. Alternative hypothesis: Decision and decision confidence arise from the same process.
   Predictions: a) The increase in performance with attention is correctly reflected in the confidence ratings.
   b) The effects of endogenous and exogenous attention on decision confidence are comparable.
   Explanation: If decision and decision confidence are derived from the same process, both endogenous and exogenous attention affect performance and confidence in the same way.

The analyses revealed that both criteria were met: both attention manipulations led to comparable performance improvements. However, only endogenous, but not exogenous, attention led to an increase in decision confidence. Further analyses suggested that endogenous attention led to relative overconfidence. These findings supported Hypothesis 1, suggesting that different processes contributed to decision making and performance, respectively.

### 2.3. Discussion

The results of this study support the idea that decision confidence is computed in a different process than the decision itself. However, the results can only be interpreted with respect to confidence in perceptual decisions, and methodological and theoretical caveats have to be taken into account. Methodologically it has to be acknowledged that the distinction between endogenous and exogenous attention relies only on previous research about the different time courses of the two forms of attention[30,40,41]. The different stimulus onset asynchronies between the different experimental conditions could have distorted the results by giving subjects the feeling of being rushed or having enough time to prepare for a trial influencing their subjective feeling of the quality of their performance. In addition, it should be mentioned that there is no way of determining whether attention really had an effect on the confidence process itself or the process of reporting confidence. However, combined with other findings the results do allow interesting conclusions.

First, until fairly recently much of the discussion about confidence concerned its timing. It has been unclear whether confidence arises simultaneously with the decision, only taking sensory evidence into account that was known at this time point (decisional-locus model [42]), or whether it arises after the decision, possibly taking sensory evidence into account that became available after the decision (post-decisional-locus model [43]). In contrast, a recent theory proposed that confidence could be obtained in a different, separate process that could be affected selectively without changing the amount of sensory evidence [38,44,45]. Our study adds supporting evidence for this hypothesis. This argues in favor of shifting the perspective away from the question of when confidence arises to the question of how the decision process and the generation of confidence are connected and how they interact. However, it might still be interesting to investigate the onset of the confidence process and when it is completed.

Second, even if decision and decision confidence are different processes, that does not necessarily mean that confidence is a metacognitive process, as which it is interpreted in many publications [46,47]. In our study it is not exogenous (stimulus-driven) attention that leads to overconfidence but endogenous (cognitively-controlled) attention. Together with the finding that subjects are more overconfident in general knowledge tasks than in perceptual tasks [3] and that neural correlates of confidence were found in prefrontal areas [48] (which are important for cognitive control [49]), this strongly suggests that confidence is more closely connected to higher-level cognitive mechanisms than to perceptual processes. Further research could assess the possible correlation between overconfidence and metacognitive abilities (for example, see [50]), which would suggest that confidence might indeed be an aspect of metacognition.

Third, it might be of interest to investigate the neural networks that mediate the selective influence of endogenous attention on decision confidence. Arguably, endogenous and exogenous attention are linked to different neural networks [36]. Interestingly the neural network for endogenous attention overlaps with the neural network linked to confidence [51,52] in the intraparietal sulcus and the pulvinar nucleus of the visual thalamus [53,54], which constitute brain regions worth further investigation.

Finally, it could be attempted to extend the findings of this study to other aspects of confidence such as confidence in knowledge. If this were successful it might help assessing the accuracy of confidence ratings and possibly open ways to reestablish coherence between objective performance and subjective confidence. Knowing the accuracy of confidence could help in a number of different fields. For example in eyewitnesses it could be used to estimate the trustworthiness of their reports [55]. Reestablishing coherence between objective performance and subjective confidence would also be useful in the medical field. It would allow a better understanding and maybe eventually even a treatment of conditions that show dissociations between objective behavior and its subjective evaluation, for example blindsight or Anton's Syndrome. Further examples are more frequently found with neuropsychiatric symptoms such as neglect, where patients claim to see the entire visual field but ignore half of it in their behavior, or hallucinations where patients are sure to see or hear something that cannot be observed objectively. At first this might sound far-fetched but neurophysiological studies have linked both hallucinations [56] and confidence in perceptual decisions [57] to activity in the frontal lobes. While that may be too imprecise to suggest a connection, both hallucinations [56] and memory confidence [58] have also been linked to activity in the anterior cingulate. Moreover, hallucinations have been linked to cognitive disorders, for example in Parkinson's patients [59]. Our results suggest that higher cognitive processes can lead to distortions between performance and confidence.

Neglect is of particular interest because it is seen as a disturbance of the distribution of spatial attention [60–62]. It could be investigated if in patients with this symptom the input from the attentional network to perceptual processes is deficient while the inputs to subjective evaluation of the environment remain intact.

Overall, using a novel methodological approach to study the connection between attention and confidence, this study supported a metacognitive view of confidence. Its findings point to interesting paths for future investigations both in human psychophysics and in neurophysiological and clinical research.

## 3. Published Manuscript

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# The Influence of Endogenous and Exogenous Spatial Attention on Decision Confidence

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**Spatial attention allows us to make more accurate decisions about events in our environment. Decision confidence is thought to be intimately linked to the decision making process as confidence ratings are tightly coupled to decision accuracy. While both spatial attention and decision confidence have been subjected to extensive research, surprisingly little is known about the interaction between these two processes. Since attention increases performance it might be expected that confidence would also increase. However, two studies investigating the effects of endogenous attention on decision confidence found contradictory results. Here we investigated the effects of two distinct forms of spatial attention on decision confidence; endogenous attention and exogenous attention. We used an orientation-matching task, comparing the two attention conditions (endogenous and exogenous) to a control condition without directed attention. Participants performed better under both attention conditions than in the control condition. Higher confidence ratings than the control condition were found under endogenous attention but not under exogenous attention. This finding suggests that while attention can increase confidence ratings, it must be voluntarily deployed for this increase to take place. We discuss possible implications of this relative overconfidence found only during endogenous attention with respect to the theoretical background of decision confidence.**

Spatial attention is a fundamental aspect of everyday life that helps us carry out efficient perceptual decisions. The literature differentiates between two forms of spatial attention: endogenous (or top-down) attention is voluntary deployed and sustained[1], exogenous (or bottom-up) attention however, occurs reflexively[2]. 'Reflexive' and 'voluntary' in this context refer to the finding that peripheral cues (i.e. placed near or directly at the experimental target stimulus) that are used to guide exogenous attention cannot be ignored or interrupted voluntarily[2,3], whereas central cues (i.e. placed away from the target, often around the fixation point) for endogenous attention rely on the validity of the cue and the willingness or cognitive control of the subjects to deploy their attention[3]. Additionally, time courses are different between the two forms of attention: Exogenous attention is very rapidly deployed. It takes only 90–120 ms until an attention effect with a peripheral cue can be detected, yet benefits only last until 300 ms following cue onset[1,4,5]. Endogenous attention on the other hand is engaged only 300–500 ms after onset of a central cue[1,4,5] but can be kept at one location for at least 1200 ms[1]. Therefore, due to the different phenotypes of these two forms of spatial attention they are believed to arise from distinct neuronal mechanisms[6,7] and might differently affect perceptual decision making. Previous research established that endogenous attention can increase perceptual decision accuracy[8–11]. Whether exogenous attention has a similar effect is not well understood. A primary goal of this study was therefore to directly compare the effects on endogenous vs exogenous spatial attention on perceptual decision accuracy.

