Subliminal Techniques: Considerations and Recommendations for Analyzing Feasibility

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Abstract

In an attempt to provide users with more information while maintaining a calm ubiquitous environment, researchers have investigated the possibility of presenting information "subliminally". We explore the historical issues associated with examining perception without awareness with special emphasis on the difficulty associated with ensuring stimuli have been presented below the participant's subjective threshold of awareness. It may be possible to circumvent this issue by taking a results-oriented approach. However, the advancement of subliminal techniques requires stronger experimental evidence that information is actually being presented below the subject threshold of awareness and gaining the desired effect on user performance. We offer three considerations that help designers weigh the costs and benefits of employing a subliminal technique. We also offer three recommendations that help designers' present information below the subjective threshold of awareness and measure their users' awareness of the information.

Keywords: Perception; Ubiquitous Design; Measurement; Theory; Human Factors

Subliminal Techniques: Considerations and Recommendations for Analyzing Feasibility

Our interaction with computing technologies has rapidly changed over the last decade through the exponential growth of technology. This growth has resulted in smaller and less expensive computing devices filling our surroundings and creating a Ubiquitous Computing (Ubicomp) environment (e.g., Baber, 2001; Crook & Barrowcliff, 2001; Kurzweil, 2006). Designing better Ubicomp experiences has been a popular theme within the field of Human-Computer Interaction (Henry, Goodell, Elmqvist, & Fekete, 2010). When interactions are too prominent they can become overwhelming (e.g., Wisenski et al., 1998). To retain a calm environment, technology must fade into the background of our daily tasks. One way to accomplish this is to embed technology, unobtrusively, into the environment and create "natural" user interactions with the intent of keeping interactions at the periphery of attention (Weiser, 1993; Weiser & Brown, 1996; Wisneski et al., 1998). A second way to facilitate a calm environment is to limit users' awareness of the information source. Here instead of disguising information or relegating it to the periphery, the goal would be to prevent users from even realizing the information had been presented. Subliminal presentation involves just that. Researchers hope to influence behavior through the subconscious presentation of information (e.g., Chalfoun & Frasson, 2008; DeVaul, Pentland & Corey, 2003; Riener, 2012; Riener, Chalfoun, & Frasson, 2014).

Although subliminal presentation seems to be the ideal mechanism to provide information without imposing high processing costs, a review of the cognitive psychology literature quickly reveals that there are many challenges to successfully using subliminal techniques. One significant challenge lies in ensuring the information is actually presented subliminally. Our goal is to translate pertinent cognitive findings to this emergent area of

research in human-computer interaction. To do this, we will provide a working definition of what it means for something to be subliminal, describe the difficulties associated with measuring subliminal effects and ensuring subliminal presentation, and provide practical considerations for designers who may be interested in using the subliminal presentation of information. We believe that whether the designer wants to present information at the periphery of attention, create "natural" interactions, or present information subliminally, one goal is the same, to create a user experience that requires fewer cognitive resources to be spent on the secondary task. This common goal underlies our considerations and practical recommendations for using subliminal information. We believe that considering the impact of presenting information below the subjective threshold of awareness and providing reliable measures of participant awareness (or lack of awareness) of subliminal information are vital in this area of research. These features are necessary for establishing internal validity, and interpretability, of future studies. This emphasis on methodology is critical as there is an inconsistent use of methodologically rigorous techniques when using subliminal cues in applied settings (c.f., Aranyi et al., 2014, p. 34).

Defining the Subliminal Experience as Perception without Awareness

Much of the original debate surrounding subliminal perception concerned the definition of *subliminal* and the related issue of determining how to measure the influence of subliminal stimuli (Bornstein, 1992; Debner & Jacoby, 1994; Merikle & Reingold, 1992). In response to some of the controversy, many psychologists have abandoned the term *subliminal* and instead attempt to describe stimulation in relation to the subjective threshold and the objective threshold of awareness (Cheesman & Merikle, 1984). These thresholds index both stimulus effects and participant perception. Stimuli exceeding this *subjective* threshold have a measurable effect on behavior (thoughts, emotions, actions) and are perceived by participants (i.e., participants claim

to have an awareness of the stimuli). Stimuli exceeding the *objective* threshold also have a measurable effect on behavior, but participants claim not to have detected the stimulus. A stimulus that does not appear to affect performance in any way is assumed to have been presented below the objective threshold. Thus, stimuli presented above the objective threshold, but below the subjective threshold are the most analogous to the concept of subliminal presentation (see figure 1). Individuals in this state are often referred to as having perception without awareness.

