Reporting on the Temporal Properties of Subliminal Events

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ABSTRACT

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What is the fate of a stimulus which is processed, but not consciously seen? Are there any properties of subliminal or preconscious stimuli which are available for conscious report? While psychologists have long been interested in these and similar questions, the answers obtained have varied. This variation is partly a function of the process of uncovering previously overlooked methodological limitations, and then advancing beyond them. The present work takes advantage of a masking technique known as continuous flash suppression to examine an underexplored stimulus property - temporal order. Data from three studies indicate that participants are able to judge whether a subliminal event comes before or after a cued button press. This data is taken to indicate that not all processing is suppressed equally in subliminal masking paradigms. In particular, it seems probable, especially in light of previous work, that processing in the dorsal visual pathway is spared to a greater extent, and is available for introspection. Given this, future work will focus on investigating whether these effects are robust to manipulations of physical action. Implications for theories of action control and visual awareness are discussed in light of the present findings.

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Chapter 1

Introduction

In 1957, James Vicary, a market researcher, issued a press release outlining the results of a study on the effectiveness of subliminal advertising. In it, he claimed that after subliminally priming people with the words "eat popcorn" during a movie, popcorn sales increased by a whopping 57.5 percent. A similar effect was claimed for soda, with the words "drink coke" leading to almost a 20 percent increase in soda sales (Weir, 1984). Though Vicary later disavowed the claims and, in all likelihood, the study never actually took place, the idea that subliminal information can influence behavior was then and today remains a captivating idea within popular culture.

The fascinating idea that things for which we lack awareness can influence our behavior does not elicit interest solely with the general public. It has also motivated a considerable amount of research within scientific psychology. This work has convincingly demonstrated that stimuli for which individuals report no awareness has the capacity to change behavior. Moreover, related work has demonstrated a diversity of ways in which stimuli can be presented without the observer's awareness. There are also clinical cases, such as blindsight or neglect, in which the patient reports no awareness of the stimulus, but seems to behave in ways which indicate that they do.

Indirectly at least, each of these areas is also concerned with the question of subliminality.

If an observer verbally states that they have no awareness of the presented stimulus, what does this mean for the fate of the stimuli? Clearly, if it is to influence behavior, certain aspects of it are at least minimally processed. How much of this processing might be available for conscious report is question which is yet unsettled.

This chapter will synthesize work related to these issues. In the first section of this chapter, I will outline the research demonstrating that subliminal stimuli can influence behavior and, importantly, the methodological issues in conducting such research. Following this, I will introduce a classification of stimuli which do not reach awareness, with the goal of demonstrating that the fate of a stimulus varies largely depending on why it failed to reach awareness. The third section will draw parallels with experimentally induced invisibility with clinical conditions in which patients report lacking awareness while their behavior indicates otherwise. Finally, in the fourth section, I will turn to work which speaks very specifically to an observer's ability to introspect on qualities of stimuli they report no awareness of and controversies in this area of work. At the close of this fourth section, I will introduce the present studies.

1.1 Subliminality and Subliminal effects

The investigation of how subliminal stimuli can influence behavior has a long history of research. In an early investigation, Sidis (1898) showed subjects characters printed on cards, though at a distance much too far for easy identification. Despite subjects claiming that the stimulus was too far, or that they did not know what the stimulus was, they were better than chance at discriminating whether the character was a number or a letter. Others soon found similar kinds of effects (Baker, 1938; Pillai, 1939; Williams Jr, 1938), including in other modalities (Stroh, Shaw, & Washburn, 1908). In the years following these early studies, certain methodological problems became apparent. Scholars, in critiquing methodology or interpretation, suggested that the evidence did not back up the claims (Eriksen, 1960;

Holender, 1986).

Critiques of this type of reesearch has been revived in recent years, though in somewhat of a different domain. Social psychology, partially as an attempt to remove expectancy effects from experimental investigation of basic social behavioral mechanisms, turned to subliminal stimulation. Beginning with a series of landmark papers in the late 1980's and early 1990's (e.g., Higgins, Bargh, & Lombardi, 1985; Bargh, Chen, & Burrows, 1996), researchers soon began systematically demonstrating that social behavior could be dramatically influenced by exposure to subliminal primes. However, following the recent controversies surrounding data fabrication and failed replications within the broader field of psychology, social priming has become the "poster child for doubts about the integrity of psychological research" (Kahneman, 2012), and there is, once again, a wave of critical thought crashing over the subfield.

Nevertheless, while specific experimental demonstrations may be questioned, the idea that subliminal stimuli can influence behavior is today almost certainly more widely accepted. Most of the work surrounding this issue has turned to what kinds of behaviors can or cannot be done unconsciously or facilitated with subliminal stimuli. In particular, research in recent years has found that many higher cognitive processes, including those typically dubbed as System 2 (Kahneman, 2011), such as task preparation (Lau & Passingham, 2007), goal pursuit (Bargh, Gollwitzer, Lee-Chai, Barndollar, & Trötschel, 2001), response inhibition (van Gaal, Ridderinkhof, Scholte, & Lamme, 2010), and even basic arithmetic (Sklar et al., 2012) are all susceptible to influence via subliminal information. Recently, Hassin (2013), even outlined the provocative Yes It Can hypothesis, delineating the circumstances under which subliminal information can influence cognition. His suggestion is, in short, all of them.

Though Hassin (2013) is referring to unconscious cognition rather than subliminal stimuli per se, the primary point here is that the scientific consensus toward subliminal stimuli and the unconscious has shifted considerably in recent years. How is it that the current thinking has gone from one in which it is widely acknowledged that the evidence needed for these types of claims did not exist to one where it is not only widely accepted that the claims are true, but that some will even go so far as suggesting that subliminal information can influence every aspect of behavior? I suggest that this shift has happened for two primary reasons.

First, it is one consequence of the way we presently conceive of the mind. The popularity of dual-process theories throughout psychology, in which one of the processes proceeds unconsciously (e.g., Kahneman, 2011; Cacioppo & Petty, 1985; Strack & Deutsch, 2004; Stanovich & West, 2000) is an illustration of the strong hold that the cognitive unconscious has on thinking within the field. It is difficult to conceptualize a psychology without room for the effect of information outside of conscious awareness (Bargh & Morsella, 2008). Again, much of this work concerns unconscious cognition - a set of processes which are not synonymous with subliminal stimuli. However, subliminal stimuli are often key in showing the outputs of the cognitive unconscious, and as a result they are often swept up in the larger discussion of unconscious cognition.

Second, and more directly relevant to the work presented here, this transition can also be thought of in terms of methodological advances. Although there is still no 'gold standard' for how to demonstrate the effect of a subliminal stimulus, there are a variety of approaches which are commonly used.

In order to investigate the effect of subliminal stimuli, an investigator must take certain steps to ensure that the stimulus does not reach conscious awareness. A variety of methodological techniques are available for this purpose. Backward and forward masking (Breitmeyer, Hoar, Randall, & Conte, 1984), change blindness (Simons & Levin, 1997), and attentional blink (Raymond, Shapiro, & Arnell, 1992) are just a few commonly used strategies. Once one of these strategies has been used, the experimenter is then left with the task of demonstrating that the stimulus is indeed below the level of awareness. The simplest way to do this is to simply ask the subject whether he or she saw the stimulus. Unfortunately, this leads one to the issue of not knowing precisely what it takes for a response indicating awareness. In other words, different subjects, under different circumstances will almost certainly use different criteria for a report of 'seen' versus 'not seen', leading to justifiable concern over the extent to which these reports are reflective of the subject's actual experience.

A second way to demonstrate that the presented stimuli are subliminal is to use more objective measures. For example, if an experimenter uses words for primes, some trials with nonwords could be mixed in. The subject is then asked to discriminate, trial-by-trial, whether the presented stimulus is a word or a nonword. If the stimuli are truly subliminal, so the reasoning goes, then responding should be no better than a guess (i.e. chance performance). This too, is not without potential problems. In particular, there is no guarantee that this measurement fulfills what Reingold and Merikle (1988) referred to as the exhaustiveness assumption. This assumption specifies that an objective measure of awareness should capture all aspects of awareness. In other words, even though, in the above example, a subject may be at chance discriminating whether a letter string is a word, that is not to say that they would also be at chance if you had asked them to introspect on some other aspect of the stimulus (e.g. the color of the font). That different aspects of the same stimulus may yield to differing levels of objective awareness is an interesting question I will deal with quite directly. Why might a subject be at chance when identifying the word/nonword status of a stimulus, but be able to report quite well on the color or some other property? I will take up this issue in some detail in the discussion.

A related issue raised by Reingold and Merikle (1988) is the exclusivity assumption. This is the assumption that the objective measure of awareness the experimenter chooses should only measure conscious awareness, and should never be influenced by unconscious processes. This assumption is also problematic, as it seems almost inevitable that a subject, confronted with a question for which they have no conscious information, might well draw (at least passively) on unconscious processes in order to inform decision making, a point made initially by Marcel (1983). If this highly probable strategy is something subjects really use, then it stands to reason that it will never be possible to show a complete lack of sensitivity.

Although these criticisms of the unrealistic requirements to demonstrate subliminality were warranted, the solutions proposed by Reingold and Merikle (1988) proved to be methodologically unwieldy, and convincing evidence was difficult to come by. Fortunately, Greenwald, Klinger, and Schuh (1995) highlighted a way forward. If the experimenter's objective is to demonstrate some effect in the absence of awareness, he or she should obtain some objective measure of awareness (the direct effect), and a measure of the effect of interest (the indirect effect). The experimenter then uses linear regression to estimate the direct effect on the indirect effect, looking in particular for the predicted level of the indirect effect, given a score of zero on the direct measure. That is, regress the effect of interest on the objective measure of awareness, and examine the y-intercept. If the y-intercept is reliably different from zero, then one can claim that, at zero objective sensitivity, there is still some evidence for an effect.

Another frequently used approach is to obtain metacognitive measures such as wagering or confidence judgments with respect to the perceptual experience (Persaud, McLeod, & Cowey, 2007; Rahnev, Maniscalco, Luber, Lau, & Lisanby, 2012; Schurger & Sher, 2008). If a subject has some conscious perceptual experience of a stimulus, they will rate their confidence as higher and will wager more resources on the veracity of a judgment they make about the stimulus than if they had no such perceptual experience. While this is an encouraging approach, subjects can also display metacognitive patterns which would suggest they saw the stimulus under conditions in which it is unlikely that they have done so, making it difficult to interpret what else, aside from visibility, these ratings might reflect (Kanai, Walsh, & Tseng, 2010).

In sum, there exist a variety of techniques for demonstrating that a stimulus is subliminal. Although no individual method can hope to provide convincing evidence for the subliminality of a stimulus, the confluence of data from multiple approaches can certainly strongly suggest that, even if one is not sure that a particular stimulus is always subliminal, it can still influence behavior under conditions where subliminality is likely. The use of these methodological advances, therefore, has lead to a surge in interest and evidence for the effects of subliminal stimuli on higher-level cognition.

How is it, however, that a subliminal stimulus can influence behavior? To what extent are such stimuli processed which allows them to exert leverage on cognition? I now turn to exploring the ways in which stimulus visibility may be reduced, and what the various techniques mean for the fate of the stimulus.