A second goal was to understand the benefits of attention on decisions beyond accuracy, namely on decision confidence. Decision confidence describes the probability that a decision is correct or accurate as estimated by the subjects themselves given the evidence available[12]. People can intuitively report confidence with numerical ratings[13] or on a continuous scale[14,15]. Recent neurophysiological studies have argued that this is so easy because an evaluation of the quality of the evidence is inherent to every decision process[16,17]. Several models of decision confidence therefore assume that the sensory evidence (i.e. the information about the stimulus that is available

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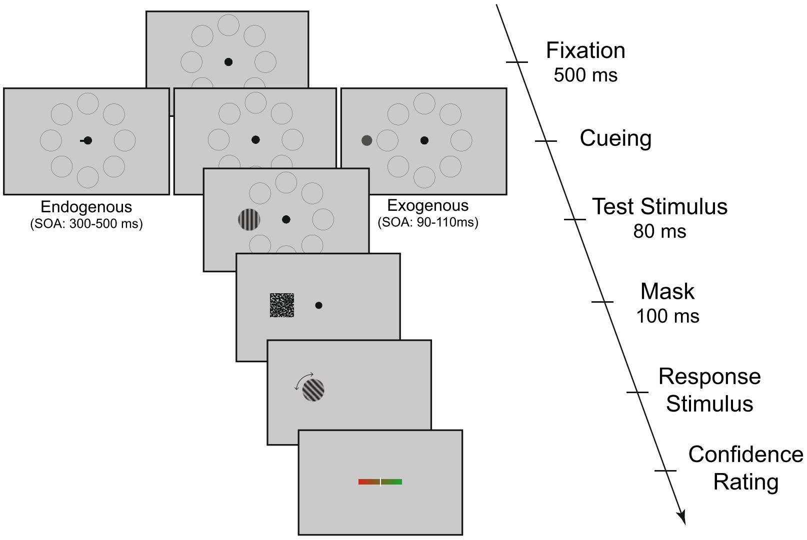

**Figure 1.** Orientation matching task. Participants attempted to reproduce the orientation of a grating test stimulus using arrow keys to turn the response stimulus. Afterwards they reported the confidence in their decision on a continuous scale, again using arrow keys. During the fixation and cueing period eight grey circles indicated the possible locations at which the grating could appear. The average trial time was the same across the three conditions and the only difference in the trial sequence between conditions was during the cueing period. In the endogenous condition a foveally presented "Posner" line pointed for 300–500 ms to the location where the stimulus would appear. In the exogenous condition a small grey dot was briefly (16 ms) flashed immediately next to the location of the target. Stimulus onset asynchrony (SOA) between cue and target onset was 90–110 ms in the exogenous condition. Both cues were 100% valid.

to the subject) is the major input to the computation of confidence ratings[14, 16, 18–21]. In simplified terms these models compute a decision variable based on accumulated sensory evidence which determines the choice the subject makes in the task. Decision confidence is then derived from the strength of the sensory evidence for the respective decision. Indeed, confidence is coupled to the objective quality of a decision (performance)[22, 23], but it can also be modulated by a number of contextual factors. For example task type[24], task instruction[23], feedback[25], decision time[26] and individual differences[27] all influence decision confidence. Recent psychophysical and neurophysiological studies have even suggested a separate process for the calculation of confidence[13, 28, 29].

Might spatial attention influence perceptual confidence? If confidence and performance are a result of the very same brain process, one might expect a positive effect of attention on both. If however, confidence and performance arise from separate processes, attention may affect both differently. To the authors' knowledge only two studies so far have investigated the influence of spatial attention on perceptual confidence. A study by Wilimzig *et al.*[30] reported that spatial attention has no influence on decision confidence. In contrast, Zizlsperger *et al.*[29] found that both spatial and feature-based attention have larger effects on confidence than on performance, and may even cause over-confidence. They argued therefore that decisions and decision confidence are likely to arise from at least partially separate brain processes, which are differently influenced by endogenous attention.

In this study we provide supporting evidence for the findings of Zizlsperger *et al.* on the effects of endogenous attention. In addition, we show that this finding cannot be extended to exogenous attention. While both endogenous and exogenous attention enhanced performance, only endogenous attention increased confidence ratings. We show that this increase could not be explained solely by enhanced performance, which indicates relative overconfidence resulting from endogenous attention.

Therefore, our results demonstrate that it is only the voluntary (endogenous) form of attention that affects both performance and confidence while the reflexive (exogenous) form of attention affects performance but not confidence.

## Results

28 participants (23 were analyzed, see Methods) performed an orientation matching task with sinusoidal gratings under three different conditions: endogenous attention with central cueing, exogenous attention with peripheral cueing and a control condition without cueing. Every participant performed 100 trials per condition. At the end of each trial, participants gave a confidence rating about their performance in the respective trial (Fig. 1).

To assess the influence of attention, we initially compared whether performance and confidence differed between a condition without cue and endogenous and exogenous cueing. Figure 2a shows mean values for performance in every subject. Performance was more accurate when attention was endogenously or exogenously cued compared with the no-cue condition. To quantify this effect and summarize it across all subjects, a one-way repeated-measures ANOVA confirmed a significant effect of attention condition on performance (F (df = 2, 44) = 7.48, p = 0.002). Compared to the no-cue condition (27.5° ± 9.95°), performance was significantly higher under endogenous attention (23.6° ± 9.41°) (t (df = 22) = 3.5, p = 0.006). Similarly, performance was significantly

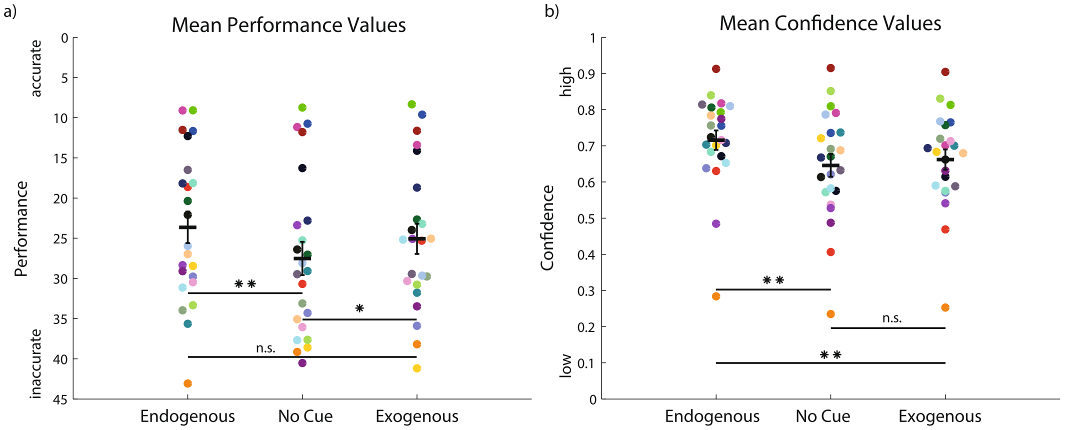

**Figure 2.** Performance and confidence compared across attention conditions. (**a**) Distribution of subject-averaged performance data. Every dot represents the mean performance of one participant in the respective condition. Every color corresponds to one participant showing how the individual participant contributed to the observed result. Both endogenous (left) and exogenous (right) attention conditions have greater means (grand average) than the no-cue condition (center). (**b**) Distribution of subject-averaged confidence data. Note the similarity of the exogenous and no-cue distributions. Means are indicated in black. Levels of significance were computed using post-hoc comparisons following a one-way repeated-measures ANOVA on mean values of participants. Asterisks denote significant results of the post-hoc comparison; $^{**}p < 0.01$, $^{*}p < 0.05$, n.s.: not significant ($p > 0.05$). Error bars are standard error of the mean.

better under exogenous attention (25.08° ± 9.03°) compared to the no cue condition (t (df = 22) = 2.87, p = 0.027). Although there was a small trend for better performance under exogenous compared to endogenous attention, the difference was not statistically significant (t (df = 22) = 1.35, p = 0.57).