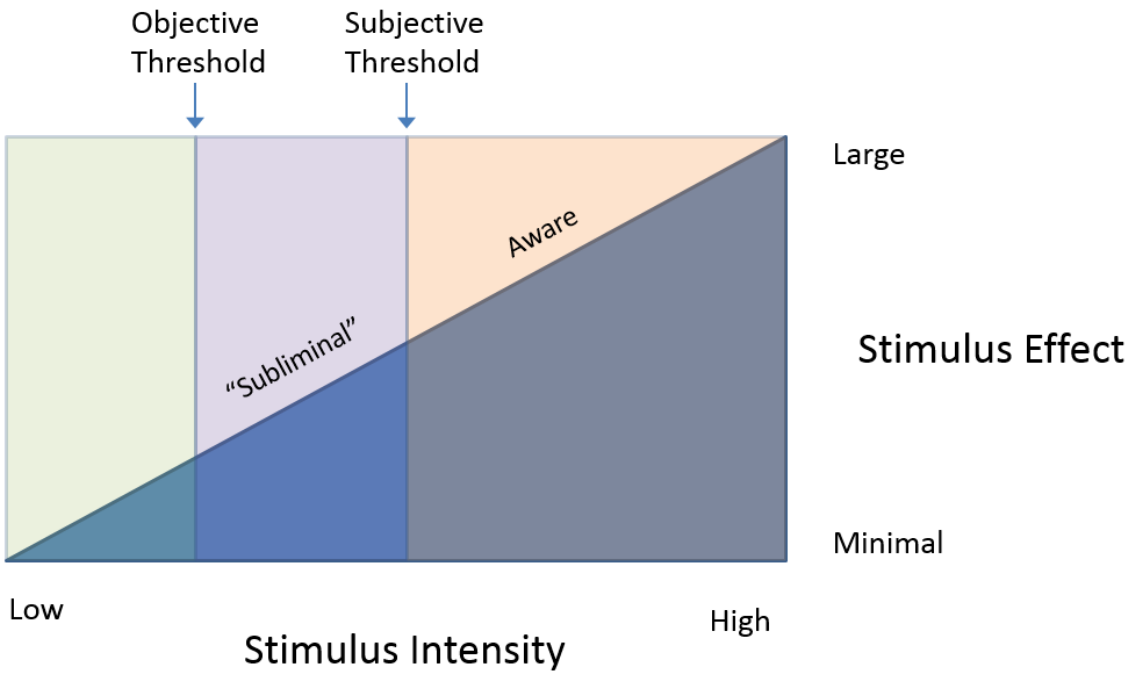

Figure 1. Our operational definition of 'subliminal' emerges from the objective and subjective thresholds. We assume that as stimulus intensity increases, so does the potential stimulus effect on the user. If a stimulus is presented below the objective threshold, the stimulus has no discernible effect on the user; any stimulus intensity above the threshold has some measurable effect on the individual. However, this effect will not necessarily produce awareness of the stimulus. If a stimulus is presented above the subjective threshold, the user becomes aware of the stimulus. Thus, subliminal perception falls between the objective and subjective thresholds.

There is a large body of evidence supporting the existence of perception without awareness (see Kouider & Dehaene, 2007 for a review). In one very simple task described by Merikle and Reingold (1992), participants are presented with a briefly displayed (e.g., 50 ms) stimulus (a word or a blank screen) that is forward and backward masked; masking serves to move this easy task below the subjective threshold. After stimulus presentation, participants are shown two words and asked if either one of them had just been presented. This question is meant to test subjective awareness, or detection, of the stimulus. Then participants are given the same two words and asked which one was presented. This recognition question is meant to indicate whether or not the stimulus exceeds the objective threshold. The results of this type of study consistently show that even when participants do not report seeing the stimulus, they occasionally have processed the stimulus as they perform above chance on the recognition task. Similar results have been found using a variety of stimulus types and contexts (e.g., DeVaul et al., 2003; Kunst-Wilson & Zajonc, 1980; Whalen, Rauch, Etcoff, McInerney, Lee, & Jenike, 1998). Clearly, this shows evidence that participants can be affected by stimuli for which they have no awareness.