1.2 Visibility Reduction

One can differentiate two primary classes of stimulus visibility reduction methods. In the first, a stimulus can be rendered invisible by reducing the strength of its signal. This form of invisibility is often referred to as *subliminal* (Dehaene & Changeux, 2011), and is frequently accomplished via visual masking. A presented prime may, for instance, be preceded or immediately followed by a visually loud mask. Similar ends are achieved through continuous flash suppression, in which a prime is presented to one eye, while a dynamic mask is presented to the other (Tsuchiya & Koch, 2005). In each of these masking procedures, the general effect is to reduce the ability of the stimulus to achieve activation sufficient for conscious report. In general, this is accomplished by interfering with the neural feedback processing which seems to be an important component of conscious awareness (Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006). As highlighted above, stimuli presented in this manner have been shown to change or facilitate performance in a variety of task areas (Lau & Passingham, 2007; Bargh et al., 2001; van Gaal et al., 2010; Sklar et al., 2012)).

As an illustrative case, consider Klotz and Wolff's (1995) findings on unconscious priming of form processing. Participants were told to respond to two different targets, each assigned a different response key. Unbeknownst to the participants, these targets masked a prime via metacontrast masking. These primes could be either congruent, incongruent, or neutral with respect to the target's form. Participants reported no awareness of the primes, and a subsequent experiment showed them to be objectively invisible in a forced-choice task. However, despite this invisibility, they exerted an influence on reaction times to the targets. Participants were quicker to responded on congruent trials, and slower on incongruent trials. Thus, although participants did not report on the form directly, they clearly processed it in a way which biased their reaction time.

However, effects such as the one reported above tend to be limited in important ways. In principle, the higher the level of cognitive processing and the longer amount of time since the prime, the smaller the influence of a subliminal prime (van Gaal, Ridderinkhof, Fahrenfort, Scholte, & Lamme, 2008). Further, the capacity for such subliminal primes to lead to any durable changes in higher-level functioning seems to be relatively restricted. For example, Heinemann, Kunde, and Kiesel (2009) showed that while context can modify the strength of interference in response-conflict paradigms, this context-dependent modification does not occur when the conflicting information is masked. Further, measures of the effect of subliminal stimuli rely on indirect measures such as reaction time to a subsequent stimulus. It is not the case that observers report directly on the stimulus itself.

Alternatively, a stimulus can be rendered invisible by manipulating the observer's attention. Stimuli rendered invisible via such methods have been described as *preconscious* (Dehaene & Changeux, 2011). In this case, the stimulus is present and visible, but because attention is diverted elsewhere, the observer will fail to notice it. In general, these kinds of preconscious stimuli tend to elicit stronger effects as the underlying signal is much stronger than that of a subliminal stimulus, which is made subliminal precisely because the signal is weakened. For example, in attentional blink paradigms, instructions to attend to a particular item in a rapid serial presentation stream will reduce awareness of a second item presented shortly afterwards (Raymond et al., 1992). In this paradigm, the missed item has been shown to prime responding to subsequent stimuli which are categorically or semantically similar (Shapiro, Driver, Ward, & Sorensen, 1997). There is also neural evidence indicating that semantic information is processed in these paradigms, but is not available for conscious report (Luck, Vogel, & Shapiro, 1996).

In a related series of studies, Mack and Rock (1998) report results from a paradigm they referred to generally as inattentional blindness. In these studies, approximately one quarter of subjects fail to notice a briefly presented, unexpected stimulus. However, despite reporting no subjective awareness of the stimulus, and not being able to identify the stimulus in a forced-choice procedure, these participants were often able to report on other aspects of it, such as color, motion, location, and numerosity at levels which exceeded chance. These findings clearly suggest that while some properties of a subjectively invisible stimulus (such as identity) are not available for report, others certainly are.

As a contrast to the findings typically obtained with subliminal stimuli, one paper which manipulated the observer's focus of attention showed that unattended stimuli could prime responding to a subsequent target after a single exposure, and after delays of up to a month (DeSchepper & Treisman, 1996). Although it is likely that the primes in this negative priming paradigm were clearly visible, the fact that observers did not attend to them and had no explicit memory of them is certainly reminiscent of preconscious stimuli in inattentional blindness and attentional blink paradigms.

In sum, the two forms of unconscious perception seem to lead to similar outcomes. One notable difference, however, is that the influence of subliminal information is often only seen via indirect measures, such as a bias in reaction time to a subsequent stimulus. Observers who have been exposed to stimuli which are subjectively invisible due to a lack of attention (i.e. preconscious stimuli), on the other hand, have occasionally shown evidence of being able to verbally report on the stimulus for which they claim no awareness. Their phenomenal experience may be one of sheer guessing, but these guesses are often clearly above chance. This observation shares parallels with certain clinical conditions, to which I now turn.

1.3 Neuropsychological Modulations of Awareness

While there are a number of ways to present stimuli below the level of awareness in the lab, there are also certain neuropsychological deficits which lead to similar outcomes. Patients with hemispatial neglect, for instance (Driver & Vuilleumier, 2001), exhibit what is essentially a failure to attend to stimuli on one side of space. This condition is typically associated with a unilateral lesion to the parietal lobe (Vallar, 1998). When a stimulus is presented in the affected region (typically contralateral to the lesion), they will report having no visual experience of it. However, despite these deficits, there is often evidence of intact processing in the absence of verbal reportability. For example, patients have been shown to be able to identify at levels exceeding chance whether an object in the neglected region is the same as one in the unaffected region (Berti et al., 1992). This remains true even when the stimuli are of different orientations. Further research has shown that numerical and semantic information from stimuli in the neglected region can influence responding to a target presented at fixation. Thus, although patients with neglect report having no visual experience of information in the neglected side of space, they show evidence of processing these stimuli, and can often report directly on them at levels exceeding chance, even while they feel that their response is nothing more than a guess.

A second neuropsychological condition which leads to a deficit in visual awareness is known as blindsight. In blindsight, an individual who has lesioning to their primary visual cortex and reports lacking visual awareness is nonetheless able to perform some tasks at levels significantly above chance. Perhaps the most famous patient experiencing this is DB. In work reported by Weiskrantz, Warrington, Sanders, and Marshall (1974), DB, despite claiming no visual experience, was able to accurately reach toward targets, could discriminate between different shaped stimuli, and could also guess the color of visual stimuli. While intriguing, investigation of blindsight patients are frequently criticized on the basis of methodological issues. For example, Campion, Latto, and Smith (1983) suggested that the performance observed could be due to a scattering of light into the intact visual areas, or that some portion of the visual cortex may have been retained. Despite these criticisms, most scholars believe that the patients are not normally sighted, even if they are also not fully blind (Cowey, 2010).

The literature on these clinical cases suggests that even in circumstances where the visual signal is degraded or unattended, and thus, not represented in the way typically needed for verbal report, patients are still able to report some properties of the presented stimulus. In addition to sheer verbal report, there is even stronger evidence of this in forced choice and reaction time paradigms. Due to the unusual nature of these patients, however, it is unwise to fully generalize to normal visual awareness based on their conditions.

We are thus left with the question of to what extent individuals can report on stimuli for which they claim no awareness due to either a neuropsychological condition or an experimental manipulation. If we assume that the subjects' reports are veridical, what should be concluded about the nature of this sensing of stimuli for which there is no awareness? If, on the other hand, subjects are misleading the experimenters in each of these cases, what can we say about the nature of this misleading behavior? Some of these questions have been addressed quite specifically in a relatively recent debate to which I now turn.

1.4 Sensing without Seeing

The question of what aspects of a stimulus subjects can report upon when they have no visual experience was recently and provocatively addressed by Rensink (2004). In a set of studies, participants were exposed to a change-blindness display and asked to make two responses. They were to respond initially when they had a general sense that there was a change, and then respond a second time when they were able to identify and localize the change. Rensink reasoned that instances in which difference in time between the two responses was greater than one second likely represented trials in which the observer had some sense that a change had occurred before having a visual experience of it. On this basis, he identified approximately one third of his participants who met this criteria on more than 5% of trials, and had false alarm rates of less than 50% on catch trials. Rensink's interpretation of these findings was that approximately one third of his participants had the ability to sense changes in their visual environment for which they had no corresponding visual experience - a phenomenon referred to as *mindsight*.

These interpretations were quickly disputed on methodological grounds by Simons, Nevarez, and Boot (2005). In a replication of Rensink's (2004) study, they suggested that the findings could be accounted for a with a more banal explanation - sensing was simply seeing, but associated with a lower response threshold. In their critique, Simons et al. (2005) showed that false alarm rates to catch trials were strongly correlated with mindsight rates. They further suggest that the two responses simply correspond to a two-step verification process, in which an observer detects a change with a relatively low evidence threshold, and then verifies it with a somewhat higher evidence threshold.

This question has been explored further in the years since, with mixed results. In one example using event-related electrophysiology (Busch, Dürschmid, & Herrmann, 2010), two components of interest were identified - one relatively early, and one somewhat later. Change-blindness trials were divided on the basis of whether a participant was able to only localize the change on a gross level (i.e. left or right side of the screen), if they were able to localize and identify the change, or if they remained wholly blind to the change. Results showed that the early component, which had previously been associated with detection of change in change-blindness paradigms (Koivisto & Revonsuo, 2003), was present for both localized only, and localized and identified trials, though there was a difference in magnitude. In contrast, there was a qualitative difference in the late component, where a signal was only observed on trials which were the change was localized and identified. The authors' interpretation was that this pattern likely indicates that localization and identification are sequential processes with localization occurring first, followed by identification, if the signal is strong enough. In light of this evidence, they concluded that mindsight not a reliable phenomenon.

There are, however, some suggestions that mindsight may exist, though in a more limited fashion. Galpin, Underwood, and Chapman (2008) investigated the prevalency of mindsight without the relatively arbitrary group distinctions imposed by Rensink (2004). In addition, their subjects also provided confidence ratings, and the authors more closely examined what type of changes might be most strongly associated with mindsight. In particular, using a comparative visual search paradigm, some trials featured a uniformity of object type in the display (e.g. an array of plastic butterflies), while others featured variable object types in the display (e.g. an array of many kinds of plastic toys). They interpreted two key results to indicate support for a somewhat more limited existence of mindsight. First, sense responses on false alarm (catch) trials were associated with significantly lower confidence ratings when compared with sense responses on trials in which a change was actually present. Second, while there was no effect of display type on accuracy or speed of identifying the change, there was an effect of display type on sensing responses. In particular, participants were more likely to sense a change in a uniform array. However, this was not true if the change was a simple object switch (e.g. if a of the butterflies was replaced with a different one). Given this double dissociation, and the difference in confidence ratings between false alarms and change trials, the authors concluded that there is some evidence for the existence of the mindsight phenomenon.

1.5 The Present Studies

The preceding discussion has focused on three issues. The first point made was that stimuli for which an observer has no conscious experience can influence behavior. This is important because it demonstrates that stimuli are processed, even if they do not reach conscious awareness. Although to the modern-day researcher this is trivially true, it has not always been as widely accepted (Eriksen, 1960; Holender, 1986). Regardless, it raises the possibility that one may be able to introspect on either the stimulus itself, or at least the consequences of having encountered the stimulus. In short, although one may not know what the stimulus was, one may still be able to report various features of it.

