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Confidence Forced-Choice and Other Metaperceptual Tasks*

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Abstract

Metaperception is the self-monitoring and self-control of one's own perception. Perceptual confidence is the prototypical example of metaperception. Perceptual confidence refers to the ability to judge whether a perceptual decision is correct. We argue that metaperception is not limited to confidence but includes other judgments such as the estimation of familiarity and the aesthetic experience of sensory events. Perceptual confidence has recently received a surge of interests due in particular to the design of careful psychophysical experiments and powerful computational models. In psychophysics, the use of confidence ratings is the dominant methodology, but other paradigms are available, including the confidence forced choice. In this latter paradigm, participants are presented with two stimuli, make perceptual decisions about these stimuli, and then choose which decision is more likely to be correct. One benefit of confidence forced choice is that it disregards confidence biases to focus on confidence sensitivity. Confidence forced choice might also be a paradigm that will allow us to establish whether confidence is estimated serially or in parallel to the perceptual decision.

Keywords
cognition, perception, color, motion, spatial vision, face perception

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Introduction

Perceiving is to commit to a decision based on sensory information that is often uncertain. Across different sensory modalities, I can see that the person in front of me is a woman,

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I can hear that she has a French accent when she speaks, and I can smell roses in her parfume. Metaperception is the perception of our own perception. I can be convinced that the face is a woman, I can be confident that the accent is of Latin origins but not necessarily French, and I can admit that roses in the parfume was a pure guess.

The distinction between perception and metaperception has occupied philosophers since the ancient Greeks. In *De Anima*, Aristotle (250 BC) reasons that

> Since it is through sense that we are aware that we are seeing or hearing, it must be either by sight that we are aware of seeing, or by some sense other than sight. But the sense that gives us this new sensation must perceive both sight and its object, viz. color: so that either there will be two senses both percipient of the same sensible object, or the sense must be percipient of itself. (III.2, 425b11)

Metaperception, and more generally metacognition, is still being debated in philosophy (Denison, 2017; Proust, 2013). However, thanks to clever psychophysical experiments, detailed physiological recordings, and powerful computational models, we now have a fair knowledge of the reasons why we perceive what we perceive. The time is now ripe for psychophysicists, physiologists, and computational modelers to tackle the problem of metaperception and the links between perception and metaperception.

Metaperception

We can appreciate the difference between perception and metaperception with some examples. People suffering from the Capgras delusion believe that significant others, such as their spouse, has been replaced by an impostor (Capgras & Reboul-Lachaux, 1923). Interestingly, these patients do not have any difficulty in recognizing the person's face, on the contrary, they are surprised by the close ressemblance of the impostor's face to that of their close relatives. Yet, the face no longer looks familiar to them, and it is because of this loss of familiarity that Capgras delusion patients believe the person in front of them is an impostor (Ellis & Lewis, 2001). Therefore, it is important to distinguish face recognition from the familiarity of the face, and while recognizing a face is a perceptual task, evaluating the familiarity of that face is an example of metaperception.

Maybe the best studied instance of metaperception, and indeed the one discussed at further lengths here, is the case of perceptual confidence. Perceptual confidence is our ability to evaluate the correctness of our perceptual judgments. Being able to perform a visual task with some precision should be distinguished from the ability to evaluate how well this task is performed. For instance, while looking at an apple, I can perceive the color of the apple as being red and be more or less confident that the apple is really red rather than green. Visual perception and visual confidence often go hand in hand but can sometimes be dissociated. Subliminal perception refers to those perceptual processing that trigger some kind of perceptual response (for instance, by affecting the interpretation of the subsequent stimulus) and yet the observer will not be able to make any meaningful judgment on her subliminal percept (Dehaene et al., 2006). At the clinical level, blindsight patients, who present a lesion in their primary visual cortex, report not being able to detect the presence of an object in their blind visual field, but they can often localize this object with a performance better than chance (Perenin & Jeannerod, 1975; Pöppel et al., 1973; Weiskrantz, 2009). Subliminal perception and the experience of blindsight patients illustrate that the processing of visual information can be effective up to some level, and yet visual confidence can be absent.

We believe that metaperception is not limited to perceptual confidence or the feeling of familiarity. In particular, it is tempting to also include the aesthetics appreciation of a sensory stimulus as metaperception. In the visual modality, two observers might have the same visual acuity, the same easiness to recognize an image of water lilies, the same ability to identify the painter as Claude Monet, but they might not share the same appreciation of the impressionist rendering. Here again, aesthetics experience needs to be distinguished from visual experience, even though the two might share some properties (Mamassian, 2008). But should all affective responses triggered by an image treated as metaperception? Should the feeling of pride for some people when they look at a flag, or the feeling of joy when others look at cute kittens, be considered instances of metaperception or just emotional responses? A key element to consider when attempting to answer this question is to determine whether the metaperceptual judgment actually involves another decision on the outcome of the perceptual decision. In addition, this secondary decision should refer back to the self, it should involve the perceiver. Am I sure that my perceptual decision is correct? Am I familiar with the person I just met? Am I feeling moved by the painting in front of me? In general, we can argue that metaperception is the self-monitoring and self-control of one's own perception.

To rely on a secondary decision to qualify for metaperception is not new. Since the origins of Signal Detection Theory, researchers have distinguished Type 2 from Type 1 tasks (Clarke et al., 1959). Type 1 judgments are the ones that are traditionally studied in the psychophysical laboratory. They can refer to the evaluation of the shape, size, or color of a visual stimulus. While Type 1 judgments focus on one particular property of a stimulus, Type 2 judgments refer to the outcome of a Type 1 judgment. Thus, examples of Type 2 judgments include judging whether the shape of an object is aesthetically pleasing, whether its size is consistent with a familiar size, and whether we are confident that its color is really red. It is important to keep in mind that Type 2 judgments as they are defined here are reevaluations of Type 1 decisions. Therefore, the distinction between Type 1 and Type 2 judgments is not the same as other dichotomies discussed in the psychophysics literature, such as the difference between Class A and Class B observations that are better qualified as the distinction between sensitivity and bias (Morgan et al., 2013).