Establishing Pure Subliminal Processing is a Challenge

Despite the now convincing evidence for perception without awareness, many difficulties remain in the interpretation of these data. One of those difficulties lies in determining the validity of measures of awareness. The most common measure of awareness is participant self-report. For instance, a researcher might simply ask participants whether or not they had detected the stimulus; if they say “no” any effect that is obtained might be attributed to “subliminal” effects. Unfortunately, self-reported awareness is subject to bias and may not be a pure measure of awareness (e.g., Jacoby, Allan, Collins, & Larwill, 1988; Sandberg, Bibby, Timmermans,

Cleeremans, & Overgaard, 2011). In a visual detection task participants may set different criteria when determining whether or not they detected a stimulus. For example, one participant might set a strict criterion like, “I will only say I saw something if I can describe what I have seen” and another participant might set a lax criterion like, “I will say I saw something if I have a hunch something was there.” Given the same amount of perceptual information, and presumably the same underlying processes, these participants provide divergent evidence whereby one appears to have been aware of the stimulus while the other has not. Cheesman and Merikle (1984) suggest that this type of bias results from decreased participant confidence during difficult identification tasks; by design, detecting a “subliminal” stimulus is a difficult identification task.

In addition to participant biases, one must consider what information participants use during detection and recognition tasks. It is often assumed that when a stimulus is not detected, participants base their recognition judgments on information unavailable to awareness; this simply may not be true. It is possible that the recognition task is based on partial awareness of the stimulus (see Cheesman & Merikle, 1984 for additional discussion). For example, consider a participant is completing a word identification task like those described by Merikle and Reingold (1992). In a relatively straightforward case, the participant may have been aware of the identity of one letter in a briefly flashed stimulus, but was not confident enough to say they detected a word. Awareness of that one letter could be used during the recognition task, thereby boosting their performance above chance. It may be the case that correct decisions can be made when even less evidence (e.g., line segment or feature) is available to awareness (for a detailed discussion of participant confidence see Kunimota, Miller, & Pashler, 2001). The possibility of this type of informed guessing can be exacerbated when participants have specific expectations about what the subliminal information might be (e.g., they know the primes in a Stroop task are

color words) and when only a small set of stimuli (e.g., four color words) are used to convey that information (e.g., Kouider & Dupoux, 2004). Therefore, participant bias and the lack of evidence for pure processes (e.g., a task only sensitive to aware or only sensitive to unaware processing) can severely limit our ability to make strong claims regarding the "subconscious" processing of stimuli. Even in laboratory settings, it is extremely difficult to ensure that a stimulus is presented below the threshold of awareness (Merikle, 1998; Sandberg et al., 2011).

Reframing the Question of Awareness

It is difficult to effectively use subliminal presentation. Determining participant awareness of stimuli and determining the psychological processes underlying performance is challenging and often the results are inconclusive when carefully examined (Jacoby et al., 1992; Merikle & Reingold, 1992). When subliminal presentation is used in more applied settings, the challenges associated with indexing participant awareness are compounded. Indeed, Aranyi et al. (2014) suggest that "many attempts [in HCI] fall short in terms of rigorous application of established subliminal perception paradigms from the field of experimental psychology, such as controlling carefully for the conscious visibility of masked stimuli" (p. 34). We believe one of the primary reasons for this is tied to the ultimate goals of the researchers. In most psychological experiments the goal is to examine the underlying mental processes supporting a task. For the experimentalist, it is therefore extremely important to have a clear delineation between aware and unaware processing. The same may not be true for the practitioner. In many cases, the primary reason for using "subliminal" presentation is to present information to users in a way that is less disruptive and less resource consuming. To illustrate, imagine a virtual button that provides subtle contrast cues that encourage users to act on it over other buttons. This visual nudge would guide users through an interface. The visual difference between the higher contrast

button and other buttons is so slight that participants report being aware of the difference 40% of the time. Imagine that this contrast manipulation leads to faster and more accurate task completion. In this case, does it matter that participants sometimes were aware of the cue? Probably not, because we have accomplished our goal of improving interface navigation.