The second idea covered here was that the fates of these stimuli vary, depending in large part on the reason for their being invisible (Dehaene & Changeux, 2011; Kouider & Dehaene, 2007). Specifically, the neural and cognitive traces of subliminal stimuli are characterized as short-lived, rapidly decaying, and not available for conscious report. As such, demonstrations of the effect of subliminal stimuli rely primarily on biases in reaction times in related tasks, or toward other stimuli, and not judgments of the stimulus itself (for a review, see Dehaene & Changeux, 2011). On the other hand, processing of preconscious stimuli is relatively longer-lasting, and aspects of them frequently are available for conscious report (Dehaene & Changeux, 2011). In addition to these preconscious stimuli leading to the same kinds of biases described for subliminal stimuli, there is also evidence of observers making reports directly upon the stimulus itself at levels which exceed chance. Thus, while it is expected that observers could report directly on preconscious stimuli, any observation that an observer could potentially report on subliminal stimuli would be relatively unexpected. Were such evidence found, it could suggest rethinking theoretical views of unconscious processing.

Third, I reviewed literature on preconscious stimuli which suggests that an observer might be able to sense a change in a stimulus before having a visual awareness of what the change is (Rensink, 2004). Though the veracity of this claim is contested (Simons et al., 2005), it is not implausible that such an ability exists. Indeed, although we are widely known to have an inability to introspect on many facets of our own behavior, Nisbett and Wilson (1977), in their landmark treatment on the topic, suggest that subliminal perception may be one area in which introspection could bear some veridical truths, though they stop short of suggesting that we might be able to report on subliminal stimuli directly:

> "Thus, subliminal perception, once widely regarded as a logical paradox âĂę may be derived as a logical consequence of the principle of selective filtering. We cannot perceive without perceiving, but we can perceive without remembering.

> The subliminal perception hypothesis then becomes theoretically quite innocuous: Some stimuli may affect ongoing mental processes, including higher order processes of evaluation, judgment, and the initiation of behavior, without being registered in short-term memory, or at any rate without being transferred to long-term memory."

While we may be unaware of the offending stimulus, it may nonetheless register some change in the cognitive machinery which represents the outside world. And although Nisbett and Wilson (1977) convincingly show that we are relatively poor at reporting on our own mental processes, it is clear that, in general, we do not display such deficiencies with regards to external stimuli - something for which we typically have quite fine-grained representations. Even in cases, such as subliminal perception, in which we are unable to report on external stimuli, the representation is available for processing. That the representation is available for processing, suggests, in turn, that changes in that representation are also processed and, perhaps this second order representation could be available for report.

At a fundamental level, this is what Rensink (2004) suggested. However, the change-blindness paradigm he employed seems ill suited to answer such a question. For instance, Rensink's paradigm relied on observers reporting only on their subjective experience of sensing a change, and then the subsequent experience of identifying the change. This leads to the difficulty of ascertaining exactly what subjects are reporting on when they sense a change. Indeed, much of the criticism directed toward Rensink was due to the suggestion that the sense report was really no different than the identification report, but with a lower criterion level (Simons et al., 2005). Further, the change Rensink's observers were reporting upon was continual, with the display repeatedly switching back and forth between two images. Thus, the change is always present. This is not ideal because even if subjects are able to sense a change before having a corresponding visual experience, this makes it difficult to ascertain how accurate or precise this ability might be.

To remedy these problems, and to push the investigation of introspecting on subliminal stimuli a little further, I used an alternative methodology. Observers watched for stimuli which were masked using continuous flash suppression. Their job was to report whether the stimulus appeared before or after a button press they made in response to a briefly presented cue. Thus, this overcomes the aforementioned shortcomings of the previous research. Specifically, subjects are making judgments of discrete events. Thus, I can evaluate to what extent the judgments of observers are accurate and precise with respect to the event. This will also allow me to determine that their reports correspond to some physical objective difference. Additionally, unlike other studies investigating the ability of observers to introspect on stimuli for which they claim no visual experience, the present investigation uses subliminal stimuli. As mentioned previously, in comparison to preconscious stimuli, subliminal stimuli elicit much weaker and shorter-lived activation of sensory systems. Therefore, any observed ability to introspect on such stimuli would strongly suggest that observers are either not introspecting directly on the stimulus itself, or perhaps that the claim that subliminal stimuli elicit relatively weak activation is overstated.

Chapter 2

Temporal Order Judgments of Subjectively Invisible Stimuli

2.1 Introduction

The most straightforward way to demonstrate that an observer can introspect on a stimulus for which he or she lacks awareness is to have them make an introspection, and then ask them whether they had any visual experience of the object. If the data suggest that the observer is making accurate reports about the stimuli, but claims not to have seen anything, this would constitute evidence in favor of introspecting on the subliminal. Though there are clear shortcomings to such an approach, this was the first step I took to address this question.

2.2 Methods

2.2.1 Participants

Including the author, twenty students (11 female; Mage = 22.85, SD = 4.65) participated in this experiment.[1] The data from one participant was removed for not following instructions, leaving a total of 19 participants.

2.2.2 Materials

All parts of the experiment were controlled through Matlab's PsychToolBox (Brainard, 1997).

Stimuli consisted of 10 gray-scale faces displaying fearful expressions taken from the standard Ekman set (Ekman, Friesen, & Press, 1975). I elected to use fearful faces due to previous evidence indicating that this type of stimulus is more likely to break through suppression into awareness (Tsuchiya, Moradi, Felsen, Yamazaki, & Adolphs, 2009; Yang, Zald, & Blake, 2007). Though the aim was to keep the stimuli subliminal, I reasoned that if the stimuli more easily gained access to awareness, then temporal properties of the stimuli might also be easier to access, even in the absence of awareness of the stimulus itself.

The mask consisted of 20 random color mondrian patterns, which cycled through at a rate of 60hz. Mask (3.7°x 3.7°) and stimulus (2.3°x 2.3°) were presented in a dimly lit room on a gray, uniform background. Participants viewed mask and stimuli enclosed within black and white checkered borders (4.8°x 4.8°) with crosshairs to facilitate fixation. Stimuli were presented centered on the left and right half of the computer monitor (24", 1920x1200 resolution, 60hz frame rate) and were viewed through a mirror stereoscope attached to the edge of the desk, approximately 60cm from the computer monitor. I randomly varied the display side of the mask and face across trials, such that each were equally likely to be

[1] The results of this and subsequent studies do not substantially change if the author is excluded from the analysis

displayed on the left or right side.

2.2.3 Procedure

Participants first went through 10 contrast adjustment trials to determine the level of contrast suitable to keep the faces below the level of conscious awareness. A trial began with a 60hz series of mondrian masks displayed to one eye. A face appeared between 500ms and 1500ms after the beginning of the trial. The face was one of 5 possible contrast levels: 1%, 4%, 7%, 10%, or 13% of full contrast. Each trial lasted 7500ms, or until the participant indicated, via button press, that he or she saw the face. Each contrast level was presented twice. Subliminal trials in the experimental block were presented at the level immediately below that which was successfully detected in this contrast-adjustment block. If participants reported having seen the face at 1%, the contrast was set at .5% of full contrast.

Following this, participants engaged in a series of practice trials. Each practice trial began with a 60hz series of mondrian masks displayed to one eye. At a randomly selected time between 0 and 2000ms, a cue in the form of a white dot appeared in one of the four corners of the checkered borders. Participants were instructed to press the space bar as rapidly as possible in response to this cue. The face appeared at a 500ms uniform distribution, randomly centered 35ms after the participant's average reaction time. At the end of each trial, participants were asked to indicate which they thought occurred first - their button press, or the appearance of the face. A correct answer resulted in a gain of 1 point, while incorrect answers resulted in a loss of 1 point. Play proceeded to 25 points. Faces in the training block were displayed at full contrast.

After finishing the training trials, participants moved on to complete two blocks of experimental trials (see Figure 2.1). Each block consisted of 100 trials. The experimental trials were identical to the practice trials with a few exceptions. For half of the trials, the face was displayed at full contrast, and for the other half, it was displayed at the reduced contrast previously determined. Additionally, the time at which the face appeared differed from these

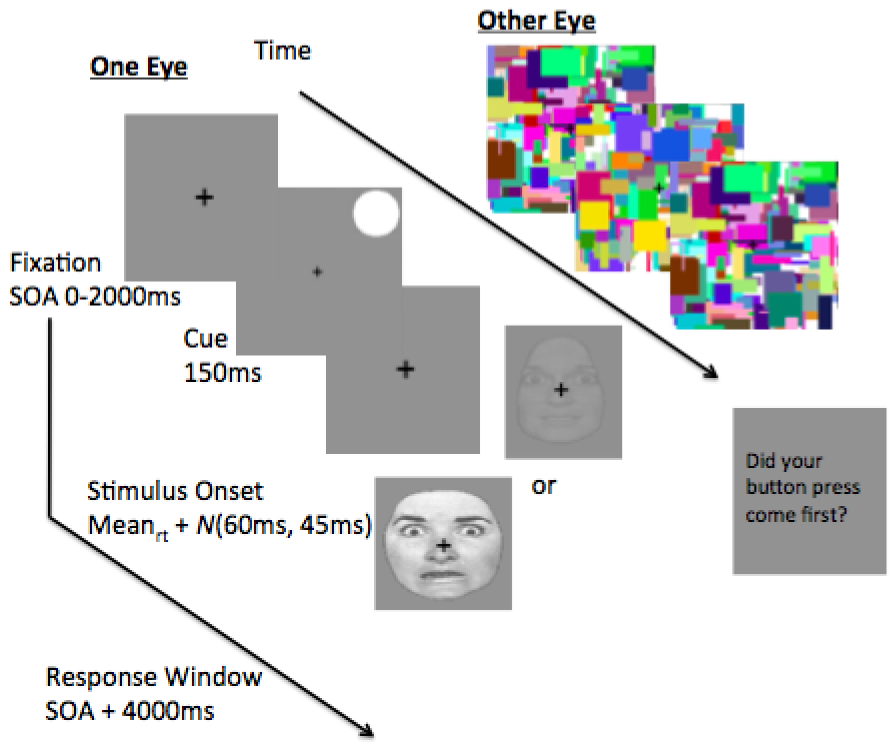

Figure 2.1: Trial procedure for study 1. Participants viewed a mondrian mask in one eye and the stimulus in the other eye through a mirror stereoscope. Participants responded to the cue by pressing the space bar. The face appeared at a time pulled from a normal distribution centered 60ms after the participant's average response time and remained on screen through the end of the trial. The face was presented at high or low contrast. At the end of each trial, participants reported whether their button press or the face came first.

practice trials. For half of all trials, the face appeared at a time as defined by the following function:

$$facetime = mean_{rt} + (.06 + N(0, .045)) \tag{2.1}$$

In other words, the face appeared at a time pulled from a normal distribution with a standard deviation of 45ms centered 60ms after the participant's average reaction time. Figure 2.2 displays the distribution of face onset times, centered on the button press. For the remaining half of trials, the face appeared either 135ms (block 1) or 35ms (block 2) after the button press, depending on the block. Finally, participants indicated whether they saw

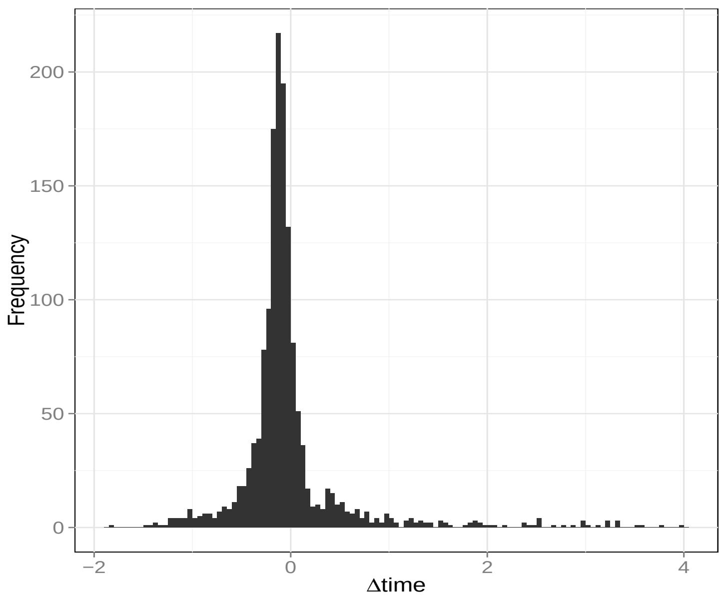

Figure 2.2: Distribution of button press times. Observations are centered on the time at which the face ocurred. Negative values of $\Delta time$ indicate that button press came first.

the face.