For decision confidence a slightly different pattern was observed. The distribution for endogenous attention shows that mean confidence ratings were higher than in the other two conditions (Fig. 2b). As the distributions of confidence values were not normally distributed, we used a non-parametric Friedman test to statistically compare the effect of attention condition on confidence ratings. This gave a Chi-square value of 12.9 (df = 2, 44), which was significant (p = 0.002). Post-hoc comparison with Wilcoxon signed rank tests indicated a difference between median confidence in the no-cue condition (median = 0.67, mean = 0.65 ± standard deviation = 0.15) and in the endogenous attention condition (0.72, 0.72 ± 0.13) (Z = −3.25, p = 0.003). In addition, mean confidence in the endogenous attention was higher than in the exogenous attention condition (0.68, 0.66 ± 0.13) (Z = 3.41, p = 0.002). However, there was no difference between exogenous attention and no-cue conditions (Z = −0.91, p = 1). Thus, while both attention conditions enhanced performance, only endogenous cueing resulted in increased confidence ratings.

We then investigated whether attention changed the relationship between performance and confidence. To accommodate for the different distributions underlying the confidence vs performance measures, we binned single subject data into quintiles based on performance. In every participant the mean confidence rating for all trials in the respective performance quintile was calculated for every condition (Fig. 3a). A two-way (3 attention conditions x 5 performance bins) repeated measures ANOVA yielded main effects of attention (F (df = 2,44) = 11.75, p < 0.001) and performance (F (df = 4,88) = 45.25, p < 0.001), while there was no statistically significant interaction between both factors (F (df = 8, 176) = 1.73, p = 0.09). Hence, endogenous attention led to higher confidence ratings irrespective of the performance level. This showed that the increase in confidence with endogenous attention was not just a faithful reflection of enhanced performance, but rather that trials with equal performance showed higher confidence with endogenous attention than in the control condition. We call this a relative over-confidence. Exogenous attention led to higher performance but not to higher confidence ratings. Relative overconfidence was therefore found selectively for endogenous attention.

To further objectify the impression in Fig. 3a that endogenous attention led to an upwards shift of the performance-confidence relationship, a linear model was fit to the data for every participant for every attentional condition. On the results of the fitting parameters a repeated-measures ANOVA was conducted separately for slope (see Fig. 3b) and intercept (see Fig. 3c) of the fitted relationship. This showed that while there was no significant effect of condition on the slope of the linear fit (F (df = 2, 44) = 1.98, p = 0.1502), the intercept differed significantly between conditions (F (df = 2, 44) = 14.4, p < 0.0001). Multiple comparisons revealed that the endogenous condition had a significantly higher intercept than both no-cue (t (22) = 4.57, p < 0.001) and exogenous conditions (t (22) = 3.5, p = 0.006). Again there was no difference between no-cue and exogenous condition (t (22) = −2.14, p = 0.13). We therefore concluded that endogenous attention led to an upward shift of the performance-confidence relationship leaving the slope of the relation intact. In contrast, exogenous attention left this relationship unaffected. This analysis showed that the relative overconfidence we found for endogenous attention was not just an effect of binning the data. More elaborate statistical analyses techniques examining interactions or using performance as covariate (see Supplementary Analysis S1) confirmed these results.

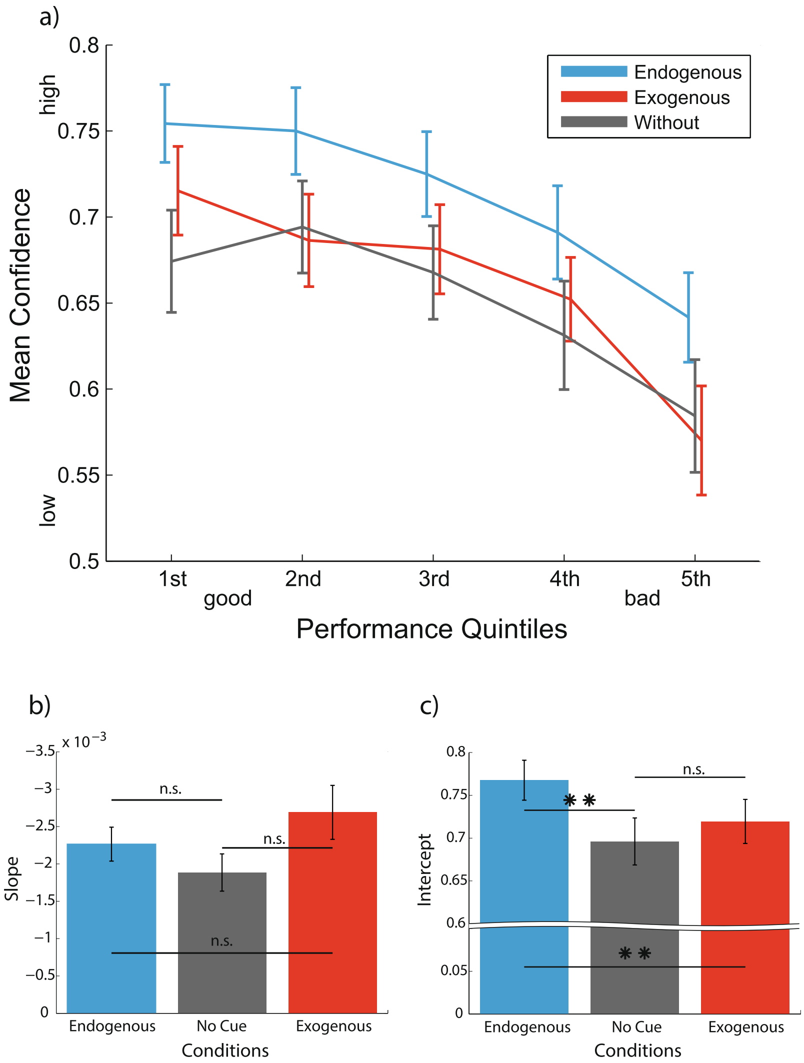

**Figure 3.** Relationship between confidence and performance. (**a**) Mean confidence is higher in the endogenous attention condition for a wide range of performances. For this plot we binned single subject data into quintiles based on performance. Shown is the grand average for confidence in the respective performance quintile. Error bars are standard error of the mean. (**b–c**) A linear model was fit to the data for every participant for every attentional condition. Shown are the mean values for the slope (**b**) and the intercept (**c**) of the linear fit for every condition respectively. Asterisks denote significant results of the post-hoc comparison; $^{**}p < 0.01$, $^{*}p < 0.05$, n.s.: not significant ($p > 0.05$). Error bars are standard error of the mean.