The strict experimental approach to identifying pure influences of perception without awareness is challenging and sometimes incompatible with the practical application. In response to these challenges, we pose three questions to consider when making the decision to present stimuli below the subjective threshold of awareness and make three recommendations for measuring participant awareness of those stimuli. This list of considerations and recommendations were motivated, in part, by the results of basic cognitive studies in recognition memory, visual attention, and word processing that use subliminal techniques, as well as by the more recent use of subliminal techniques in applied settings. We believe the cognitive findings presented here are important to consider when employing subliminal techniques. Because, they are relevant for successful use within applied settings when users complete multiple tasks simultaneously or when designers attempt to employ subliminal techniques in novel ways. First, we ask researchers to weigh the costs and benefits associated with subliminal techniques by considering 1) whether or not subliminal presentation is necessary, 2) what cognitive processes support stimulus processing, and 3) how various levels of stimulus intensity might impact performance.

Consideration 1: Is performance differentially affected by awareness of the stimulus?

We have already argued that even in highly controlled experimental settings it is hard to ensure stimuli are presented to individual participants below the threshold of awareness. The same challenges, if not more, exist in applied settings. Therefore, it is important to consider

whether or not it is necessary to present the stimuli below the subjective threshold of awareness. A factor that should contribute to this decision is if participant awareness of the stimulus has a meaningful impact. One way to determine this is by examining behavioral outcomes when stimuli are presented below and above the subjective threshold (Merikle & Daneman, 1998, make a similar recommendation). Some processes, and participant's subsequent behaviors are greatly affected by awareness of the stimulus (e.g., Bornstein, 1992). For example, Jacoby, Toth, Lindsay, and Debner (1992) describe an unpublished study by Chalfonte that was aimed at investigating participants' ability to solve anagrams when given the solution beforehand. The solution was either briefly presented and masked, preventing participants from recognizing it, or the solution was unmasked allowing participants to recognize the word. Participants were asked to try to identify the briefly presented word, solve the anagram, and then report how difficult the anagram would be for others to solve. As long as the time between the solution and anagram presentation was short (500 ms), participant anagram solving was facilitated regardless of their initial awareness of the solution. Interestingly, participants who had not "seen" the solution predicted that the task would be easier for others while participants who reported seeing the solution did not change their difficulty rating. In other words, participants in the unaware condition misattributed the ease of solving the anagram to the anagram difficulty (e.g., it was an easy one) instead of to the fact that they had been given the solution. By contrast, when participants knew they had been given the solution, they did not make the same misattribution. In this case, awareness or unawareness of the presentation of the solution had little impact on objective behavior (time to solve the anagram), but it is clear that stimulus awareness affected participants' rating of the anagram task.

In other cases, awareness of the stimulus has very little effect on participant responses and attributions (e.g., Forster, 1998). In a word recognition study, participants completed a lexical decision task – they were asked to decide whether or not a given letter string – the target – was a word. By presenting a prime with a similar spelling before the target, one can hinder or facilitate target processing. Forster (1998) used identity primes – the prime is the same as the target (e.g., *fork* – FORK) – in a lexical decision task, but used either a briefly displayed, masked prime or a clearly visible prime. Regardless of prime awareness, participants made faster lexical decisions to targets after the presentation of the identity prime. Awareness did not matter.

Many researchers have taken a similar approach by not focusing on participant awareness of the stimulus but instead examining how encountering a stimulus can, unbeknownst to participants, affect their future behavior (e.g., Bargh, Chen, & Burrows, 1996; Bargh, Gollwitzer, Lee-Chai, Barndollar, & Troetschel, 2001). Subliminal stimuli are seldom used in these long-term priming studies, but the manipulations can lead to outcomes that are similar to those designers are interested in, that is, they can affect behavior while minimizing additional processing requirements for the user. Interestingly, the impact of previous exposure to a stimulus, in some cases, can be so strong that even warning participants about stimulus influence fails to attenuate the effect (e.g., Jacoby, Allan, Collins, & Larwill, 1988).

Given some behavioral outcomes are greatly affected by stimulus awareness, whereas others are not, it is important to know which is true for the task at hand. If participant performance is affected similarly by stimuli presented below and above the subjective threshold, perhaps it is less important to ensure stimuli are always presented below the threshold of awareness. Providing evidence of this “indifference” to stimulus presentation would allow

researchers and designers to circumvent many of the challenges associated with the subliminal presentation.

Consideration 2: What resources support stimulus processing?