Monitoring and Control

What are the links between Type 1 and Type 2 judgments? Extrapolating the influential model that Nelson and Narens (1990) have proposed for metamemory, we can call the perceptual level the representation that helps us perform Type 1 judgments, and the metalevel the representation that helps us perform Type 2 judgments. Nelson and Narens distinguished two flows of information between these two levels, monitoring and control. Through monitoring, the outcome of a decision performed at the perceptual level is made available at the metalevel. For metaperception, examples of monitoring include the examples discussed earlier, namely, the feeling of familiarity, the judgment of perceptual confidence, and the aesthetic appreciation of a visual experience (Figure 1).

Through control, the state of the metalevel activity will modify the information used at the perceptual level. This produces some kind of action at the perceptual level, which could be to initiate an action (e.g., via selective attention or hypothesis generation), to continue an action (e.g., by motivation), or to terminate an action (e.g., stopping the accumulation of sensory evidence). For instance, if an observer attends to her left visual field, she might selectively sample the sensory information that is present only on that side, and this will impact all subsequent perceptions (Figure 1). Likewise, hypothesis generation is where the perceiver is emitting some hypothesis about what she is about to see or hear, and this hypothesis is then channeling the likelihood that some sensory information has a particular origin. For instance, assuming that light comes from above explains the presence of dark

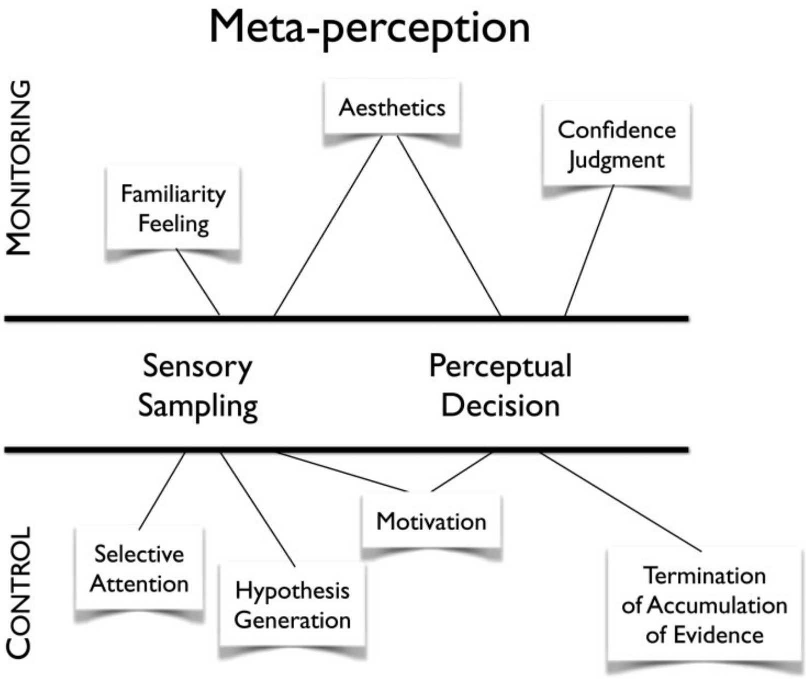

Figure 1. Distinction of Monitoring and Control in Metaperception. Monitoring corresponds to collecting some information at the metalevel about a perceptual decision. Examples of monitoring include the feeling of familiarity, the judgment of perceptual confidence, and the aesthetic appreciation of a visual experience. In contrast, control corresponds to the use of some information at the metalevel to constrain perceptual decisions. Examples of control include selective attention and the generation of hypotheses about percepts, but also motivation, and controls on some aspects of a perceptual mechanism such as the termination of accumulation of evidence. Sensory sampling and perceptual decisions are examples of processing that help make the connection between perceptual and metalevel representations. Illustration inspired from Nelson & Narens (1990).

patches below objects. Another type of control is motivation that can help participants to continue processing sensory information. A final example is the termination of accumulation of evidence whereby the perceiver elects to stop collecting uncertain information about an on-going event so as to make a decision within a reasonable time (Vickers, 1979). Through control, the state of confidence could modify the information used at the perceptual level, for instance, by actively stopping the accumulation of sensory evidence in the perceptual decision process (Balsdon et al., 2020).

We find the distinction between a perceptual and a metaperceptual level a useful one, and we will use it below to distinguish sensory evidence from confidence evidence.

What Is Confidence Good for?

Trying to justify the benefits of some facets of metaperception can be hazardous. Is there any use for the aesthetic experience of looking at a painting, listening to a poem, or smelling a flower? Do people who are better able to sense their familiarity to people and places have a longer life expectancy? For confidence, however, we have a number of reasonable candidate answers.

Being able to judge the correctness of our perceptual judgments could help us engage in a risky business such as road crossing. Having an explicit representation of the uncertainty of a perceptual decision may help us compute the risk of being wrong and estimate the cost of bad perceptual decisions from past experience. A related benefit is to improve our model of the world that can then be used within a predictive coding framework (Rao & Ballard, 1999).

Having a good confidence sensitivity will also give us the possibility to allocate appropriate resources to a task, and this could be beneficial during perceptual learning (Fahle, 2004; Seitz & Watanabe, 2005). Knowing that we are not very good in a task could indeed help us pay more attention to the upcoming stimuli (Rahnev et al., 2011), and this in turn could improve learning rates.

Good confidence can also help us appreciate whether and how we can control the environment. Knowing that we are responsible of some changes that we can monitor perceptually is at the origins of the sense of agency (Haggard, 2017). Finally, it can help us communicate a graded judgment to other individuals and improve the group decisions (Bahrami et al., 2010).

What Is Confidence?

As discussed earlier, confidence is one type of monitoring of our perceptual decisions. In layman's terms, it refers to our ability to judge the validity of our perceptual decisions. In this section, we attempt to give a more precise definition of confidence.

Classical Definition

Visual confidence is defined in the context of a specific perceptual decision in a specific task. It refers to the subjective evaluation of the observer that the perceptual decision she has just taken is correct (Mamassian, 2016; Pouget et al., 2016). This definition of confidence implies three characteristics. First, confidence refers to a single trial and not to a global abstract evaluation of one's ability to perform a task, such as the overall aptitude to recognize faces or to discriminate color hues. Second, the definition also assumes that the decision is completed, rather than still an ongoing process at the time confidence is assessed. Once the observer has committed herself to a choice, confidence refers to the correctness of that choice. Finally, confidence is not an estimate of the amount of uncertainty in a sensory stimulus. This allows us to distinguish confidence from visibility judgments.