Finally we wanted to confirm that the correlation between performance and confidence was also not just an effect of artificial binning. Therefore, we calculated Spearman's rho for every participant and ran a one-sample t-test across participants. This analysis confirmed that in every condition the correlation was statistically significant (no-cue: mean $= -0.18 \pm$ standard deviation $= 0.12$, $t(22) = -7.39$, $p < 0.001$, endogenous: $-0.22 \pm 0.11$, $t(22) = -9.51$, $p < 0.001$, exogenous: $-0.23 \pm 0.12$, $t(22) = -9.33$, $p < 0.001$). However, using a one-way repeated measures ANOVA no statistical difference between conditions could be detected ($F(df = 2, 44) = 1.58$, $p = 0.22$). This analysis confirmed there was a correlation between performance and confidence and that this correlation was comparable across conditions.

One potential caveat of these results might be that confidence was heavily clustered in the high confidence range. There was a tendency in some of the subjects to report the highest possible confidence. However, even after exclusion of all trials in which the highest possible confidence was reported, neither the effect of attention condition on performance nor on confidence changed qualitatively. Results of the repeated-measures ANOVA and following multiple comparisons are given in Supplementary Tables S2–S5.

Another possibility was that participants might have performed or rated confidence differently depending on the difference between starting orientation of the response grating and the recalled stimulus. This might have been because it felt less difficult or was less difficult to match the orientations if this difference was small. If the orientation difference did influence performance or confidence, then we should have found that these measures were correlated to it. Therefore, we calculated this correlation using Spearman's rho for the 15 subjects for which the difference in orientation was recorded. We then performed a one-sample t-test across participants for the correlation with both performance and confidence. This yielded no significant result, neither for performance ($t\ (df = 14) = -0.16$, $p = 0.88$) nor for confidence ($t\ (df = 14) = 1.12$, $p = 0.28$). A mediating effect of the starting orientation is therefore unlikely.

A final confound that we examined was whether systematic differences in gaze position towards the cued location and therefore differential sensory input might account for the observed effects. Details of this analysis are provided in supplementary material (see Supplementary Figure S6). Gaze positions were not significantly directed towards the cued location in either of the attention conditions and therefore could not explain the observed differences between the attention conditions.

## Discussion

We compared the effects of endogenous and exogenous spatial attention on performance and confidence during a perceptual decision task. While both forms of attention led to an increase in performance, only endogenous attention also led to higher confidence ratings. Additionally we found that endogenous attention went, in some cases, beyond an accurate reflection of the enhanced performance and led to relative overconfidence. We found higher confidence with endogenous attention compared to the other conditions even when performance was poor. We showed that this effect could not be observed with exogenous attention, which did not change the relationship between performance and confidence.

Two previous studies examined the effects of endogenous spatial attention on decision performance and confidence and reported discrepant findings. Our work supports the findings by Zizlsperger *et al.*[29] that endogenous attention increases decision confidence more than performance. Wilimzig *et al.*[30] on the other hand observed no effect of attention on confidence. As Zizlsperger *et al.* already pointed out this might be because Wilimzig *et al.* instructed participants to answer "as fast and as accurate as possible" because this might have caused subjects to rate their confidence before the computation of it was completed. Furthermore, in Wilimzig *et al.*'s task performance increased with attention but confidence did not, perhaps due to a ceiling effect. If a task is very easy, participants still sometimes report low confidence. This has been attributed to "a general form of underconfidence"[22, 31] as little effort is required and successes can be attributed to the task design. This might have been the case in the attended condition in Wilimzig *et al.*'s task, since in their yes/no paradigm performance could never be below 50% correct. Zizlsperger *et al.* used 4 possible answers and we, at least in theory, provided 180, which substantially increased overall uncertainty and difficulty of the decision and therefore should have prevented a ceiling effect.

The dissociation between the effects of the two forms of attention adds supporting evidence for the hypothesis that endogenous and exogenous attention are separate processes[4, 32]. The neural networks for orienting spatial attention have not yet been identified unambiguously but it has been proposed that at least two different networks exist that might correspond to endogenous and exogenous attention[7] (but see refs 33, 34). The neural network for decision confidence[16, 20] overlaps at least in part with the network linked to endogenous attention in the intraparietal sulcus and in the pulvinar nucleus of the visual thalamus[35, 36]. How attention and decision confidence are integrated at the neuronal level is still largely unknown. The results of our experiments indicate that under the tested conditions, endogenous, but not exogenous, attention will influence decision confidence. Neurophysiological recordings could test for possible neural networks which are responsible for the effects of the different forms of attention.

Previous studies on decision confidence have focused on whether confidence is computed at the time point of the decision (decisional locus model, see for example ref. 18) or whether it takes information into account that was perceived after the decision (post-decisional locus model, see for example ref. 37) (for a review see ref. 38). However, these models assume that confidence represents the probability of the decision being correct and can therefore in some way be read out from the sensory evidence on which the decision is based[14, 16, 17, 19–21]. A relatively new theory proposes that confidence could be obtained in a process that is separated from the decision and can therefore selectively be manipulated (i.e. without manipulating the sensory evidence)[13, 28, 29]. Whether the objective (performance) and subjective evaluation of a decision (confidence) arise from the same or from different processes remains an open question. Our findings add supporting evidence in favor of a separation between these processes.

In theory both forms of attention could in some way affect the evidence accumulation process and consequently the decision variable, which determines the decision in a positive manner. This is reflected in the increased performance in both attention conditions. If confidence was obtained mainly depending on the strength of the sensory evidence for the respective decision - as suggested by many models[14, 16, 18–21] - one would expect that it would be affected by attention in the same way as the quality of the decision itself (performance). In our study however, confidence was only affected by one form of attention. During exogenous attention, confidence faithfully reflected the quality of a decision. For endogenous attention we found selective relative overconfidence relative to performance. This dissociation can only be explained when we assume a second, separate process for obtaining confidence ratings. While attention can improve the first process (performance), it seems to have an even stronger effect on the second process (confidence). It is the voluntary, or cognitively controlled, form of attention that affects this process while the reflexive, or involuntary, form of attention leaves it unchanged, suggesting that confidence might ultimately arise from higher cognitive processes. Another finding that might potentially link confidence to higher cognitive processes is that participants are more likely to be overconfident in higher cognitive tasks than in perceptual tasks[24] (but see ref. 39). Additionally neural correlates of confidence have been found in prefrontal areas[40], thought to be important for cognitive control[41]. Taken together, these considerations set confidence apart from the externally triggered perceptual decision process itself and link it to metacognitive processes, i.e. monitoring mechanisms over perception or memory using high level control[42].