We have implied that when equivalent effects are obtained for subliminal and supraliminal stimuli, researchers could be justified in not measuring participant awareness of the stimulus. But, it remains that one of the goals of subliminal presentation is to present information without taxing cognitive resources (e.g., Negri, Garnberini, & Cutini, 2014; Riener, Jeon, & Reiner, 2014). This is often done to reserve those cognitive resources for other tasks. Therefore, resource consumption associated with stimulus processing continues to be a concern, particularly in dual-task or multi-task situations.

The most obvious processing concern would arise when participants are aware, or are occasionally aware, of the "subliminal" stimulus. At minimum, when participants are aware of the stimulus, their attention may be directed to that stimulus leaving fewer resources (or less capacity) to devote to another task; this is the typical cost associated with dual-task situations (Strayer & William, 2001). The users' resource usage is more nuanced, depending on the characteristics of the stimulus and the ongoing task. According to Wickens (2008), some multiple task workloads use independent resources (light interference), while others are dependent on some of the same resources (heavy interference). As one example, it has been suggested that visual and auditory information can be processed and maintained independently because they rely on different resources. In this context, awareness of a stimulus would have the greatest impact when the resources required to process that stimulus are the same as those required for the primary task. Utilization of the same resources can lead to task errors and slower completion times.

Riener's (2012) driving study provides a valuable illustration of resource requirements. In the original study, participants were presented with subtle vibrotactile feedback in the seat and safety belt related to their driving behavior. When participants drove in a way that did not conserve energy they received disharmonic vibrations, when they drove in a way that conserved energy they received harmonic vibrations. If the driving task relies primarily on the interpretation of visual information, then the perception of tactile sensations is unlikely to use the same resources. Therefore, one might not expect a decrease in driving performance even when participants are aware of the vibrations. Consider, by comparison, what would happen if a visual stimulus was used. Imagine a word such as *conserve* were presented on a heads-up display to users. It is possible that recognition of that word would tax the same pool of resources being used for the driving task leading to a performance detriment. In this hypothetical situation, it is much more important for visual feedback to be presented below the threshold of awareness than it would be for tactile feedback to be presented below the threshold of awareness.

Even when the stimulus is presented below the subjective threshold, there is the possibility that adding another task or changing the primary task could lead to unexpected changes in resource requirements. When stimuli are presented below the subjective threshold, it is often assumed that they are processed resource-free. In part, this assumption is based on the fact that when a stimulus is processed in the absence of awareness, it must rely on automatic processes. These processes are uncontrolled, unintentional, efficient, and fast; importantly though, in the cognitive psychology literature, they are defined as requiring *minimal* resources (e.g., Moors & Houwer, 2006). Card, Moran, and Newell (1983) make a similar supposition in the Goals, Operators, Methods and Selection rules (GOMS) model, where it is suggested that all human processes, automatic and effortful, require cognitive resources. Even very simple tasks

driven by automatic processes can be impacted by cognitive load indicating that the processes themselves also require cognitive resources (c.f., Grgic, Still, & Still, 2016).

Importantly, there is evidence that subliminal stimuli also require processing resources to be effective. Naccache, Blandin, and Dehaene (2002) asked participants to complete a number-comparison task where they were presented with a number and then had to determine if that number was higher or lower than a comparison number. For instance, the participant might be presented with an 8 and they have to decide if it is lower or higher than 5. Before the target, participants are presented with a prime that is congruent or incongruent with the target response. The entire sequence of events was embedded in a stream of visual masks so that there was a series of visual events appearing at the same location on the screen. Naccache et al. (2002) were able to vary participant temporal attention by manipulating the position of the prime and the target in the visual stream, by using external cues to exogenously engage attention, and by using the word primes *early* and *late* to direct attention. Across a series of experiments, the only significant priming effects were obtained when attention was directed toward the stimuli. In another masked priming experiment, Kiefer and Brendel (2006) found evidence that attention to the subliminal stimulus modulates the impact of that stimulus. In their experiment, the subliminal stimulus was a briefly presented, masked word that was either semantically related or unrelated to a subsequent target word. When the meaning of a word is accessed, a specific event-related potential (ERP) component, the N400, is elicited. Attention to the subliminal word was manipulated by changing the timing of events during the trial; specifically, the delay between the mask and the prime was either longer or shorter. Less attention is directed to the prime when there is a longer pause between the mask and the prime. The results of this study found that when temporal attention is not directed toward the prime, no N400 was elicited. Based on these results,

diverting attentional resources from a subliminal stimulus reduces its effectiveness; by proxy, this suggests that, at minimum, temporal attention is required to effectively process subliminal stimuli. With this knowledge, it is clear that researchers should consider the type of resources that may be required to process the subliminal stimulus and how that might interact with ongoing task demands.