This definition does not assume anything about the information used to make the confidence judgment. In particular, it does not assume that this information is identical to the one used to make the perceptual judgment. To allow sensory information to be distinct from confidence information, we call the latter "confidence evidence" (in the terminology used earlier for Figure 1, sensory evidence is the information at the perceptual level, whereas confidence evidence is the representation at the metalevel). In summary, the accepted definition of confidence is the probability that the perceptual evaluation is correct given the perceptual decision and the confidence evidence

$$\text{confidence} \triangleq P(e_1 = \text{correct} | d_1, w)$$

where w is the confidence evidence for the current trial, and d_1 is the perceptual decision (Type 1) for the current trial. In that equation, e_1 is the evaluation that the perceptual decision is correct. Objectively, this evaluation can be carried out by the experimenter who has access to the stimulus that was actually presented to the participant. Therefore, asking the participant about her confidence is asking her to take the place of the experimenter to evaluate the probability that her perceptual decision is correct.

The equation for the confidence probability rests on the perceptual decision d_1 and the confidence evidence w for that particular trial that confidence is estimated. How are these two entities defined? Following the framework of Signal Detection Theory (Green & Swets, 1966), sensory evidence S is obtained from the transduction of the physical stimulus U by the sensory apparatus of the observer. This sensory evidence is corrupted by sensory noise N that is often assumed to be additive. Whenever a new stimulus is presented, a new sample s of the sensory evidence is available to the observer who then has to infer what the original stimulus was given this sample. If the stimulus can take only two forms, "A" and "B," and the task of the observer is to discriminate between "A" and "B," the perceptual decision process D_1 involves a sensory criterion. Whenever the value of the sensory sample is above the criterion, the observer decides that stimulus "A" was presented ($d_1 = A$), and when it is below, "B" is chosen ($d_1 = B$). Depending on whether stimulus "A" or "B" was actually displayed, this choice can be correct or incorrect. This evaluation of the correctness of the perceptual decision E_1 can be objectively performed by an external observer, typically the experimenter, who has access to both the original stimulus that was displayed (U) and the reported percept of the observer (D_1). The flow of information and processing from the physical stimulus to the perceptual decision defines the mechanism underlying the Type 1 task (Figure 2).

To be as generic as possible, we can assume that there is a mechanism underlying the Type 2 task that mimics the flow of information and processing that we have just described for the Type 1 task. In particular, just like the perceptual decision D_1 relied on some sensory evidence S, we postulate that any confidence decision D_2 relies on some confidence evidence W. Just like the sensory evidence can be corrupted by sensory noise N, we assume that the confidence evidence can be corrupted by additive confidence noise M. In a confidence rating task, the observer will set a confidence criterion, such that whenever the confidence evidence is above that criterion, the observer will have a "high" confidence of being correct, and when it is below, confidence will be "low." Where is the confidence evidence coming from?

Let us first consider the ideal confidence observer scenario. By definition, the ideal confidence observer is as good as the human observer for the perceptual judgment (same sensory noise N) and is using exactly the same information for the confidence judgment as the one that was used for the perceptual decision (zero confidence noise M). Therefore, for the ideal confidence observer, the confidence evidence will be based on a copy of the sensory evidence, neither corrupted by confidence noise nor benefiting from any additional information. When the sensory sample was close to the sensory criterion, a perceptual decision was taken based on the location of the sample relative to the criterion, but it is clear that a small amount of noise could have led to the opposite decision. In contrast, when the sensory sample is far from the criterion, the perceptual decision was stable. Therefore, confidence evidence can be taken as the distance of the sensory sample away from the criterion (Galvin et al., 2003). In simple terms, the sign of the sensory sample determines the percept and its magnitude the confidence. Finally, the magnitude of the sensory sample should be normalized by sensory sensitivity to provide a proper estimate of confidence probability. Without this normalization, the direct use of confidence evidence could lead to over- or underconfidence judgments.

Human observers can deviate from the ideal confidence observer in two main ways. First, confidence evidence can be corrupted by confidence noise M that is making the evaluation of

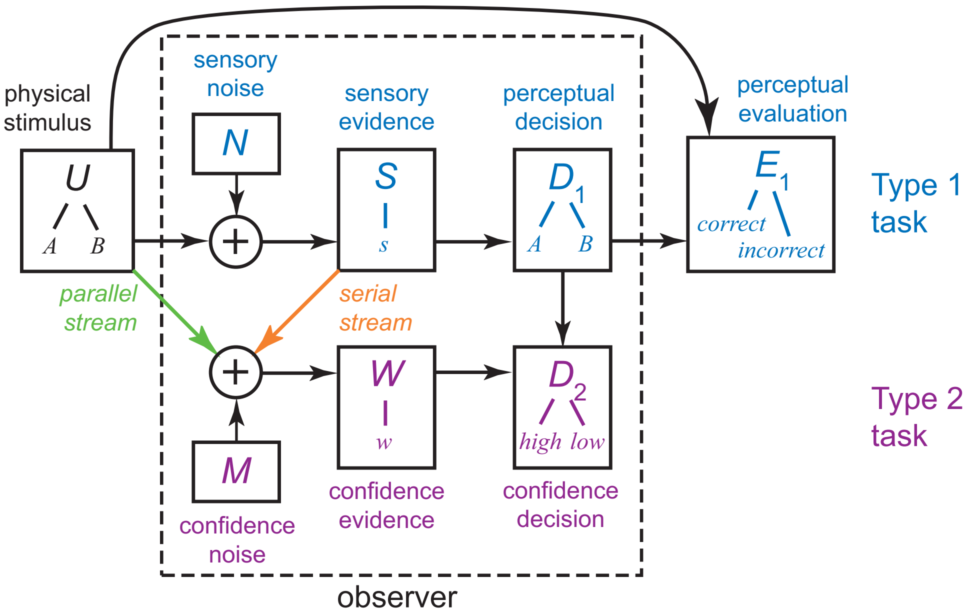

Figure 2. Flow of Information for the Perceptual and the Confidence Judgments. Perceptual decisions rely on sensory evidence, whereas confidence judgments rely on confidence evidence. This confidence evidence can be a noisy duplicate of the sensory evidence (serial stream), a novel estimation of the stimulus (parallel stream), or a combination of both. See text for details.

the correctness of the perceptual decision more difficult. In the extreme, when M is infinite, observers are no longer able to evaluate their own performance, even though that performance is above chance. This extreme example is known as blindsight as we have discussed earlier. The second way human observers can deviate from the ideal confidence observer is by benefiting from sensory information that was not used during the perceptual decision. This confidence boost can be modeled as another look at the stimulus for the purpose of the confidence judgment, but it can include any information that did not directly contribute to the percept, such as for instance the response time to report the percept. Therefore, confidence boost helps the confidence judgment, whereas confidence noise hinders it. Because of their opposite effects, these two components of our model of confidence are difficult to disentangle.