If participants twice reported having seen the face when it was displayed at reduced contrast, the contrast was reduced by 1% of the maximum contrast. If the contrast was already below 2%, the contrast was reduced by .1% of the maximum contrast.

2.3 Results

I first examine whether participants were sensitive to the time at which the face appeared, relative to their button press. For the first analyses, the models will be fit to the entire data set. In subsequent analyses, I will specify various subsets of the data to give stronger tests of the hypothesis that people can report on the temporal contingencies of events below the level of awareness.

I began by fitting a multilevel logistic regression predicting the probability that a participant reported that the face came first, with Δtime (Face onset time - Button press time) and participant's subjective report of whether they saw the face, plus their interaction as

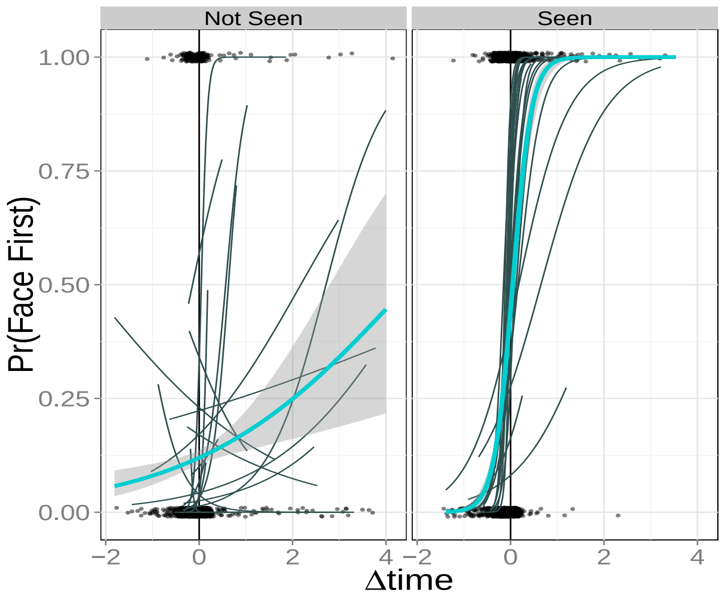

Figure 2.3: Probability of reporting "face first" as a function of time. Negative values for $\Delta time$ indicate that the button press came first. Thin grey lines represent random effects slopes fit to individual participants. Thick turquoise line is the fixed effect across all participant. Shading represents 95% confidence intervals. Plot is faceted by whether participants reported the presence of the face. Black vertical line indicates time at which keypress and face would appear simultaneously.

predictor variables. The intercept and effect of Δtime were allowed to randomly vary by participant. This model yielded main effects for Δtime (fixed effect = 1.24, SE = .59, $p < .05$) as well as subjective report of vision (fixed effect = 1.92, SE = .10, $p < .01$), and an interaction between the two (fixed effect = 4.59, SE = .51, $p < .01$). This model thus suggests that participants can reliably introspect on the difference in time between their button press and the onset of the face, and that this effect is stronger when participants report having seen the face. This pattern of results can be seen in Figure 2.3. The effect of time remains significant even when fitting a model containing only observations in which participants reported not seeing the face (fixed effect = .65, SE = .18, $p < .01$).

I conducted a similar analysis examining the probability that a participant reported that the face came first as a function of the interaction between Δtime and whether the face was presented at high or low contrast. This model yielded similar results to the one fit to

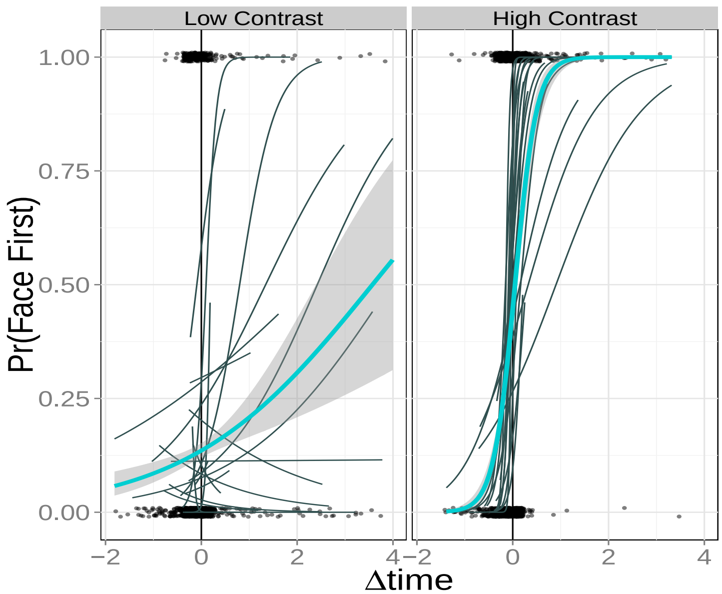

Figure 2.4: Probability of reporting "face first" as a function of time. Negative values for $\Delta time$ indicate that the button press came first. Thin grey lines represent random effects slopes fit to individual participants. Thick turquoise line is the fixed effect across all participant. Shading represents 95% confidence intervals. Plot is faceted by contrast. Black vertical line indicates time at which keypress and face would appear simultaneously.

subjective reports of vision. Specifically, I observed main effects for Δtime (fixed effect = 3.42, SE = .62, $p < .01$), contrast (fixed effect = 1.25, SE = .07, $p < .01$), and an interaction between the two (fixed effect = 2.82, SE = .35, $p < .01$). This pattern of results can be interpreted as evidence that participants are sensitive to the difference in time between their button press and the onset of the face, and that the effect is stronger when the face is presented at high contrast. This pattern of results is displayed in Figure 2.4. The effect of time remains significant when fitting a model to only low contrast trials (fixed effect = .53, SE = .15, $p < .01$).

As a more stringent test of the hypothesis that participants are able to introspect on the time course of events occurring below the level of awareness, I discarded all low contrast trials participants reported having been able to see (i.e. trials I anticipated they would not see, but actually did), and high contrast trials they reported failing to have seen (i.e. trials I anticipated they would see, but said they did not). This lead to excluding a total of 371

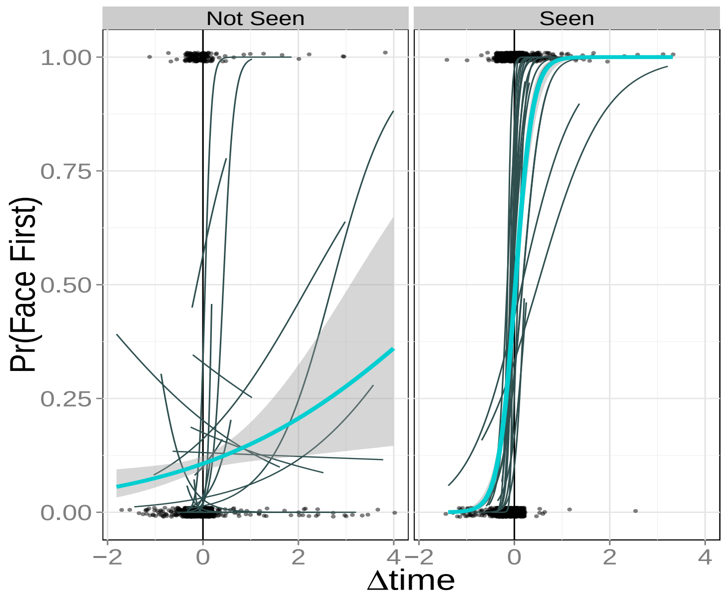

Figure 2.5: Probability of reporting "face first" as a function of time. Negative values for $\Delta time$ indicate that the button press came first. Thin grey lines represent random effects slopes fit to individual participants. Thick turquoise line is the fixed effect across all participant. Shading represents 95% confidence intervals. Plot is faceted by whether participants reported the presence of the face. Black vertical line indicates time at which keypress and face would appear simultaneously.

out of 3682 trials (10.1%). I then proceeded to fit a multilevel logistic regression with Δtime and participant's subjective report of whether they saw the face, plus their interaction as predictor variables. I observed the same pattern of results as in the full dataset, with main effects of Δtime (fixed effect = 1.71, SE = .72, p = .02) and subjective report of visibility (fixed effect = 2.16, SE = .07, $p < .01$), and their interaction (fixed effect = 2.82, SE = .35, $p < .01$). These results can be interpreted as further evidence that participants are sensitive to the time at which masked stimuli appear, though they are more sensitive when they report seeing the stimuli. This pattern of results can be seen in Figure 2.5.

2.4 Discussion

In sum, the first study provides reasonably strong evidence that observers are able to accurately introspect on the appearance of a stimulus, relative to their button press, even when that stimulus is presented unconsciously. This initial experiment is not, however, without its shortcomings.

To what extent can we be certain that these stimuli were definitively unconscious? Although subjects reported not being able to see the masked faces, it is still possible that they were somewhat aware of a portion of the face, for a portion of the time. Not enough, perhaps, to confidently report having seen the face, but possibly enough to allow them to report on the temporal order of events in a reasonably accurate fashion.

Furthermore, a full 50% of our trials occurred at a fixed interval after the button press, while the remaining mass of the trials were centered just after the button press. A more ideal scenario would have the trials distributed more evenly around the button press. In fact, if participants truly are able to introspect on the order in which events occurred, the unusual setup deployed in the first study may actually underestimate the extent to which individuals can introspect on these relationships, as the range of times they were discriminating were relatively confined. Allowing for the time between the button press and the onset of the stimulus to vary more could potentially allow for a more reliable estimate of the effect.

Finally, the manner in which the contrast was set in this study was inexact. There are more rigorous ways of determining the appropriate contrast for any given subject.

In order to alleviate these concerns, I conducted a second study. In study 2, I establish the contrast (and hence, visibility) of the stimuli using a much more rigorous procedure. I also obtain trial-by-trial ratings of subjective visibility, and include an additional block of trials in which participants provide an objective measure of awareness.

Chapter 3

Temporal Order Judgments of Stimuli Varying in Objective Visibility

3.1 Introduction

Study 2 improves and extends upon the results of study 1 in several ways. First, an alternative measure of subjective awareness was taken. Whereas in study 1, subjects reported subjective awareness using a binary decision, in study 2, I measured subjective awareness using a more continuous scale, which should allow for potential nuances in awareness (Overgaard, Rote, Mouridsen, & Ramsøy, 2006; Sergent & Dehaene, 2004). In study 2, I also used a more objective measure of awareness, including an additional block of two-alternative forced-choice trials in order to elicit a measure of objective sensitivity.