One limitation to this study is that there is no possibility to validate post-hoc that the experimental manipulations really resulted in the deployment of different forms of attention. This claim relies on the well documented differences in the time courses between exogenous attention and endogenous attention[1, 4, 5, 43, 44]. Another possible caveat is that attention might not affect confidence as such but simply the reporting process of this internal confidence value. For example, participants might have only reported "certain" rather than truly felt this way during their confidence rating, simply because they thought they should be more certain under this task condition. It is also possible that in the exogenous attention condition participants felt rushed by the short SOA or were surprised by the cue and therefore reduced their confidence ratings accordingly (However, an effect of SOA could be ruled out at least within conditions (see Supplementary Analysis S7)). In our experiment these factors cannot be ruled out completely and our results should therefore be further validated in combination with a greater range of psychological methods assessing metacognitive processes[45].

## Conclusions

Reflexive attention to external information does not affect the assessment of a decision in a metacognitive process even if it enhances the objective quality of the decision. Deciding voluntarily to do so on the other hand may lead us to overestimate the quality of our decisions. Thus, higher level cognitive processes can influence each other, while they appear to be at least partially decoupled from the basic reflexive processes that help us perceive our environment in an optimal manner.

## Methods

**Subjects.** 28 healthy participants performed the task (12 female, median age: 25 years). All participants had normal or corrected to normal vision. Written informed consent was obtained from all subjects. All methods were carried out in accordance with relevant guidelines and regulations and approved by the ethics committee of the Goethe University Medical Faculty. Participants 1–10 received small gifts for their participation, participants 11–28 were paid € 15. Apart from 4 participants from the author's lab (including the first author), all participants were naïve to the task. Performing the task including training trials, giving informed consent, task instructions (See Supplementary Information S8) and pauses took between one and one and a half hours.

Five participants (8, 9, 13, 21, and 26) performed at chance level and were therefore excluded from analysis. We determined participants at chance level by using their median accuracy, which from random guesses between 0 and 90 would be around 45°, and excluded all participants with a median accuracy larger than 40°. However, excluding these participants did not qualitatively change the observed effect.

Task settings were slightly changed from subject 17 onwards (see below) because of feedback from participants without experience in psychophysical experiments. Comparing the descriptive statistics between the first and second group of participants we found that performance was poorer in the second group in all conditions (endogenous: mean = 18.41° ± standard deviation = 8.36 vs. 30.44° ± 5.67°; exogenous: 21.95° ± 10.49° vs. 29.15° ± 4.49°; no-cue: 22.77° ± 9.97° vs. 33.71° ± 5.84°). This was reflected also by lower confidence ratings (endogenous: 0.74 ± 0.083 vs. 0.68 ± 0.172; exogenous: 0.68 ± 0.116 vs. 0.64 ± 0.159; no-cue: 0.68 ± 0.128 vs. 0.6 ± 0.173). We attribute this to the fact that the second group included only participants without experience in psychophysical experiments. The main differences between conditions, however, were very similar for both groups. Therefore, all participants were treated as one population.

**Task Design.** The experiment was performed in a quiet, dimly lit room. Participants placed their head in a headrest ensuring a constant viewing distance of approximately 60 cm. Stimuli were presented on a Samsung SyncMaster 2233RZ monitor with a resolution of 1680 by 1050 pixels and a refresh rate of 120 Hz[46]. Presentation was controlled by a Dell Computer with an Intel Xeon W3503 processor (2.4 GHz) and a NVIDIA Quadro 2000D graphics card. The operating system was a 64-bit Windows 7 Professional. The experimental procedure was programmed using the Psychtoolbox version 3.0.12[47] for Matlab version R2014b (Mathworks Inc. TM).

The orientation matching procedure shown in Fig. 1 was based on a paradigm used by Whitney *et al.*[48]. All stimuli were presented on a grey background. Participants had to fixate a small fixation point with a diameter of 0.2 visual degrees to start a trial. Eight light grey circles indicated possible stimulus locations at 5 degrees eccentricity. This presentation stayed on for 500 milliseconds (ms) after fixation was acquired and was the same in all trials.

Three different conditions were tested: endogenous versus exogenous cueing and a no-cue condition. Conditions were pseudo-randomly drawn on a trial-by-trial basis so that every condition was tested in exactly one third of the trials.

In the no-cue condition the initial presentation stayed on the screen for an additional 300–700 ms (from participant 17 onwards for 350–750 ms) after the initial 500 ms fixation period until the stimulus was presented 800–1200 ms after trial onset. This condition served as a control condition to assess decision performance and confidence in the absence of cued attention.

In the endogenous attention condition a 1 visual degree long black line pointing from the central fixation spot towards one of the locations appeared within 200 ms after the end of the fixation period and stayed on for a duration of 300–500 ms (from participant 17 onwards for 350–550 ms) instructing the subjects to shift their attention covertly (without detectable eye movements) to the indicated location. Offset of the cue and onset of the target happened simultaneously in this condition.

In the exogenous attention condition after an additional 200–600 ms (from participant 17 onwards: 250–650 ms) of the initial display, a small dark grey dot (0.5 visual degrees diameter) was flashed for 16 ms next to the location where the stimulus would later appear reflexively drawing the subjects' attention to that location. In this condition the time between cue onset and target onset was 90–110 ms. These stimulation times were selected to accommodate the known time courses of endogenous and exogenous attention[1, 4, 5, 43, 44].

The stimulus was a circular (2 visual degrees diameter) sinusoidal grating. Michelson contrast was between 0.05 and 0.5 and was set according to performance in a staircase procedure during a prior psychophysical threshold measurement (see below). The spatial frequency of the stimulus and response grating was 6 cycles per degree, which yielded robust effects for exogenous attention in a similar task[49]. The grating's orientation was randomly drawn on every trial. The target stimulus was presented for 80 ms followed by a random white noise mask that was presented for 100 ms to prevent afterimages that could influence the decision process.

After a 500 ms period with a blank screen, a second randomly oriented response grating was presented. Participants tried to match the orientation of the response grating to the orientation of the stimulus grating by changing the orientation of the response grating in steps of 1° with the arrow (left and right) keys on a keyboard. When satisfied with the orientation of the gratings, participants pressed another key to log in their response. Then participants rated the confidence in their decision on a continuous scale again using the arrow keys to move a slider on the scale. The scale showed the transmission from red on the left side of the scale corresponding to low confidence, to green on the right side of the scale for high confidence. The starting point of the slider was set to the right edge. A value read out from the position of the slider on the scale between 0 for lowest possible confidence to 1 for highest possible confidence was recorded. The scale was divided into 256 possible values corresponding to a span of 256 pixels, giving the impression of a continuous scale. The length of the scale in visual degrees was 6.94.

Participants received an oral instruction either in English or German, which did not contain speed or accuracy statements. Then they performed a training session of 30 to 50 trials using the exogenous cue. These trials were used to determine an individual Michelson contrast for the gratings for each subject with a staircase function. Since the response was given on a continuous scale we used 15° deviation as a correct/incorrect criterion in the staircase procedure. A correct response decreased, and an incorrect response increased the contrast by a step of 0.05. We then used the lowest contrast at which participants were able to perform better than the threshold for the main experiment. In the actual experiment participants performed a total of 300 trials (100 trials per condition).