The introduction of confidence boost creates a parallel stream to process confidence. In the extreme, when confidence relies exclusively on this confidence boost and no longer on the sensory evidence that was used to compute the perceptual decision, perceptual and confidence processing are independent of each other. We can contrast this parallel processing to a serial processing of confidence that uses exclusively sensory evidence (see again Figure 2). The extent to which confidence is computed mostly serially or mostly in parallel is an important issue that undoubtedly will receive a lot of attention. Unfortunately, to be able to contrast serial and parallel models, we will first need to disentangle confidence noise and confidence boost, and this is a difficult task as we mentioned earlier.

Updated Definition

The classical definition of confidence is based on an estimate of the correctness of a perceptual decision. However, without any fair feedback, it is impossible for the perceiver to know whether her percepts are actually correct or not. This issue is critical when the perceptual decision is biased. Obvious instances of biased perception are visual illusions. For example, in the vertical–horizontal illusion, the vertical segment of a T-figure appears longer than the horizontal segment even though the two segments have the same physical lengths (e.g., Mamassian & de Montalembert, 2010). Another example of visual illusion is illustrated in Figure 3 where two gray patches that have the same physical luminance appear to have different brightnesses due to the context. In these examples, an observer is convinced of seeing a longer vertical segment or a patch darker than the other, and yet according to the classical definition of confidence, one should conclude that the observer is overconfident.

To circumvent this problem, one may prefer to define confidence as the estimate of the probability that perceptual decisions are self-consistent rather than correct. By self-consistent, we mean the following: Should we were to face again the same stimulus in the same experimental conditions, we should take the same perceptual decision. In terms of Signal Detection Theory, perceptual decisions are defined relative to some internal sensory criteria. In particular, every time the observer is presented with a stimulus that she has to categorize as “A” or “B,” she is thought to decide alternative “A” if the sensory evidence is above the criterion, and alternative “B” if it is below the criterion. Over repeated trials, one of the two alternatives is going to be chosen more often, and the self-consistent decision is the one that is consistent with that alternative. In contrast to correctness, self-consistency is arguably something that can be computed at the neural level, for instance, by looking at the variability of neural spikes within a population of neurons. Thus, we offer an updated definition of confidence as the probability that the perceptual evaluation is self-consistent given the perceptual decision and the confidence evidence

$$\text{confidence} \triangleq P(E_1 = \text{self-consistent} | d_1, w).$$

Relaxing the definition of confidence to take into account the inherent biases of the perceiver has a cost for the experimenter. From a behavioral point of view, the experimenter does not have access to the sensory criterion used by the observer on a given trial. The best the experimenter can do is to evaluate the sensory criterion over repeated trials. Confidence is then evaluated relative to this estimated sensory criterion. Another cost for the experimenter is the added burden to instruct participants what a self-consistent report is. Pragmatically, we concede that it is fine to ask participants to estimate their subjective probability of being correct. If they are biased, they will make confidence judgments relative to their biased percept, which is compatible with our definition of self-consistency.

Overconfidence is ubiquitous in cognitive psychology (Tversky & Kahneman, 1974). Using the relaxed definition of confidence should allow us to study the interesting cases of overconfidence that are not trivially explained by a biased perception. For instance, our perception is spatially less precise and the colors are more uncertain in our peripheral visual fields, and yet we do not seem to be aware of this loss of sensitivity (Odegaard & Lau, 2016). Why, then, would we be overconfident for what we perceive in our peripheral visual field? Such questions are more challenging than the systematic qualification of overconfidence for the metaperceptual judgments of visual illusions.

Figure 3. Overconfidence in a Visual Illusion. The two diamond-shaped patches on either side of the double-headed arrow have the same intensity in the image, yet the top-left one is seen darker than the bottom-right one. The illusion comes from the subtle luminance gradient over the checkerboard. Such an illusion illustrates that an observer can be very confident about her percept and yet be completely wrong (stimulus used in a study by Mamassian & Sinha, 2001).

Confidence, Uncertainty, and Belief

At this stage, it is useful to distinguish perceptual confidence from sensory uncertainty and perceptual belief. Uncertainty refers to the variability in the representation of sensory information before a decision is taken. High uncertainty can result from bad image quality (e.g., low contrast, brief duration, pixel noise) or from anatomical or physiological limitations of the observer (e.g., the availability of only three types of cones to discriminate millions of different colors). Uncertainty contributes to confidence but is not just the inverse of confidence (Pouget et al., 2016). Sensory uncertainty might lead to bistable perception, but both possible percepts might be equally consistent with the sensory information, so that not just one of the interpretations is correct (van Ee et al., 2003).

We have linked confidence to the self-consistency of a perceptual decision after that decision has been taken. The self-consistent percept is determined by both signal and noise in the stimulus. Low confidence can result from an exaggerated reliance on stimulus uncertainty (e.g., if the stimulus has low contrast, I might tempted to conclude that I cannot possibly be good at judging its properties) or a depreciation of the signal (e.g., if a line is almost vertically oriented, I might tempted to conclude that I cannot possibly be good at judging its deviation from vertical). A bad combination of signal and noise will necessarily result in a bad confidence estimate (de Gardelle & Mamassian, 2015; Navajas et al., 2017).

Perceptual belief is yet different from uncertainty and confidence. It refers to the knowledge we acquire from our perceptual experience. Our belief usually matches our perceptual experience, but not always. In the example of Figure 3, I can occlude the parts of the image other than the two diamond-shaped patches to convince myself that they have the same gray levels. In this case, I see the two patches having different brightnesses, but I do not believe my eyes. As another example, I can believe that the dress I am looking at is blue even though the color I experience is white. I am ready to accept this discrepancy between my perception and my belief because I know that I can easily be fooled by making the wrong assumption on the color of the light source (Brainard & Hurlbert, 2015). Making wrong perceptual assumptions can lead to delusions in healthy and clinical populations (Schmack et al., 2013).