I made two other methodological changes in the second study. First, I used a QUEST bayesian staircase procedure to establish the contrast setting (Watson & Pelli, 1983). In this procedure, the experimenter establishes a parameter for accuracy (e.g. 75%), and then the contrast is adjusted to the value most likely to yield 75% correct on the basis of the participant's responses on previous trials. As such, the contrast is a bayesian posterior, given the participant's history of responding to various contrast settings. The second methodological change made was to distribute the face onset times more evenly around the button press, rather than centering the mass of times in a very narrow window of time occurring just after the button press. This should allow for more robust detection of any effect.

Furthermore, one possible interpretation of the data from study 1 is that subjects may have simply been introspecting on their reaction time. Any pattern in the tendency to say that the face came first may really just reflect the tendency for participants to give that report on trials when they took a particularly long time to press the button, correctly reasoning that if they waited a long time to press the button, then the face was more likely to have occurred first. In order to account for this, study 2 includes some trials with the contrast of the face set at zero, such that, although the computer determined a face onset time, the face that was presented was objectively invisible. If participants showed any indication of accurate introspection on these trials, this would strongly suggest that they were not introspecting on the stimulus itself, but rather, on their own reaction times.

3.2 Methods

3.2.1 Participants

Including the author, twelve students (5 female; Mage = 25.5, SD = 4.5) participated in this experiment. A computer error occurred during one participant's objective, AFC block, rendering their data unusable. The data for this block includes the other 11 participants.

3.2.2 Materials

Materials used in this study are the same as those used in study 1.

3.2.3 Procedure

Participants first engaged in a contrast-adjustment block. I used a QUEST staircase procedure (Watson & Pelli, 1983) to determine the threshold for 75% detection accuracy in a 2 alternative forced choice task. Participants were presented with two sequential 2500ms duration 60hz streams of mondrian masks to a randomly selected eye. The two sequential streams were separated by a blank gray screen for 400ms. One of the two sequential displays included a face presented to the other eye 750ms after the beginning of the display. Participants indicated whether they thought the first or the second display contained the face. The contrast level of the face was computed as the most likely value from a posterior probability density function. Participants completed 105 trials total.

As in study 1, participants then completed a training block. This training block was similar in form to that in the first study, but the time at which the face appeared was determined by pulling a time at random from a 2000ms uniform distribution centered on the participant's average RT (Figure 3.1). After attaining 25 points, the experimental trials began. The experimental trials consisted of two separate blocks, each with 140 trials. The experimental trials were similar to the practice trials, but with 4 different levels of awareness - low, medium, high, and no stimulus presented. The low, medium, and high levels of awareness were determined by taking the contrast set from the QUEST staircasing procedure and further adjusting the contrast to 50%, 70%, or 125% of that level, respectively. For the no stimulus trials, a face was programmed to be presented, but the contrast level was set to zero so that it was objectively invisible. At the conclusion of each trial, participants indicated, as before, whether their keypress or the face came first as well as provided a rating of subjective invisibility using the Perceptual Awareness Scale (PAS; Overgaard et al., 2006).

Finally, in order to determine participant objective sensitivity to the presence versus absence of faces, they completed one final block of AFC trials. PAS ratings were also provided to these trials. During this block, participants viewed two sequential 2500ms duration 60hz

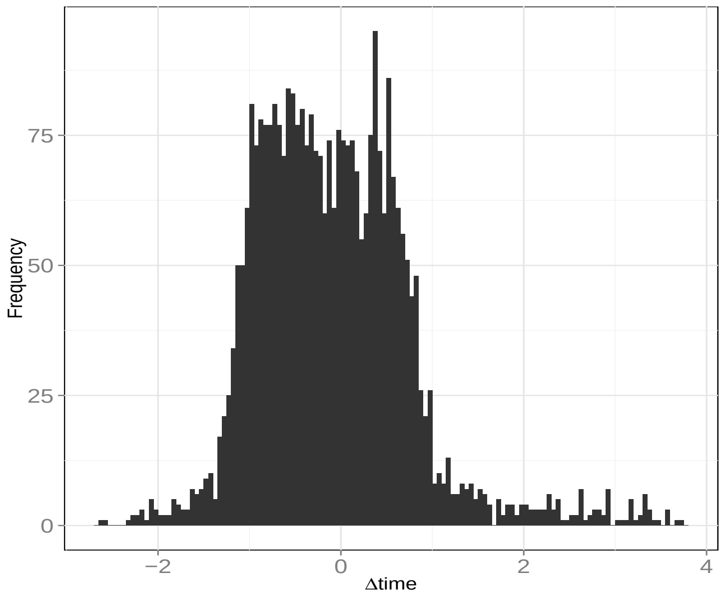

Figure 3.1: Distribution of button press times. Observations are centered on the time at which the face ocurred. Negative values of $\Delta time$ indicate that button press came first.

streams of mondrian masks to a randomly selected eye. The two sequential streams were separated by a blank gray screen for 400ms. One of the two sequential displays included a face presented to the other eye 750ms after the beginning of the display. Participants indicated whether they thought the face came in the first or second display. Sensitivity to the 4 levels of awareness was probed with 30 trials at each of the 4 stimulus contrast levels. Trials were presented randomly within the block, and the PAS was presented at the end of each trial.

3.3 Results

The first step in analysis was to examine each participant's subjective visibility responses to the four different contrast levels. The expectation was that participants would report increasing levels of awareness as the contrast was increased from zero to low, medium, and high. A repeated measures ANOVA showed a main effect of contrast type F(3, 3229) = 312.75, $p < .01$. Post-hoc comparisons revealed significant differences between all four con-

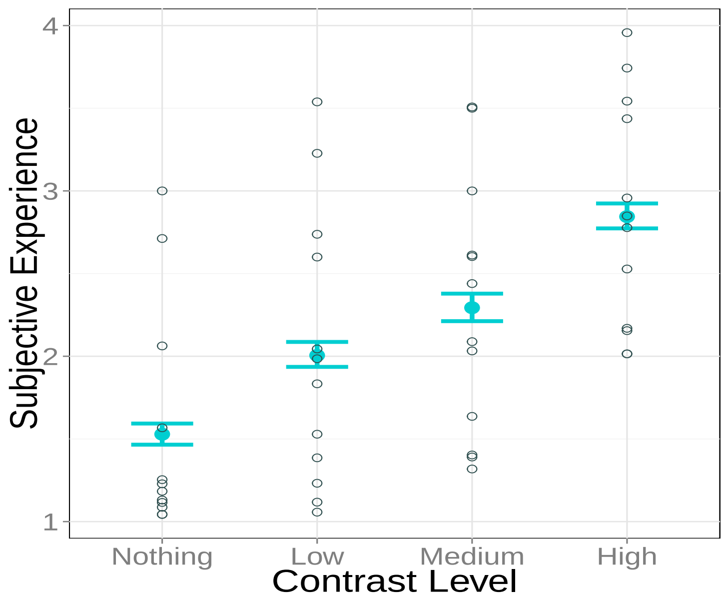

Figure 3.2: Responses to PAS scale by contrast type. Larger values of PAS indicate higher visibility. Turquoise points represent means by condition. Error bars represent 95% confidence intervals. Grey circles are individual participant means

ditions. This pattern of results can be seen in Figure 3.2. Investigating PAS responses from the final, 2AFC block yielded similar results.

Next, I sought to determine participant objective sensitivity to the contrast levels. For this analysis, I computed the d-prime scores for each contrast level for each participant, as determined by their responses to the 2AFC block. A one-way repeated-measures ANOVA showed a main effect of contrast type $F(3, 33) = 9.41$, $p < .01$. Post-hoc comparisons revealed significant differences between the no stimulus condition and the medium ($p<.05$) and high contrast trials ($p<.05$). There was also a significant difference between the low and high contrast conditions ($p<.05$). There was a trend for increased sensitivity in the low condition when compared to the no stimulus condition, but the comparison did not reach significance ($p = .07$). Furthermore, and more crucially, the mean d-prime value for each contrast level was significantly greater than zero (all p's $< .05$). These results can be seen in Figure 3.3.

Although these results are inconsistent with the idea that participants are introspecting

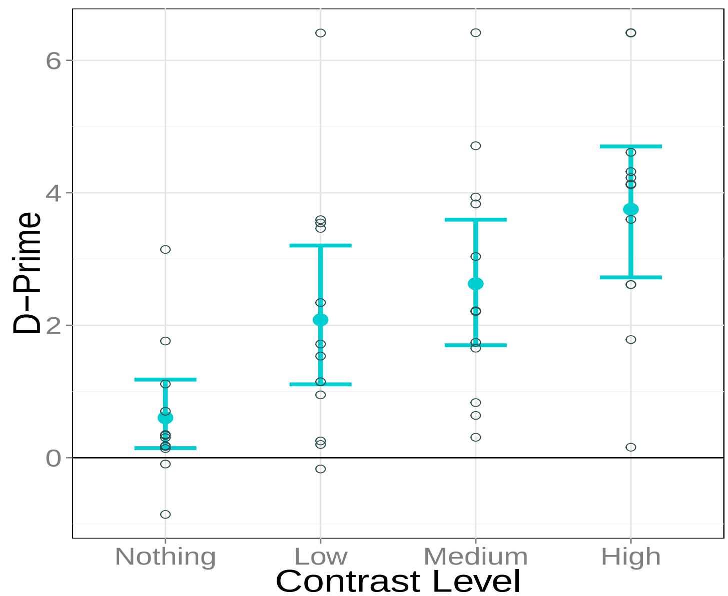

Figure 3.3: D-prime scores by contrast type. Turquoise points represent means by condition. Error bars represent 95% confidence intervals. Grey circles are individual participant values

on truly subliminal stimuli, I nonetheless turn to investigate the extent to which participants can introspect, leaving the implications of the previous analysis until the discussion. Thus, I now begin to investigate whether individuals can introspect on the temporal properties of masked stimuli. As in study 1, I begin by fitting a multilevel logistic regression to the probability that a participant reported that the face came first, as a function of Δtime, dummy coded contrast level with zero contrast as the baseline, and an interaction term between these variables. This model allows the effect of Δtime to vary randomly by participant to account for the non-independence of repeated measures. The results of this analysis are displayed as Model 1 in Table 3.1.