Additionally we recorded the starting angle of the response grating from participant 11 onwards to check for possible influences on responses. The SOA for endogenous trials was prolonged to 350–550 ms for subject 17–28 because we noticed that participants took longer than expected to allocate attention according to the cue. In trials with exogenous attention cues and in trials without cueing we prolonged the waiting time accordingly to obtain consistent trial lengths.

**Eye-Tracking.** The participant's eye movements and pupil diameter were recorded throughout the whole experiment to ensure fixation with an Eyelink 1000 Version 4.56 system from SR Research Ltd. (Mississauga, Ontario, Canada). Gaze position was used to initiate a trial as soon as it reached the central fixation window. Trials were aborted if gaze position went outside the fixation window before the fixation point was turned off. Eye-movement data was saved from subject 7 onwards. The directionality of the eye position was assessed using a Rayleigh test.

**Statistics.** All statistical tests were programmed using the Matlab version 2011a and 2015b and its Statistics and Machine Learning Toolboxes (Mathworks Inc.). The two-way repeated measures ANOVA was performed using the RMAOV2 function[50].

Performance was calculated as the absolute deviation between the response orientation that participants had logged in and the orientation of the stimulus grating. Confidence was measured as a value between 0 and 1 in 256 steps, read out from final position of the slider on the scale.

To assess the statistical significance of effects across participants, we conducted one-way repeated-measures analyses of variance (ANOVA) for performance and a Friedman test for confidence. When these tests revealed a significant effect ($p < 0.05$), post-hoc statistical comparison was performed using paired samples t-tests for performance and Wilcoxon signed rank tests for confidence with a Bonferroni procedure correcting for multiple comparisons.

For the analysis of confidence according to performance level single subject data was binned into quintiles and mean confidence values of trials in each condition were calculated for every quintile (Fig. 3). Then a two-way (3 attention conditions x 5 performance levels) repeated measures ANOVA was performed to assess statistical significance.

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## Author Contributions

Conceptualization, P.K., K.S., and M.C.S.; Methodology, P.K. and K.S.; Software, P.K.; Formal Analysis, P.K. and J.T.S., Investigation, P.K.; Writing – Original Draft, P.K.; Writing – Review & Editing, M.C.S., J.K. and K.S.; Funding Acquisition, M.C.S.; Resources, M.C.S.; Supervision, M.C.S., J.K. and K.S.

## Additional Information

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**Competing Interests:** The authors declare that they have no competing interests.

## 4. Author’s Contribution to Manuscript

The author of this thesis was the main researcher in the study that underlies this thesis. Under close supervision from members of the Institute of Medical Psychology and the Schmid Lab at the Ernst Strüngmann Institut gGmbH he was responsible alone for developing the experimental software, performing the experiments and writing the original draft for publication. Development of the concept and the methodology for the study and formal analysis was performed together with members of the above mentioned laboratories. Review and editing of the original draft were mainly done by researchers other than the author. The author of this thesis was not involved in funding acquisition or providing resources.

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## 6. Supplementary Information

As published with the underlying publication: Kurtz P, Shapcott KA, Kaiser J, Schmiedt JT, Schmid MC. The Influence of Endogenous and Exogenous Spatial Attention on Decision Confidence. Sci Rep. 2017;7(1):1-9. doi:10.1038/s41598-017-06715-w.

# The Influence of Endogenous and Exogenous Spatial Attention on Decision Confidence

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# Supplementary Information:

**S1 Analysis. Non-parametric (permutation-based) Analysis of Covariance (ANCOVA).** To get an estimate of the effects of attention on confidence after controlling for performance differences we performed a non-parametric (permutation-based) ANCOVA. After adjusting for performance accuracy, attention continued to have a significant effect on confidence, with F = 18.75, p < 0.001. The performance adjusted means for confidence under endogenous, exogenous and neutral attention were 0.88, 0.84 and 0.84, respectively. Post-hoc comparison on the adjusted values revealed a significant difference between endogenous and no-cue condition (t (22) = -3.11, p = 0.015) and between endogenous and exogenous condition (t (22) = -4, p = 0.002). No significant difference could be detected between exogenous and no-cue condition (t (22) = 0.088, p = 1). This analysis was done using the Fathom toolbox[52] for Matlab.

| SumSq | DF | MeanSq | F | pValue | pValueGG | pValueHF | pValueLB |
|---|---|---|---|---|---|---|---|
| 173.6488 | 2 | 86.8244 | 6.695656 | 0.00289297 | 0.00417811 | 0.00322636 | 0.0168005 |
| 570.5600 | 44 | 12.96727 | 1 | 0.5 | 0.5 | 0.5 | 0.5 |

*S 2: Repeated-Measures ANOVA for Performance (Highest Confidence Excluded). This table provides the result of the repeated-measures ANOVA for the effect of attention condition on performance after exclusion of all trials where subjects reported full confidence. The effect of attention condition on performance is still significant even after excluding these trials. pValue: p-value for the corresponding F-statistic; pValueGG: p-value with Greenhouse-Geisser adjustment; p-value with Huynh-Feldt adjustment; pValueLB: p-value with Lower bound adjustment.*

| Conditions_1 | Conditions_2 | Difference | StdErr | pValue | Lower | Upper |
|---|---|---|---|---|---|---|
| Without | Endogenous | 3.8242 | 1.1782 | 0.0111 | 0.7711 | 6.8773 |
| Without | Exogenous | 2.5092 | 0.8659 | 0.025 | 0.2655 | 4.7528 |
| Endogenous | Exogenous | -1.315 | 1.1157 | 0.7534 | -4.206 | 1.576 |

*S 3: Multiple Comparison for Performance (Highest Confidence Excluded). This table provides the results of the multiple comparison for performance after exclusion of trials with full confidence. Still both endogenous and exogenous attention show a significantly higher performance than the no-cue condition. The difference between endogenous and exogenous condition is still not significant. Difference: Estimated difference between the corresponding two marginal mean; StdErr: Standard error of the estimated difference between the corresponding two marginal means; pValue: Bonferroni-corrected p-value; Lower: Lower limit of simultaneous 95% confidence intervals for the true difference; Upper: Upper limit of simultaneous 95% confidence intervals for the true difference.*