Measures of Confidence

Confidence Ratings

In their pioneering work, Peirce and Jastrow (1885) asked participants to discriminate the strength of two pressures applied to their finger and then prompted participants to judge how confident they were in their response using ratings on a 4-point scale. Confidence ratings are by far the most common method to measure confidence. This method presents several advantages, not the least one being that most participants feel they can easily understand what is being asked from them. This method has also some technical advantages such as the possibility for the experimenter to compute the Type 2 Receiver Operating Characteristic (ROC; see, e.g., Fleming et al., 2010). The Type 2 ROC plots the conditional probability of being confident given that the response was correct against the probability of being confident given that the response was incorrect. The area under this Type 2 ROC curve is an index of confidence sensitivity.

However, there are at least three issues with confidence ratings. First, there is typically a large intersubject variability that, at least in part, is due to idiosyncratic uses of the confidence (Kolb & Braun, 1995; Morgan et al., 1997). Some participants might be plainly optimists and use only the upper part of the rating scale, while others might be pessimists and use the lower part. It is possible to train participants to use a rating scale properly, and it is also possible to incentivize the correct matching of ratings and probabilities, but the procedures are costly and reduce the immediate appeal of using raw confidence ratings (Lebreton et al., 2018; Massoni et al., 2014). A second issue is that confidence ratings are linked to undesirable free parameters that need to be estimated when confidence data are analyzed. These parameters correspond to the boundaries between confidence levels that allow participants to map an internal variable of confidence that is presumably continuous onto a few discrete confidence levels. Even though the positioning of these boundaries can be modeled (for a good example, see Aitchison et al., 2015), it remains that these boundaries are still additional free parameters whose positions are usually not determined by an independent experiment. Finally, confidence ratings can sometimes lead to a confound between perceptual and confidence judgments. Confidence ratings are indeed conventionally used in Signal Detection Theory paradigms to build the traditional (Type 1) ROC curve (Green & Swets, 1966). In this case, confidence ratings can be interpreted by the observer as a mean to report finer sensory judgments instead of the traditional binary forced choice. For instance, if the observer is asked to discriminate the color of a patch between green and red, and then make a confidence judgment on two levels, she might be tempted to split her judgments between highly saturated green, faintly green, faintly red, and highly saturated red. Here, confidence judgments are no longer evaluations of the correctness of the perceptual decisions (i.e., a Type 2 judgment) but instead a finer perceptual decision (i.e., a Type 1 judgment).

The propensity of confidence ratings to conflate Type 1 and Type 2 judgments is exacerbated when these two judgments are reported simultaneously. For instance, in the aforementioned example, the observer might be given four response keys, two on the left to report that the patch was seen green, two on the right to report red, with the two extreme keys to report high confidence and the two middle keys to report low confidence. The use of this procedure is very tempting for the experimenter and the observer as it seems like a gain of time to collect both Type 1 and Type 2 judgments. However, the simultaneous reporting of perception and confidence is problematic for at least two reasons.

The first issue is the enforcing of the use of the same information for the two judgments. As such, it is a procedure that is sometimes explicitly favored by experimenters in an attempt to prevent participants to use any information for confidence that was not also used for the perceptual decision. Indeed, it is known that after the perceptual decision is taken, there is further processing of the stimulus that is used to evaluate confidence (Pleskac & Busemeyer, 2010). This extra time could allow participants to change their mind between the perceptual decision and the confidence judgment (e.g., Resulaj et al., 2009), or to the extreme, realize that the perceptual decision is incorrect as it is the case for instance in the classical Stroop effect (Stroop, 1935). However, it is not clear that the simultaneous reporting of perception and confidence actually prevents participants to use nonperceptual information in the confidence judgment. Because this procedure is a four-alternative forced choice, it usually leads to longer response times, and it is difficult to know what participants do during this extra time. Moreover, we have emphasized that confidence is defined relative to a perceptual decision that is completed, so we believe it is important to let time to participants to reevaluate their perceptual decision. Not separating the Type 2 judgment from the corresponding Type 1 is to prevent an observer to reflect on the possible sources of conflict or interference in the stimulus, an ability that human observers clearly possess (Morsella et al., 2009).

The second issue with the use of combined Type 1 and Type 2 judgments is a bit more technical. It allows participants to set different confidence criteria for the different perceptual categories (Galvin et al., 2003). This might be an intentional choice of the experimenter, but one has to be aware that this is not a feature of the confidence judgment as we have defined it earlier. When confidence is defined relative to a perceptual decision that is completed, the observer decides whether she is more or less certain to be correct, and she reaches her decision based on the strength of the confidence evidence. As we have discussed in the context of the ideal confidence observer, this confidence evidence is based on the magnitude of the sensory sample. In the aforementioned example with two confidence levels, the observer judges whether the confidence evidence is above or below a confidence boundary, and this confidence boundary is identical, irrespective of whether the observer saw a green or red color. Combining Type 1 and Type 2 judgments into a single response thus allows observers to use different confidence boundaries for green and red. Handling different confidence boundaries for different percepts makes the interpretation difficult, unless we revert back to the sensory continuum (more or less saturated colors) rather than the confidence continuum, but then we are back to the perceptual domain. For these reasons, the Type 2 measures extracted from the procedure of asking simultaneously perceptual and confidence judgments are sometimes called “pseudo-Type 1 ratings” (Galvin et al., 2003).

Alternative Confidence Measures

While confidence ratings are by far the most common method to measure confidence, alternative paradigms have been proposed (Figure 4). Some of these methods have been tailored to be applicable to animals other than humans, where it is hopeless to instruct participants to use a rating scale. By extension, these methods can also be used in clinical studies or with preverbal infants.