When treating the no stimulus condition as the baseline, I observe no main effect of Δtime (fixed effect = -.11, SE = .26, p = .67). This indicates that when no stimulus was presented, participants did not display a consistent pattern of response to the question of which came first as a function of time. I also observed significant main effects for each of the contrast levels (all p's $<$ .05). This demonstrates that participants were less likely overall to say that their keypress came first when a stimulus was actually presented. In other words,

	Model 1	Model 2	Model 3	Model 4	Model 5
	Study 2	*Study 2*	*Study 3*	*Study 3*	*Study 3*
(Intercept)	-1.90^{***}	-2.19^{***}	-0.54	-0.66^{*}	-0.67
	(0.36)	(0.42)	(0.31)	(0.32)	(0.36)
Δtime	-0.11	0.47^{*}	0.28^{*}	0.23	0.25
	(0.26)	(0.20)	(0.14)	(0.14)	(0.15)
ContrastLow	0.70^{***}		-0.01	-0.01	-0.02
	(0.14)		(0.12)	(0.12)	(0.14)
ContrastMedium	0.66^{***}		0.25	0.24	0.21
	(0.14)		(0.17)	(0.17)	(0.19)
ContrastHigh	1.25^{***}		0.09	0.08	0.23
	(0.14)		(0.21)	(0.21)	(0.24)
Δtime:ContrastLow	0.83^{***}		0.45^{*}	0.44^{*}	0.62^{**}
	(0.18)		(0.18)	(0.18)	(0.21)
Δtime:ContrastMedium	1.17^{***}		0.42	0.40	0.53^{*}
	(0.18)		(0.22)	(0.22)	(0.26)
Δtime:ContrastHigh	2.02^{***}		1.41^{***}	1.37^{***}	1.01^{**}
	(0.20)		(0.31)	(0.32)	(0.36)
SubExperBrief Glimpse		1.62^{***}			
		(0.13)			
SubExperAlmost Clear		1.61^{***}			
		(0.15)			
SubExperClear Experience		1.74^{***}			
		(0.16)			
Δtime:SubExperBrief Glimpse		0.76^{***}			
		(0.17)			
Δtime:SubExperAlmost Clear		1.20^{***}			
		(0.19)			
Δtime:SubExperClear Experience		1.33^{***}			
		(0.22)			
rt				0.28	0.26
				(0.20)	(0.21)
AIC	2912.02	2793.18	2481.14	2481.25	1945.28
BIC	2978.95	2860.11	2544.34	2550.19	2011.83
Log Likelihood	-1445.01	-1385.59	-1229.57	-1228.62	-960.64
Deviance	2890.02	2771.18	2459.14	2457.25	1921.28
Num. obs.	3244	3244	2310	2310	1892
Num. groups: participant	12	12	21	21	21

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

Table 3.1: Statistical models

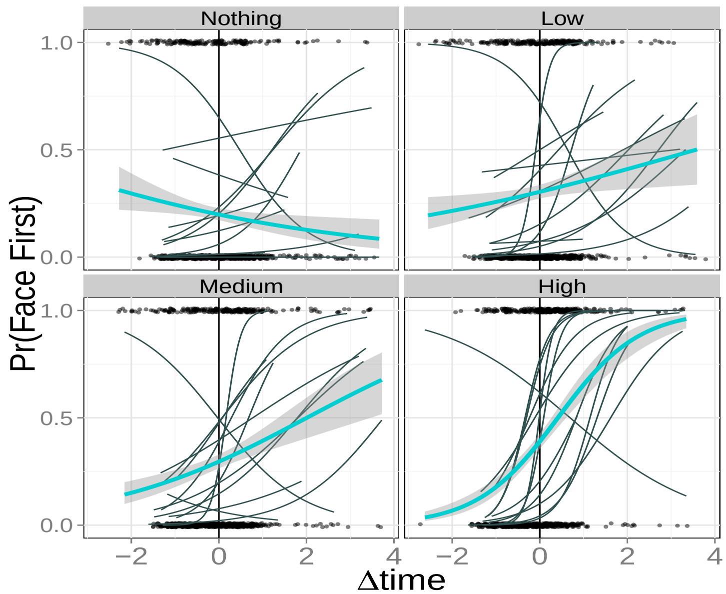

Figure 3.4: Probability of reporting "face first" as a function of time. Negative values for $\Delta time$ indicate that the button press came first. Thin grey lines represent random effects slopes fit to individual participants. Thick turquoise line is the fixed effect across all participant. Shading represents 95% confidence intervals. Plot is faceted by contrast. Black vertical line indicates time at which keypress and face would appear simultaneously.

participants were more balanced in their responding when there was actually a stimulus to respond to. Finally, participants demonstrated increased sensitivity to the change in time between their button press and the onset of the stimulus as the contrast increased. Importantly, even at low contrasts, participants show sensitivity to Δtime (fixed effect = .83, SE = .18, $p < .01$). This finding is especially important, given that the data on objective sensitivity suggests that participants are marginally more sensitive to the mere presence of a stimuli. That I observe a relatively robust effect here suggests that participants are more sensitive to the temporal properties of a stimulus than the mere presence vs. absence. This pattern of results can also be seen in Figure 3.4.

As a different test for my hypothesis, I can examine participant's sensitivity as a function of subjective visibility. If a participant says that they didn't see anything, can they still accurately introspect on the temporal dynamics of the stimulus? When investigating sensitivity across different levels of contrast settings, the hypothesis predicts that there would be no

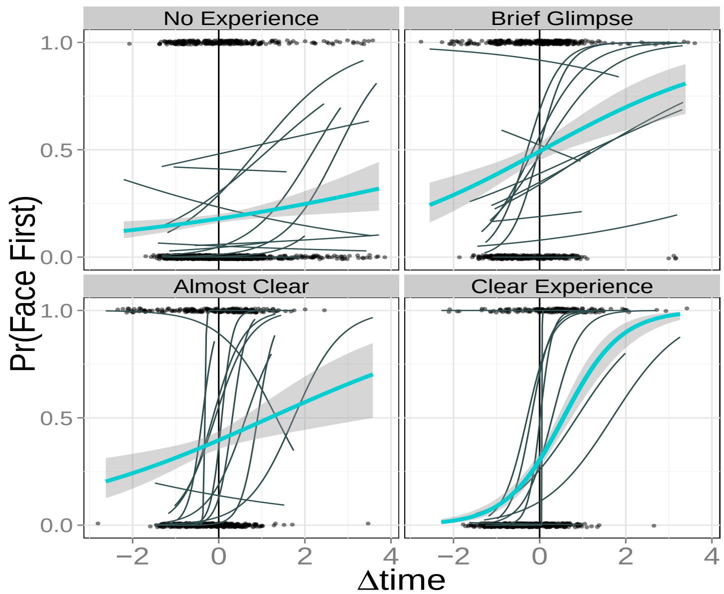

Figure 3.5: Probability of reporting "face first" as a function of time. Negative values for $\Delta time$ indicate that the button press came first. Thin grey lines represent random effects slopes fit to individual participants. Thick turquoise line is the fixed effect across all participant. Shading represents 95% confidence intervals. Plot is faceted by responses to PAS. Black vertical line indicates time at which keypress and face would appear simultaneously.

effect when no stimulus is presented, and a non-zero effect at low contrast. Here, I expect to see an effect across all levels of subjective visibility. In other words, even on trials when the participant reported 'no experience', they should still display some level of sensitivity to the temporal properties of the stimulus. As before, I fit a multilevel logistic regression to the probability that a participant reported that the face came first, as a function of the difference in time between their button press and the onset of the face stimuli, dummy-coded reported subjective awareness with no awareness as the baseline, and an interaction term between these variables. The results of this model are displayed as Model 2 in Table 3.1.

When treating the response of 'no experience' as the baseline condition, the model indicates that participants, even when saying that they see nothing, are sensitive to the temporal properties of the faces (fixed effect = .47, SE = .20, p = .02). Unsurprisingly, as subjective awareness increases, this effect becomes stronger, as indicated by the significant interaction terms. The results of this model can be seen in Figure 3.5.

Finally, as one further test of my hypothesis, I can separate models for each of the four contrast conditions, using Δtime, PAS responses, and their interaction to predict the probability of indicating that they pressed the key first. What should the expected pattern of results be to such an analytic approach? If participants are truly aware of the temporal properties of unaware events, then in the no face trials, one should expect no effect of Δtime and no interactions. In the low contrast condition, one should expect to see a significant effect of Δtime. If interactions are observed in these trials, it may indicate that at least part of the effect for low contrast trials observed in the full model came from trials presented at a low contrast that participants actually saw. However, if one still manages to find an effect within low contrast trials only, this should suggest that participant sensitivity is relatively robust. Finally, at medium and high contrast trials, one should expect to see significant effects of Δtime. Interactions may be present in these models as well, but are of less interest, as they may simply reflect instances in which participants were paying more attention.

I turn now to the first of these analyses - the no stimulus condition. Most importantly for my hypothesis, as a predictor of participants' responses to the question of which came first, Δtime did not reach significance (fixed effect = .44, SE = .26, p = .09). For the low contrast condition, we see a different pattern of results. Specifically, this model tells us that participants were sensitive to the temporal properties of the stimulus, as the estimate for Δtime was significant (fixed effect = .82, SE = .40, p =.04). Furthermore, this was qualified by an interaction with the 'clear experience' response (fixed effect = 1.40, SE = .56, p = .01), suggesting that on at least some of the trials (or perhaps, for some participants), the low contrast trials crossed the threshold of visibility, and participants were more sensitive to temporal properties in this case. The estimate for Δtime was again significant in the medium contrast trials (fixed effect = 1.81, SE = .40, $p < .01$), though was not qualified by any interactions. Finally, for the high contrast trials, I once again observe a significant effect of Δtime (fixed effect = 1.74, SE = .51, $p < .01$), which was qualified by interactions with both the 'almost clear' (fixed effect = 1.56, SE = .45, $p < .01$) and 'clear experience' PAS responses (fixed effect = 1.09, SE = .52, p = .04), suggesting that the effect was stronger on trials where participants classified their experience as 'almost clear' or 'clear'.

3.4 Discussion

Study 2 provides further evidence for the claim that individuals are sensitive to the temporal properties of masked stimuli. I show that participants display sensitivity at levels higher than would be expected by chance even when they report not having subjectively seen anything. I further show that this sensitivity exists at low levels of contrast, but not when no face was presented, suggesting that it is not reflective of a general tendency to change one's responses as a function of reaction time or trial duration.

Unfortunately, the data from this study does not definitively rule out that subjects were conscious of the masked stimuli. This is indicated in the d-prime scores from the objective block. In particular, d-prime scores from low contrast trials were marginally greater than those scores from the no-face trials. Further, d-prime scores for all contrast levels were significantly greater than zero.

Despite these data, however, discarding the hypothesis that subjects can introspect on the temporal properties of subliminal events is not warranted quite yet. In particular, there are several reasons to maintain this view. First, the objective trials were placed at the end of the experiment, while contrast was determined at the beginning. Given that subjects saw a minimum of 530 trials during the experiment, this leaves ample time for subjects to adjust to the contrast.

A second clue comes from the interesting difference observed when examining Δtime as a function of subjective visibility versus as a function of objective contrast. In line with study 1, we see that when subjects state that they had no visual experience of the stimulus, they still show an effect of Δtime on their response for which came first. This is not the case, however with objective contrast, as when the face was objectively invisible, there was no effect of

Δtime. Of note, the pattern as a function of subjective response contains trials on which there was no face presented, suggesting that the true effect when the face is subjectively invisible but objectively present may be much higher.

Finally, as noted in the introduction, establishing a d-prime of exactly zero is a somewhat unrealistic expectation. If it is expected that observers are basing their Δtime judgments on some signal which is independent of visibility, why would observers not also base their responses in the objective block on a similar signal? That is, the judgments observers are making during the objective trials could be based on the same information that they're using during the experimental trials.

The difficulties encountered in this study are, in many cases, identical to the difficulties encountered by others conducting this type of research. To summarize, despite the clear existence of the effect hypothesized, it is difficult to demonstrate convincingly that observers are always unaware of the stimuli. Furthermore, to this point, all studies have used a highly idiosyncratic stimulus set - fearful faces. If this effect truly exists, then it is necessary to show that it is more general, and as such, it should be demonstrated with other stimulus types. The objective of study 3 was to resolve some of these concerns.