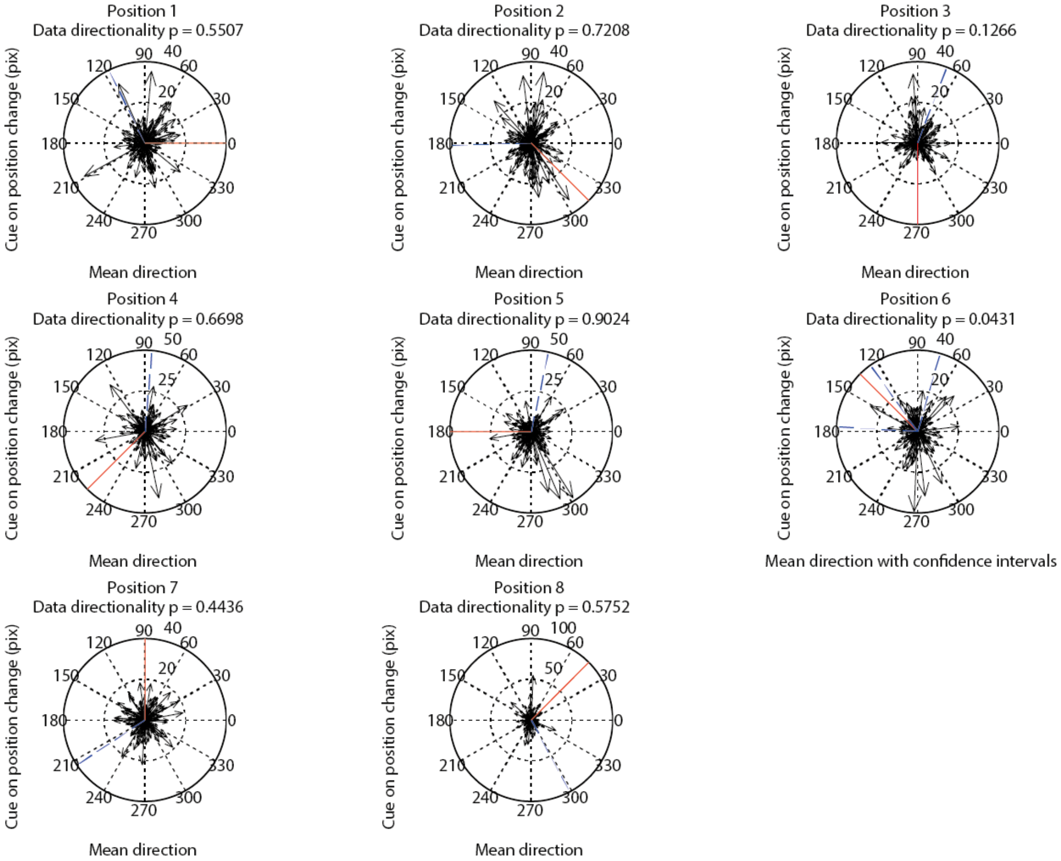
| SumSq | DF | MeanSq | F | pValue | pValueGG | pValueHF | pValueLB |
|---|---|---|---|---|---|---|---|
| 0.0532 | 2 | 0.0266 | 10.4653 | 0.00019 | 0.0005 | 0.00037 | 0.0038 |
| 0.1119 | 44 | 0.0025 | 1 | 0.5 | 0.5 | 0.5 | 0.5 |

*S 4: Repeated-Measures ANOVA for Confidence (Highest Confidence Excluded). This table provides the results of the repeated-measures ANOVA for the effect of attention condition on confidence after exclusion of all trials where subjects reported full confidence. The effect of attention condition on confidence is still significant even after excluding these trials. pValue: p-value for the corresponding F-statistic; pValueGG: p-value with Greenhouse-Geisser adjustment; p-value with Huynh-Feldt adjustment; pValueLB: p-value with Lower bound adjustment.*

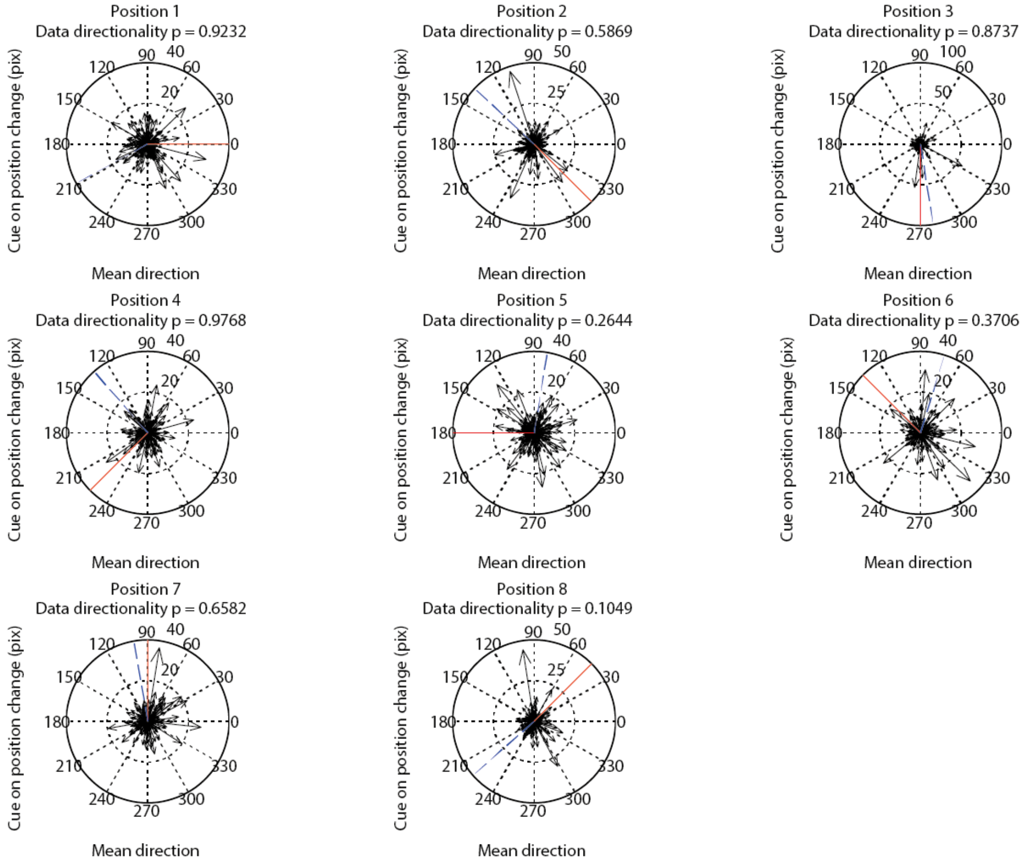
| Conditions_1 | Conditions_2 | Difference | StdErr | pValue | Lower | Upper |
|---|---|---|---|---|---|---|
| Without | Endogenous | -0.0652 | 0.01786 | 0.0042 | -0.11146 | -0.01891 |
| Without | Exogenous | -0.0157 | 0.01234 | 0.6490 | -0.04768 | 0.01627 |
| Endogenous | Exogenous | 0.0495 | 0.01387 | 0.0052 | 0.01354 | 0.08542 |

*S 5: Multiple Comparison for Performance (Highest Confidence Excluded). This table provides the results of the multiple comparison tests for confidence after exclusion of trials with full confidence. Still endogenous attention resulted in significantly higher confidence than both no-cue condition and exogenous condition. The difference between exogenous and no-cue condition was again not significant. Difference: Estimated difference between the corresponding two marginal mean; StdErr: Standard error of the estimated difference between the corresponding two marginal means; pValue: Bonferroni-corrected p-value; Lower: Lower limit of simultaneous 95% confidence intervals for the true difference; Upper: Upper limit of simultaneous 95% confidence intervals for the true difference.*

# Endogenous



# Exogenous



*S 6: Directionality analysis of eye-movements. The data of all participants were pooled together. For every grating position in the attention conditions we calculated the median eye-position in the fixation period and in the cue-on period and using this calculated the change in position between fixation and cue period. We tested if there was any directionality in these eye position changes by using the Rayleigh test for non-uniformity from the CircStat toolbox for Matlab 53Top: Endogenous attention condition; Bottom: Exogenous attention condition. Every subplot of the figures corresponds to a grating position whose angle is indicated in red. Every black arrow corresponds to one trial. The length and direction of an arrow corresponds to the eye position change in pixels after cue onset. The circular mean of all angles of the position changes is indicated in blue. As can be seen the changes in eye position are very small (rarely exceeding 25 pixels) and are not directed towards the grating position, instead they are very dispersed. Accordingly p-values of the Rayleigh test were very high, only once falling below 0.05 (position 6 under exogenous attention).*

**S7 Analysis. Effect of Stimulus Onset Asynchrony (SOA).** To rule out an effect of SOA we pooled the data of all subjects together and split trials in two halves according to SOA in the two attention conditions respectively. We then compared the longer half to the short half with a paired samples t-test. This yielded no significant effect of SOA on performance (endogenous: t (df = 1144) = -0.87, p = 0.39; exogenous: t (df = 1143) = -1.58, p = 0.11) and neither on confidence (endogenous: t (df = 1144) = 0.09, p = 0.93; exogenous: t (df = 1143) = 1.67, p = 0.1). An effect of stimulus onset asynchrony within conditions can be ruled out.