With nonhuman primates, Kiani and Shadlen (2009) used an opt-out paradigm. Animals were trained to choose one of the two options after watching a random-dot kinematogram with various levels of uncertainty, and they were rewarded for correct decisions. On half of the trials, the animals were offered a third opt-out option, and if they used it, they received a small but sure reward. The reasoning is that the animals should use the opt-out option whenever they are not confident enough with their planned response. The results of this study suggested that indeed macaque monkeys only chose the opt-out option for the most uncertain trials. One challenge in using this paradigm is to avoid confounding it with a

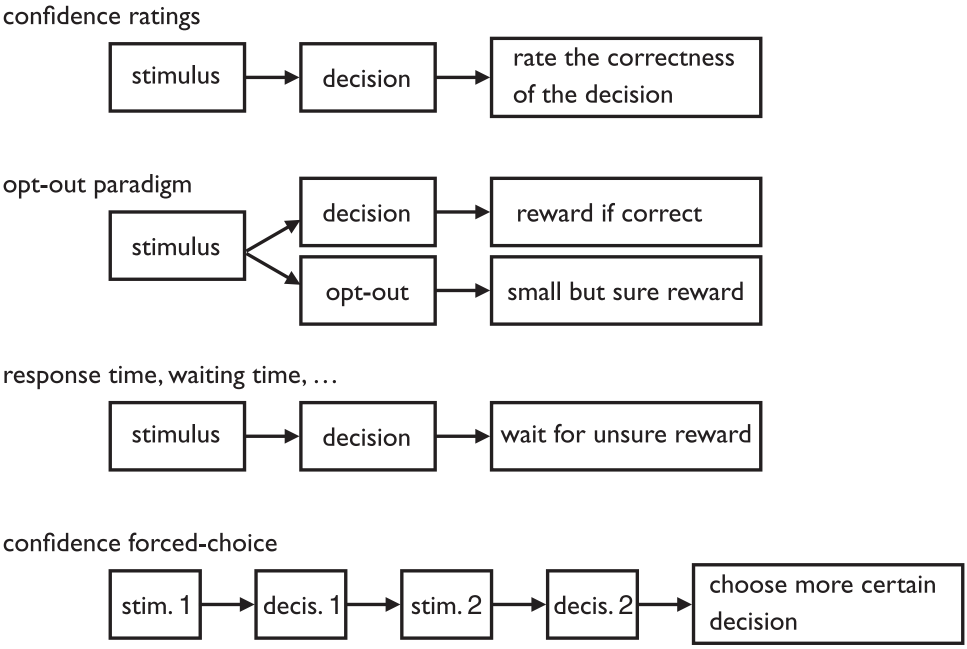

Figure 4. Varieties of Behavioral Methods to Measure Confidence. The most common way to measure confidence is by using confidence ratings whereby participants are presented with a stimulus, they have to make a perceptual decision on that stimulus, and then they have to rate the correctness of their decision. Other methods include the opt-out paradigm, a variety of methods involving processing time, and finally the confidence forced-choice paradigm. See text for details.

perceptual three-alternative forced choice. In this latter case, the sensory continuum is divided in three perceptual categories (clearly alternative "A," clearly alternative "B," and something in-between "A" and "B") rather than two perceptual categories ("A" and "B") and two confidence levels (high and low confidence). The mixing of trials with and without the opt-out option reduces this confound but does not completely eliminate it.

Alternative methods rely on some temporal property of confidence. One well-studied property is the correlation of confidence with response times, such that long response times reflect harder processing and thus should be associated with low confidence (e.g., Kiani et al., 2014). Another interesting temporal property is the time one is willing to wait to receive a reward after a correct decision. For instance, Kepecs et al. (2008) found that rats waited longer for their reward on the correct trials, suggesting that rats have some form of metaperception.

Confidence Forced-Choice

We have recently proposed the confidence forced-choice paradigm as an alternative method to study confidence (Barthelmé & Mamassian, 2009, 2010; Mamassian, 2016). In the confidence forced-choice paradigm, the observer is prompted to choose among two perceptual decisions the one she thinks is more likely to be correct (Figure 4). In a typical experiment, a first stimulus is presented, the observer makes a perceptual decision on that first stimulus.

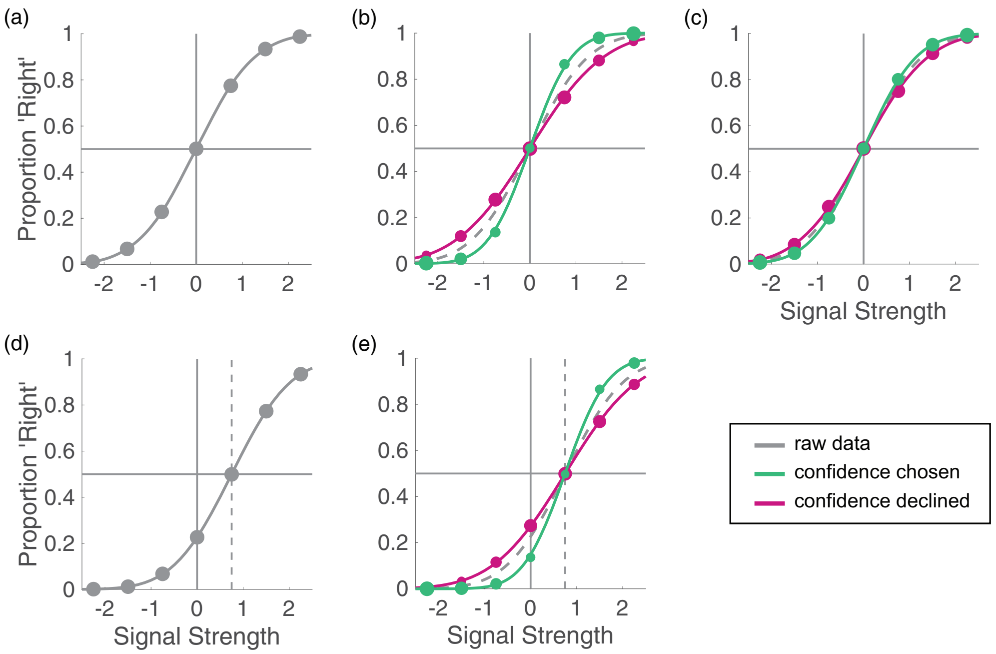

Figure 5. Analysis of Confidence Forced-Choice Data. A: Baseline psychometric function from a simulated experiment where the observer has to discriminate an uncertain stimulus with various signal strengths. B: When the data are replotted separately for “chosen” (in green) and “declined” (in red) confidence trials, the “chosen” psychometric function has a steeper slope than the baseline function, shown as a dashed line (in gray) for reference. C: Confidence noise makes the psychometric function for the “chosen” trials more similar to the baseline one. D: Psychometric function from a biased observer who has a bias to respond “left,” resulting in a psychometric function shifted to the right. E: The analysis of confidence chosen and declined trials is robust to a sensory bias. In each plot, dot size is proportional to the number of trials.

Then a second stimulus is presented, and the observer makes a perceptual decision on that second stimulus. Finally, the observer decides which of the two perceptual decisions she thinks she is more likely to be correct. The experiment goes on asking participants what they perceive when stimuli are presented, and every two perceptual decisions, participants are prompted to choose which of the last two perceptual decisions they think they are more likely to be correct (de Gardelle & Mamassian, 2015).