Chapter 4

Examining the Effect on a Trial-by-Trial Basis

4.1 Introduction

One source of the problems with demonstrating subliminality in study 2 was that the measure of objective awareness came from a separate set of trials than the measure of the effect of Δtime. This could allow for several possible problems. First, observers could adjust over the course of the experiment such that their objective awareness level was different during the contrast adjustment trials, the experimental trials, and the final set of two-alternative forced-choice trials. A second issue is that, while, in theory, one might demonstrate zero objective sensitivity at a particular contrast level for a block of trials, this does not necessarily mean that the observer had no visual awareness on any particular trial. Indeed, there may be some trials which reached full awareness.

To resolve these issues, and to extend the basic findings observed thus far to a different class of stimuli, I used a procedure described by Milyavsky, Hassin, and Schul (2012). Rather than making judgments of faces, I had participants make judgments of letter strings which could be either words or nonwords. In asking observers to indicate the word/nonword status of any given trial, and asking them to type in what they think the word was, I am able to elicit an objective measure of sensitivity from the same trials as those where the Δtime judgment is being made. Further, examining the typed responses will allow me, on a trial-by-trial basis, to discard those trials which subjects seemed to have some awareness, as indicated by correct guesses of the letter string.

4.2 Methods

4.2.1 Participants

Including the author, 21 students (13 female, Mage = 21.52, SD = 3.37) participated in this experiment.

4.2.2 Materials

Stimuli consisted of 42 letter strings. Half of these were threat words (Isenberg et al., 1999), while the other half were nonwords matched for length (Mohr, Pulvermüller, & Zaidel, 1994). For presentation, the letter strings were converted to images subtending the same visual angle as the faces in studies 1 and 2 (i.e. 2.3°x 2.3°). Masks were presented to teh dominant eye and stimuli to the non-dominant eye. All other stimulus properties and presentation procedures were identical to study 2.

4.2.3 Procedure

As in Study 2, participants first completed a contrast-adjustment block. In this study, I used the QUEST staircasing procedure to independently determine the threshold for the low, medium, and high contrast levels, which corresponded to 51%, 70%, and 90% detection accuracy, respectively. Also, to reduce the amount of time spent on the experiment, we shortened the length of each individual trial. Participants were presented with two sequential

1500ms duration 60hz streams of mondrian masks to the dominant eye. The two sequential streams were separated by a blank grey screen for 400ms. One of the two sequential displays included a randomly chosen letter string from the total set of 42 possible (word and non-word) letter strings 500ms after the beginning of the display. Participants indicated whether they thought the first or second display contained the text. The contrast level of the text was determined using a Bayesian posterior estimate with the prior based on performance in previous trials. Participants completed 105 trials; 35 for each of the three contrast levels.

As in the previous two studies, participants next completed a training block. Here, participants were instructed to press the space bar as quickly as possible in response to a white circular cue, which appeared at a random time from 250ms to 1250ms after the start of the trial in one of the four corners of the screen. A text string, randomly selected from the total set of 42, appeared at a time pulled from a 2000ms uniform distribution, centered on the participant's reaction time. At the end of each trial, participants answered three separate questions. First, they indicated whether their keypress or or the letter string came first. Next they indicated whether they thought the letter string was a word or a nonword. Finally, borrowing upon a technique utilized by Milyavsky et al. (2012), we asked participants to type in the presented text, or to type 'nor' if they did not see anything. Participants played to 20 points, with points determined, as in the previous studies, based on whether they answered the first question correctly (+1 point) or not (-1 point).

The experimental trials consisted of three separate blocks, each with 80 trials. The experimental trials were similar to the practice trials, but with 4 different levels of awareness - low, medium, high, and no stimulus presented. The low, medium, and high levels of awareness were determined via the QUEST staircasing procedure completed earlier in the experiment. For the no stimulus trials, a letter string was presented, but the contrast level was set to 0 so that it was objectively invisible. At the conclusion of each trial, participants answered the same three questions as in the practice trials.

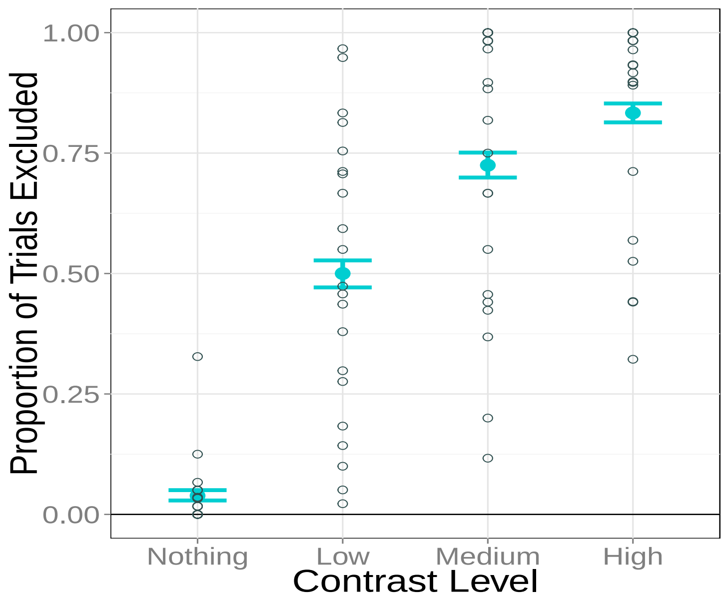

Figure 4.1: Proportion of trials excluded as a result of applying the Milyavsky et al. (2012) filtering criteria. Grey circles represent proportions for individual participants. Turquoise points represent contrast level means.

4.3 Results

I turn first to the question of how much awareness participants had over this new type of text stimulus. Before conducting these analyses, however, I applied the filtering technique described by Milyavsky et al. (2012). Essentially, this is a highly conservative criteria of participants' awareness on any given trial. This was determined by combining whether they correctly typed any letters, and whether those letters were in the correct location. Applying this criteria, we remove 47 of 1211 trials where no stimulus was presented (3.9%), 607 of 1213 low stimulus trials (50%), 882 of 1217 medium contrast trials (72.4%), and 1020 of 1224 high contrast trials (83.3%). Figures 4.1 displays the proportions of trials excluded by these stringent criteria.

The next step is to ask, of the remaining data, how sensitive were participants to detecting whether the stimulus was a word or not a word. To address this question, d-prime scores were computed for each participant's responses to the question of whether the text was or was not a word for each contrast level. A linear mixed effects model showed that none of

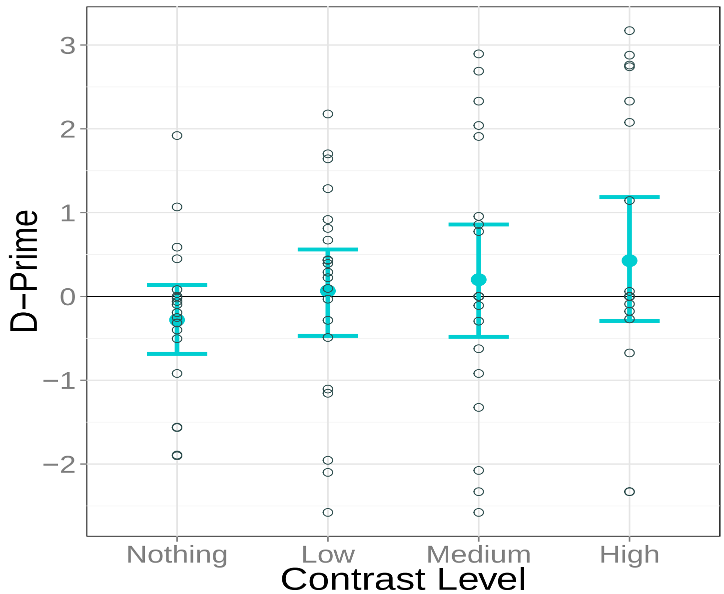

Figure 4.2: d-prime scores as a function of contrast condition, after removing all trials as specified by the Milyavsky et al. (2012) filtering criteria. Grey circles represent individual participants. Error bars represent 95% confidence intervals

the contrast conditions differed from zero. This pattern of results is displayed in Figure 4.2.

Using this filtered data, I now turn to the primary research question: Are people sensitive to the temporal properties of events which occur below the level of awareness? Using the same general analytic strategy as studies 1 and 2, I fit a multilevel logistic regression to the probability that a participant reported that the text came first, as a function of Δtime, dummy coded contrast level with zero contrast as a baseline, and an interaction term between these variables. I allowed the effect Δtime to vary randomly by participant to account for the non-independence of repeated measures. The results of this analysis are displayed as Model 3 in Table 3.1 and Figure 4.3.

When treating the no stimulus condition as the baseline, we observe a main effect of Δtime (fixed effect = .28, SE = .13, p = .05). This indicates that when no stimulus was presented, participants were more likely to report 'text first' when their button press occurred relatively late in the trial. This is in contrast with what we found in experiments 1 and 2 and will be discussed further below.

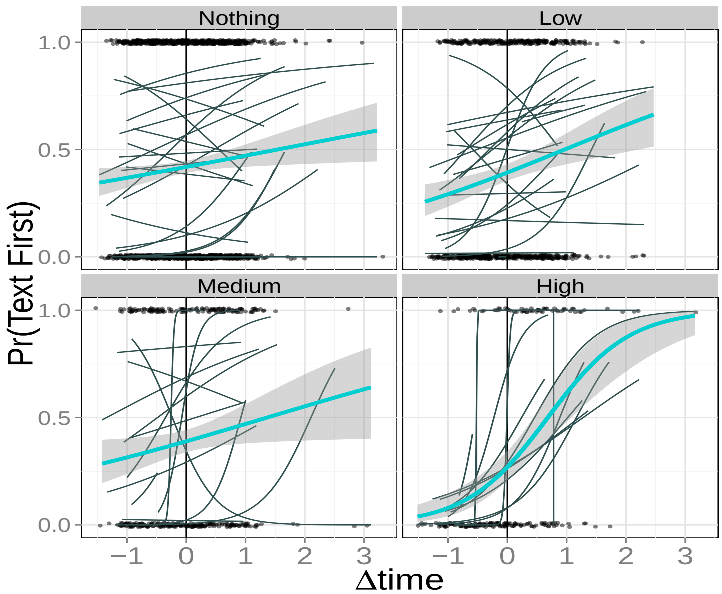

Figure 4.3: Probability of reporting "text first" as a function of time. Negative values for $\Delta time$ indicate that the button press came first. Thin grey lines represent random effects slopes fit to individual participants. Thick turquoise line is the fixed effect across all participant. Shading represents 95% confidence intervals. Plot is faceted by contrast. Black vertical line indicates time at which keypress and face would appear simultaneously.

Also in contrast to Studies 1 and 2, we failed to observe any main effect of contrast. However, similarly to the first two studies, we did see an interaction between contrast and Δtime. Specifically, the effect of Δtime was stronger at low (fixed effect = .45, SE = .18, p = .01) and high contrasts (fixed effect = 1.41, SE = .31, $p < .01$) compared to when no stimulus was presented.

In sum then, the above analysis suggests that participants may be basing their decision of whether to respond 'text first' on something other than when the button press ocurred, relative to the stimulus. The most reasonable explanation for this is that participants are basing their responses on how much time has elapsed in the trial before they made a button press (i.e. their reaction time). I investigate this possibility by repeating the above analysis, controlling for reaction time.