### S8 Instruction sheet.

## Experiment instructions:

You are taking part in a psychophysical experiment. We are trying to learn something about how visual stimuli are perceived and processed.

Throughout the experiment we will track your eye movements. So first we need to calibrate the eye-tracker. To do this there will be little targets appearing at different positions on the screen. Please look at every target and keep looking there until it disappears and the next one appears.

To ensure a quality of the eye data, please keep your head as still as possible in the headrest. Try to only remove it during the breaks you are offered (every quarter of the trials) If you accidentally move your head please tell the examiner because the Eye-Tracker will need to be recalibrated. Additionally please try to only blink between the trials as this might also influence the quality of the data.

Please always look at the small black dot as long as it is presented on the screen.

During the experiment you will see gratings with or without cues. There will be an explanation trial, where you don’t have to fixate the fixation point and can look at the grating and the cues to get an impression how they look.

Your task will be to remember the orientation of a stimulus and then try to match the orientation of another equal stimulus to the orientation of the one you briefly saw before. You'll use the arrow keys on the keyboard to turn the second grating until it looks how you remember the first one. Don’t worry if in the beginning everything happens really fast and you have the feeling you are not seeing anything. That will get better with time.

At the end of every trial you will be asked to rate how confident you are in your performance in the orientation matching task. You shall do that using a scale, where green means high confidence and red means low confidence. The range between can be used to express different gradations.

Before the actual experiment starts there will be a training session that will get harder while you solve it and where you don’t have to make confidence ratings.

Do you have any questions?

Thanks in advance and have fun.

# 7. Curriculum Vitae

## Phillipp Kurtz

| | |
|---|---|
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| **Geburtsdatum** | 30. Dezember 1991 |
| **Geburtsort** | Würzburg |
| **Familienstand** | ledig |

## Berufserfahrung/ Praktika

| | |
|---|---|
| Jan. 2018 – Apr. 2018 | **Tertial** des Praktischen Jahres in der **Inneren Medizin** am Hospital Aleman, Ausbildungskrankenhaus der **Universität von Buenos Aires**, Argentinien |
| Sep. 2017 – Dez. 2017 | **Tertial** des Praktischen Jahres in der **Chirurgie** am University Hospital No. 1 der **Sechenov Universität, Moskau**, Russland |
| Mai 2017 – Sep. 2017 | **Tertial** des Praktischen Jahres in der **Neurologie** an der **Charité Universitätsmedizin**, Berlin |
| Aug. 2014 – Jul. 2017 | **Doktorarbeit** am **Ernst-Strüngmann-Institut** für Hirnforschung und dem **Institut für Medizinische Psychologie** an der Goethe-Universität Frankfurt<br>• Titel: The Influence of Endogenous and Exogenous Spatial Attention on Decision Confidence<br>• Erlernen der Programmiersprache Matlab<br>• Planung, Vorbereitung und Durchführung psychophysikalischer Experimente<br>• Erlernen der Grundlagen statistischer Datenanalyse |
| Dez. 2016 | **Famulatur** in der **Gynäkologie** an der Frauenklinik Stuttgart |
| Feb. 2016 | **Famulatur** in der **Neurologie** an der Schön Klinik München Schwabing |
| Jul. 2015 | **Famulatur** in der Klinik für **Psychiatrie, Psychotherapie und Psychosomatik** am Vivantes Humboldt Klinik, Berlin |
| Feb.2015 - Mär.2015 | **Famulatur** am Nishtha Rural Health, Education & Environment Centre in Sidhbari, HP, Indien |

| | |
|---|---|
| Jun. 2014- Jul. 2014 | **Famulatur** in der Praxis Dr. Harry Mark, Facharzt für **Allgemeinmedizin,** Frankfurt am Main |
| Jul. 2011 – Okt. 2011 | **Pflegepraktikum** im Centro Argentino-Cubano de Rehabilitación in Cordoba, Argentinien |

## Kenntnisse

**Sprachen**

- Deutsch, Muttersprache
- Englisch, fließend in Wort und Schrift
- Spanisch, sehr gute Sprachkenntnisse
- Russisch, Grundkenntnisse
- Großes Latinum

**Sonstiges**

- Sicherer Umgang mit PC und Internet
- Gute MS-Office Kenntnisse
- Grundkenntnisse der Programmiersprache Matlab, insbesondere der Psychtoolbox
- Grundkenntnisse in Adobe Illustrator

**Hobbies** Reisen und Kultur, Musik, internationale Politik

## Veröffentlichungen

Kurtz, Phillipp et al. "The Influence of Endogenous and Exogenous Spatial Attention on Decision Confidence." Scientific Reports 7 (2017): 6431. PMC. Web. 16 Apr. 2018.

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Ort, Datum Unterschrift

## 8. Schriftliche Erklärung

Ich erkläre ehrenwörtlich, dass ich die dem Fachbereich Medizin der Johann Wolfgang Goethe-Universität Frankfurt am Main zur Promotionsprüfung eingereichte Dissertation mit dem Titel

The Influence of Endogenous and Exogenous Spatial Attention on Decision Confidence

in dem Institut für Medizinische Psychologie unter Betreuung und Anleitung von Prof. Dr. Jochen Kaiser mit Hilfe der Arbeitsgruppe von Dr. Schmid am Ernst Strüngmann Institut gGmbH selbst durchgeführt und bei der Abfassung der Arbeit keine anderen als die in der Dissertation angeführten Hilfsmittel benutzt habe. Darüber hinaus versichere ich, nicht die Hilfe einer kommerziellen Promotionsvermittlung in Anspruch genommen zu haben.

Ich habe bisher an keiner in- oder ausländischen Universität ein Gesuch um Zulassung zur Promotion eingereicht. Die vorliegende Arbeit wurde bisher nicht als Dissertation eingereicht.

Vorliegende Ergebnisse der Arbeit wurden in folgendem Publikationsorgan veröffentlicht:

Kurtz P, Shapcott KA, Kaiser J, Schmiedt JT, Schmid MC. The Influence of Endogenous and Exogenous Spatial Attention on Decision Confidence. Scientific Reports. 2017;7:6431. doi:10.1038/s41598-017-06715-w.

(Ort, Datum)　　　　　　(Unterschrift)