Results obtained with the confidence forced-choice paradigm are easy to analyze. Let us go through a simulated experiment (Figure 5) where the observer has to categorize an uncertain stimulus as “left” or “right.” The ability to accurately discriminate the stimulus as “right” grows with signal strength, and we call the resulting psychometric function the “baseline function” (Figure 5A). In the confidence forced-choice paradigm, pairs of stimuli are presented. The two stimuli in a confidence pair can have the same or different difficulty levels. The observer discriminates “left” from “right” for each stimulus and then chooses the decision (“first” or “second”) that she thinks is more likely to be correct. Each stimulus of a pair is then either “chosen” or “declined” as being confident. The baseline psychometric function can then be replotted separately for “chosen” (Figure 5B in green) and “declined” (Figure 5B in red) trials. In this simulation, the observer followed the ideal confidence observer. For the ideal confidence observer, the “chosen” interval is the one for which the sensory evidence is further away from the sensory criterion. When confidence noise is present, the new psychometric function for the “chosen” trials becomes more similar to the baseline psychometric function (Figure 5C). When the observer is biased in her perceptual judgments, her baseline psychometric function is shifted (Figure 5D). Importantly though, this perceptual bias is of no consequence for the confidence judgments. Once the trials are sorted as “chosen” or “declined” for confidence, the resulting psychometric functions have the same slopes as when there was no bias (Figure 5E).

Confidence sensitivity, the ability to make reasonable judgments about one’s own perceptual decisions, can then be easily verified. When the data are split between “chosen” and “declined” confidence labeled trials, the “chosen” psychometric function should reveal better perceptual performance if the observer has good confidence sensitivity. This property is a direct consequence of metaperception. If the observer has access to some information about her own performance, then on each trial in a confidence pair, she should be able to pick the decision that leads to better performance, and she should be able to do this better than chance. Collecting all the confidence “chosen” trials should therefore lead to a better performance than the one with all trials (baseline).

The better the observer is at estimating her own performance, the steeper the slope of the psychometric function for the confidence “chosen” trials (the green curve having a steeper slope than the red curve in Figure 5B). As the observer gets worse at inferring the likelihood of making correct perceptual judgments, the “chosen” psychometric function will become closer to the baseline psychometric function (Figure 5C), and in the extreme case of blindsight, the two functions will be identical. Therefore, confidence sensitivity can be read from the gain in slope of the psychometric functions for the confidence chosen trials as compared with the one for the baseline trials. It is nice to place an upper bound on this gain in slope, and this is the role of the ideal confidence observer. This ideal confidence observer has the same sensory limitations as the human observer (it has the same sensory internal noise that is responsible for the slope of the psychometric function for the baseline trials), but it is confidence ideal in the sense that for the confidence judgment, it reuses the same sensory evidence with no loss and no gain of information. Confidence efficiency can then be calculated as the extent to which the “chosen” psychometric function approaches the one obtained from the ideal confidence observer.

The computation of the ideal confidence observer is beyond the scope of this study, but we can at least mention one special case. This special case is the one where only one level of difficulty is present, that is, both stimuli in any confidence pair are equally difficult. In this case, the gain in the slope of the psychometric function between the baseline function and the confidence-chosen psychometric function is exactly square root of two (Appendix A). In the general case where the observer is faced with multiple difficulty levels within an experimental block of trials, the confidence gain of the confidence ideal observer is close to but no longer exactly square root of two.

The confidence forced-choice paradigm removes the three concerns highlighted in “Confidence Ratings” section with respect to confidence ratings. In particular, there is no room for idiosyncratic strategies as the observer is forced to choose one option out of a pair of stimuli. There is no criterion that the observer is free to place along her sensory internal representation and that is hidden to the experimenter. And the instruction is explicit in referring to the higher probability of being correct in the perceptual decision. It is also worth noting that this paradigm is oblivious to the presence of perceptual biases, so this paradigm is compatible with our updated definition of confidence that takes into account perceptual biases such as the ones occurring for instance in visual illusions.

All the benefits of the confidence forced-choice paradigm should not surprise the reader who is well versed in Signal Detection Theory. It is well-known that comparing two stimuli in the two intervals of a two-alternative forced-choice paradigm is good practice to obtain a bias-free measure of sensitivity (e.g., Kingdom & Prins, 2016). Likewise, comparing biases across two intervals is a way to obtain a measure of perceptual biases that is free of response biases (Patten & Clifford, 2015; Schreiber & Morgan, 2018). Finally, comparing the magnitude of differences across pairs of stimuli in the Maximum Likelihood Difference Scaling procedure is a way to measure perceptual sensitivity for suprathreshold stimuli (Knoblauch & Maloney, 2008).

Conclusion

Peirce and Jastrow (1885) conclude their report on the analysis of near threshold sensation as follows:

> [There are some] sensations so faint that we are not fairly aware of having them, and can give no account of how we reach our conclusions about such matters. The insight of females as well as certain "telepathic" phenomena may be explained in this way. Such faint sensations ought to be fully studied by the psychologist and assiduously cultivated by every man. (p. 83)

It is fair to say that most researchers have lost the impetus to search and explain telepathic phenomena, not to mention the insight of females. However, the study of faint sensations, and the confidence we have about the correctness of these sensations, are still challenging research topics in contemporary perceptual science. When we look for the origins of our confidence judgments, one of the primary issues is whether confidence is computed serially from the same information as the one used for perceptual decisions, or in parallel to that perceptual processing. Recently, we have introduced the confidence forced-choice paradigm as an objective way to measure confidence. We are currently investigating the extent to which this paradigm could help us disentangle serial and parallel processing of perceptual and confidence judgments. These studies will help us build a better understanding of confidence and other metaperceptual judgments. Addressing all facets of metaperception will eventually lead to a more complete appreciation of metacognition in humans and other animal species.

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Appendix A

We are interested here in computing the performance of the ideal confidence observer in a simple case. The task of the observer is to categorize a stimulus as category "right" if the signal strength is positive, and as category "left" is the signal strength is negative. We will assume in this example that all stimuli presented to the observer have the same difficulty level, represented by the absolute signal strength μ. In the confidence forced-choice paradigm, two stimuli are presented, the observer makes a perceptual decision on each of these stimuli and then chooses which decision was more likely to be correct. In a confidence pair, both stimuli can be positive, both negative, or one positive and the other negative. We first consider the condition where both stimuli are positive, but the other conditions actually lead to the same results when the difficulty levels are all the same.