The results of this analysis can be seen in Table 3.1 as Model 4. When controlling for reaction time and treating the no stimulus condition as a baseline, the previously significant effect of Δtime now fails to reach significance (fixed effect = .23, SE = .14, p = .12). However, there is an interaction, such that individuals are showing sensitivity to the temporal properties of the text, at low contrast (fixed effect = .44, SE = .18, p = .02) and high contrast (fixed effect = 1.37, SE = .32, $p < .01$), with a marginal effect at medium contrast (fixed effect = .40, SE = .22, p = .07).

Another analysis of interest examines whether there is an effect of stimulus type on the observed pattern of results. Namely, do participants still display sensitivity to stimuli that are not emotionally salient? There are a number of analyses we could perform to answer this question, but for expositive reasons, I opt to fit the same model as described above (i.e. controlling for reaction time) to only non-word trials. The results of this analysis are displayed in Table 3.1 as Model 5.

As in our previous analyses, we note no effect of Δtime(fixed effect = .25, SE = .15, p = .08). However, the crucial interactions seen previously remain significant with individuals showing sensitivity to the temporal properties of the text at low (fixed effect = .62, SE = .21, $p < .01$), medium (fixed effect = .53, SE = .26, p = .04), and high (fixed effect = 1.01, SE = .36, $p < .01$) contrast levels.

Additionally, I can explore whether individuals are sensitive to temporal information, even when not objectively sensitive to other types of information. Following the strategy advocated by Greenwald et al. (1995), I can explore whether a hypothetical participant who displays zero objective sensitivity, would still show evidence of a subliminal effect? For this analysis, I collapse data from Studies 2 and 3, using the d' scores for each contrast condition from the objective block in study 2, and the d' scores from the word/nonword responses for each contrast condition in Study 3. Using a random effects model to account for repeated measures on the same individual, I then regressed the individual random slope estimates from the respective mixed effects models against these d' scores. The results of this analysis indicated that, the hypothetical participant with objective sensitivity of zero, would be sensitive to temporal information at levels significantly greater than would be expected

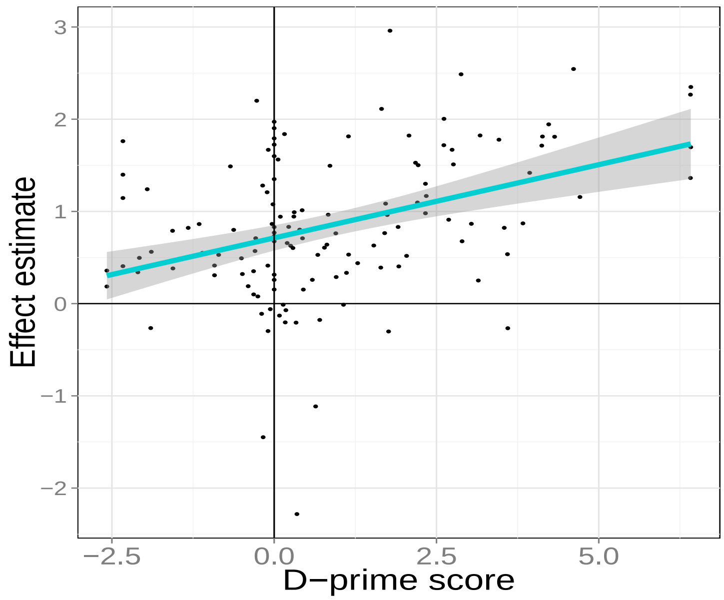

Figure 4.4: Estimates of slope effects as a function of d-prime scores. Turquoise line is the fixed effect across all participants. Shading represents 95% confidence intervals

due to chance (intercept = .73, SE = .09, $p < .01$)[1]. This pattern of data is displayed in Figure 4.4.

4.4 Discussion

Study 3 replicated and extended the findings from Studies 1 and 2. In particular, study 3 replicated the effect that participants are sensitive to the temporal properties of masked stimuli. Extending the findings of the previous two studies, I used a technique described by Milyavsky et al. (2012) to filter out (on a trial-by-trial basis) those trials on which participants seemed to have some awareness of the content of the stimuli. Examining the remaining trials allows for stronger certainty that this effect exists for subliminal stimuli. Similarly strengthening the claim that observers can introspect on temporal properties of subliminal stimuli, an intercept analysis, as advocated by (Greenwald et al., 1995) shows that even

[1]The pattern of results does not change when investigating the studies individually. The intercept for study 2, however, fails to reach significance, although it is in the predicted direction (intercept = .22, SE = .27).

for the hypothetical participant with zero sensitivity, one would expect, based on the data collected here, that an observer would be able to introspect at levels exceeding chance. Finally, the use of textual stimuli shows that the effect is not unique to faces, nor even to particularly salient emotional stimuli, as individuals remain sensitive even when examining only nonwords.

Chapter 5

General Discussion

Across three studies, I have provided evidence consistent with the notion that individuals are sensitive to the temporal properties of subliminal stimuli. When presented with a stimulus masked via CFS, participants were able to report whether their button press preceded it at levels higher than would be expected by chance. While it is difficult to demonstrate with absolute certainty that the masked stimuli were subliminal in all cases and at all times, there are three pieces of evidence which suggests that the effect shown is true for subliminal stimuli.

1. The subjective ratings of invisibility are consistent with this notion. In study 1, observers displayed a significant effect of Δtime, even while stating that they did not see the stimulus. In study 2, when examining only those trials for which subjects provided the lowest level of subjective visibility ratings, the effect of Δtime on the probability of reporting that the face came first remained significant.

2. In study 3, after using a highly conservative filtering procedure, participant sensitivity to the remaining trials was not different from zero. Despite this stringent filtering, there was still a significant effect of Δtime on the probability of an observer reporting that the text came first.

3. Using the intercept analysis advocated by Greenwald et al. (1995), I combined the

data from studies 2 and 3 to demonstrate that for the hypothetical participant whose objective sensitivity is exactly zero, one would nonetheless expect to see a nonzero effect of Δtime.

Study 3 illustrates one further noteworthy finding - the observed effect is not limited to emotionally salient or personally meaningful stimuli, as participant reports were above chance even when examining only trials composed of non-word letter strings.

5.1 Knowing Without Seeing

The studies reported here are congruent with the literature on sensing without seeing. In Rensink's work (2004), it was suggested that observers could sense a change in a visual stimulus before being aware of what the change was. One could say the same about the present studies. Observers were asked to report when a stimulus appeared - a type of change in a visual display. Thus, while a much different paradigm, one might draw similar conclusions from these results - one is much more aware of when something happens than what that something might be.

However, there are important differences between these works as well. Notably, the type of unawareness Rensink's observers experienced was because the stimuli were preconscious (Dehaene & Changeux, 2011). However, the masking technique employed in the present studies should lead to unawareness due to subliminality. In some respects, it is especially surprising that observers would be able to make these kinds of judgments for subliminal stimuli, as subliminal stimuli should be characterized by relatively weak and short-lived activation, as the mask should have the effect of reducing the underlying signal. Preconscious stimuli, on the other hand, are typically characterized by stronger activation, though without the top-down attentional mechanisms thought to be required for reportability.

This naturally raises the question of how observers might be able to report on something which should be characterized by only a very small amount of activation? One possible answer can be found in the fact that, with regards to interocular masking, not all processing is suppressed equally. Cortically, visual processing is often characterized by reference to two distinct streams of processing (Mishkin, Ungerleider, & Macko, 1983; Goodale & Milner, 1992) - one running ventrally from V1 through the anterior temporal cortex, and another running dorsally from V1 through posterior parietal cortex. These pathways are often referred to as the 'what' and 'where' pathways, respectively, though recently the dorsal stream is now thought to be better characterized as the 'how' pathway. Regardless, the ventral stream is typically thought to support conscious object recognition and identification, while the dorsal stream supports processing related to visuospatial and temporal characteristics of a stimulus (i.e. the information needed to physically interact with it) (Kravitz, Saleem, Baker, & Mishkin, 2011).

Notably, Fang and He (2005) used binocular rivalry to suppress conscious awareness of stimuli and saw that neural activation was considerably more robust in the dorsal stream than in the ventral stream, where it was almost entirely absent. With regards to the present study, this would suggest that processing of the temporal information of presented stimuli, which is known to take place in the dorsal pathway (Kravitz et al., 2011) would be spared to a greater extent than processing supporting conscious identification.

In the current studies participants did not show a simple bias in behavior as a function of the stimuli's temporal properties, as is often the methodological approach taken in studies on subliminal perception. Instead, observers reported on the temporal properties directly. This implies that in addition to processing in the dorsal pathway being spared, it must also interact with areas necessary for conscious report. Though it is not clear what sort of interaction this might be, one possibility is that, in making the judgment of which came first, the participant is implicitly generating a mental simulation of the two possible responses (i.e. stimulus first or button first). This type of mental simulation is thought to be crucial for motor cognition, and should lead to neurocognitive representations consistent with the two response possibilities (Jeannerod, 2001). Comparing the two representations to the observed outcome could then lead the observer to be more likely to give the response consistent with the best match. This sort of comparator model is popular in the literature on motor cognition and could be a mechanism through which observers are making choices in the current study.

This reasoning presents an interesting hypothesis. Given that these simulations are generated during motor acts, this implies that if participants make judgments of events independent of motor behavior (i.e. regarding external events only and not while performing an action, such as a button press), then they would not likely to be as capable of performing the discriminations seen in the current study. Any such findings would be particularly interesting in light of the considerable literature on the attenuation of sensory information during action (Matin, 1974; Kawachi, Matsue, Shibata, Imaizumi, & Gyoba, 2014; Voss, Ingram, Wolpert, & Haggard, 2008). For example, the reader will surely be familiar with the odd inability to tickle oneself (Blakemore, Wolpert, & Frith, 1998). While this literature would seem inconsistent with the above prediction, it may simply be that a more nuanced view is needed. Regardless, future work could help to resolve these apparent inconsistencies.

One final issue to consider with regards to the present studies is how this work fits into broader theorizing on conscious awareness and information access. Global Workspace Theory, for instance, suggests that information is processed by encapsulated systems, and that information is only conscious if it reaches a neuronal workspace wherein it is widely broadcast and available for processing by other systems (Baars, 1997; Dehaene & Naccache, 2001). Arguably, the studies presented above demonstrate that not all aspects of a stimulus are equally available for conscious introspection inasmuch as participants were able to make judgments about the temporal properties of a stimulus while remaining blind to other aspects. This suggest that not all features of a stimulus necessarily enter the workspace together (i.e. the stimulus features are not 'bound' together). In short, the "coalitions" of processors which Newman and Baars (1993) describe as the units which eventually dominate the workspace and achieve consciousness, in this study, seem to be relatively flexible in terms of their makeup. If this is true, then it is not as clear what the cognitive function of a global workspace would be. The coalition of processors could simply collate into different forms to achieve whatever computations neccessary, making the cognitive aspects of this theory irrelevant. However, the studies reported here were not designed to test these ideas, and so more thorough testing of this suggestion would be needed for any strong claims.

In short, despite the difficulty inherent in estimating temporal characteristics of events (Grondin, 2001), the ability of participants to do so in the described studies studies was observed to be robust. The field of subliminal perception has come a long way since the days of James Vicary's controversial "drink coke" studies. Continuous flash suppression presents researchers with a unique opportunity to investigate relatively understudied stimulus properties, such as temporal duration and sequence. The temporal properties of masked stimuli are theoretically interesting in light of work in consciousness, action production and control, and the cognitive representation of the self, and the work presented here is a demonstration of the potential for gaining insight into these areas through the study of the temporal nature of subliminal stimuli.

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