On average, the observer's ability to properly respond "right" is directly related to the signal strength μ. Within the framework of Signal Detection Theory, the stimulus is generating some sensory evidence s. We assume that the sensory noise that is corrupting the stimulus strength into the sensory evidence is normally distributed with a variance equal to 1. The blue curve in the dashed-red rectangle of Figure A1 represents the distribution of sensory evidence across multiple trials. This curve is a Gaussian centered on μ with unit variance. The observer then makes her perceptual decision based on the sign of s (we ignore here that the observer can be biased, i.e., that the sensory criterion can be different from 0). The probability of responding "right" is then the area under the blue curve to the right of 0 (the shaded blue area). This probability equals $\Phi(\mu)$, where Φ is the cumulative of the standard normal distribution.

Following the confidence forced-choice paradigm, the observer is presented with two intervals, each one containing a stimulus, so that the observer has access to sensory evidence s_1 in the first interval and s_2 in the second interval. Based on each of the two sensory evidence, the observer has to make two perceptual decisions, and then she has to choose the decision that she thinks is more likely to be correct. On what basis should the observer choose one rather than the other decision as the one she feels more confidence about? Signal Detection Theory is again providing the answer here. Ideally, the observer should estimate the magnitude of the sensory evidence for each interval and choose the interval that contains the largest magnitude. We call confidence evidence w the magnitude of the sensory evidence s. The ideal confidence decision rule is then to decide whether $w_1 > w_2$ or $w_1 < w_2$.

The space of all possible pairs of sensory evidence across the two intervals can be divided into four areas according to the confidence decision rule (see central circular plot in Figure A1). Area "A," for instance, is such that the first interval contains a confidence evidence that is larger than that in Interval 2, and the perceptual decision in Interval 1 was "right." We can summarize this by stating that area "A" is "1-right." Similarly, area "B" is "2-right", area "C" is "1-left", and area "D" is "2-left."

We can now collect all the trials that led to a decision "right" and for which this decision was chosen as the more confident one. These trials correspond to the sum of areas "A" and

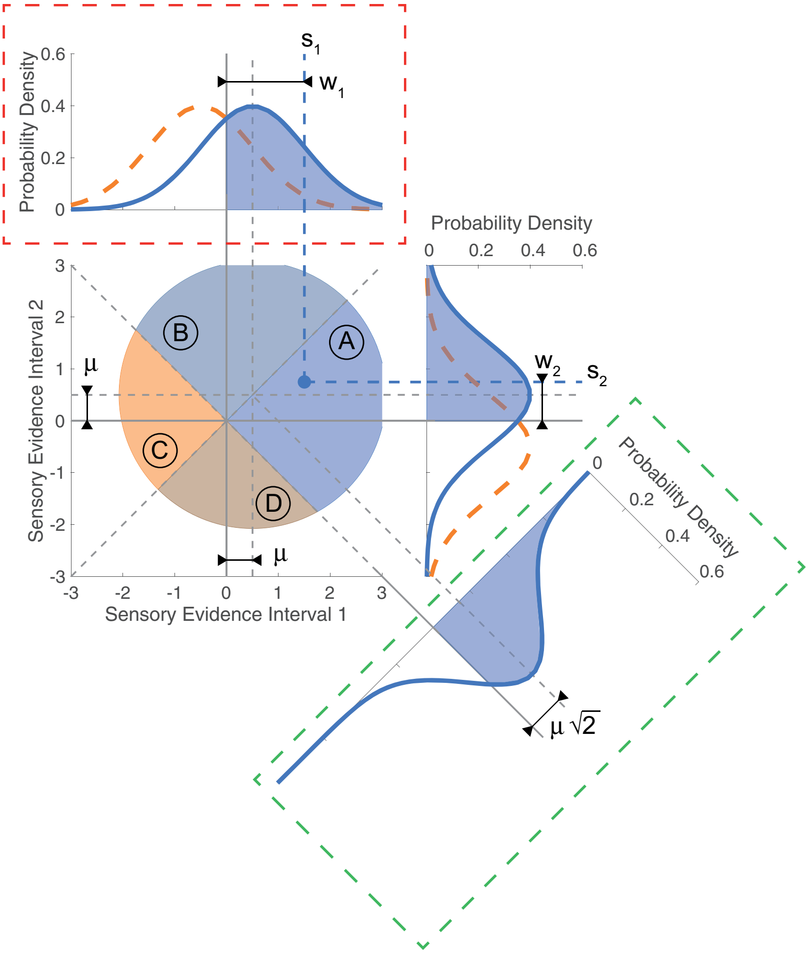

Figure A1. Calculation of the Ideal Confidence Observer in a Simple Case. We are considering here the special case where the two stimuli in a confidence pair have the same difficulty levels. In this case, the gain of the psychometric function between confidence chosen trials and baseline trials is exactly square root of two. See text for details.

"B." Out of all the confident trials (represented by the sum or areas "A," "B," "C," and "D"), the ones that led to a decision "right" are therefore located in the upper-right half space of the sensory evidence space. The probability of responding "right" in the confident trials can thus be obtained by rotating the evidence space by 45°, and taking the area under the curve in the dashed-green rectangle in Figure A1. This latter curve is again a Gaussian with unit variance but with a mean that is now $\mu\sqrt{2}$. The probability of responding "right" in the confident trials is thus $\Phi\left(\mu\sqrt{2}\right)$.

In summary, the probability of responding "right" across the baseline decisions is $\Phi(\mu)$, and it becomes $\Phi\left(\mu\sqrt{2}\right)$ for the confidence chosen decisions. If we were to model the psychometric function by a cumulative Gaussian function, the psychometric function for the confidence chosen decisions would therefore be steeper than the baseline decisions, and the gain in the slope of the psychometric function would be exactly $\sqrt{2}$. This result holds for the ideal confidence observer in the special case where only trials of equal difficulty are presented. It generalizes to cases where stimuli still have equal strengths, but where this strength can be either positive or negative. However, it does not generalize to cases where the stimuli presented in the two intervals can have any level of difficulty, and more importantly, it does not take into account any deviation away from the ideal confidence observer (confidence noise or confidence boost).

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