Consideration 3: How do different levels of subliminal exposure impact performance?

In addition to considering the different types of processes that support subliminal stimuli and any concurrent tasks, it is important to consider how stimulus intensity might impact performance. Even when information is presented below the subjective threshold, it may be processed differentially depending on the intensity with which it is presented. One example of this can be found in the cognitive psychology literature where researchers were investigating the contributions of orthography (letters) and phonology (speech sounds) to word recognition. In a series of studies, nonword primes were masked and briefly displayed before presenting participants with a target to complete a lexical decision task (Ferrand & Grainger, 1992; Ferrand & Grainger, 1994). Specifically, Grainger and Ferrand (1994) used nonword primes that shared several letters with the target word and had the same pronunciation (e.g., French stimuli *mert – mere)* or shared fewer letters but had the same pronunciation (e.g., *mair – mere*) with the target word. Prime exposure duration was also varied: 14, 29, 43, and 57 ms. It is accepted that masked nonword primes with exposure durations of 60 ms or less fall below the subjective threshold of awareness for most participants, therefore, all four levels of stimulus intensity would be considered “subliminal.” Across several experiments, it was demonstrated that participants were faster to recognize a target when it shared several letters with the prime at 29- and 43-ms exposure durations; by contrast, facilitation for items with similar phonology occurred at 43- and

57-ms exposure durations. Based on results like this, the authors proposed that phonological processes occur later or take longer than orthographic processes. If they had only examined very short prime exposure durations, they might have concluded that phonological processes require awareness or deliberative processes to generate, when that clearly is not the case. Thus, unexpected, but potentially important, characteristics of the task or underlying processes can be revealed when multiple stimulus intensities are used. Even if a researcher is not interested in those nuances, there is a practical reason to use multiple stimulus intensities; it increases the odds of finding an effect.

A procedure that is less often used, but can accomplish similar results, is to repeatedly present a “subliminal” stimulus. In an effort to overcome a common confound in the priming literature (visible primes are not only visible, they also have a longer stimulus duration then “subliminal” primes), Wentura and Frings (2005) alternated presentation of a brief word prime (14 ms) with a mask such that the subliminal prime would ultimately have a cumulative exposure duration to a comparable visible prime (143 ms). According to the authors, the identity of the repeated prime was not detected by participants, and the prime had a significant effect on participant behavior. Importantly, when a standard single masked prime (14 ms) was used, they obtained no priming effect. These results suggest that repeated, brief exposures can increase the effectiveness of a cue that is presented below the threshold of awareness. Using a similar procedure, Aranyi et al. (2014) examined the impact of repeated cues in a virtual environment. In their study, the stimulus was presented either one time for 33 ms or three times for 33 ms each. The cue (image depicting a type of food or drink) in both conditions was masked such that the mask and cue alternated. The third condition with a clearly visible cue was included for comparison. Similar to Wentura and Frings, no detectable influence of the cue was obtained with

the single, short cue presentation, but a clear influence (approximately 7% change in behavior) was obtained with the repeated, short cue. Importantly, participants did not have increased identification of the repeated cue, indicating that the researchers had successfully increased the impact of the cue without increasing visibility.

In addition to potentially providing a stronger influence on participants, repeated presentation below the subjective threshold can be used to investigate the processes that underlie the construct under investigation. For example, Grainger and Ferrand's (1994) examination of phonological and orthographic processing in word recognition could presumably have been accomplished by manipulating the number of times a masked prime was presented. Compared to their manipulation of prime duration, this alternative approach would minimize the likelihood of participants detecting the prime in situations that typically require longer exposure durations.

If researchers have reason to believe that different types or stages of processing are involved in their "subliminal" stimuli or if it is important that the stimuli reach a specific level of processing to be effective, then stimulus intensity could be a critical consideration. Whatever technique is used to modulate stimulus intensity (e.g., repeated presentation, single-exposure duration, visual opacity, frequency), it is still the case that individuals will vary in their ability to detect the stimulus. Therefore, it may be prudent to test multiple intensities to ensure that appropriate "subliminal" conditions are provided.

We have provided considerations for researchers and designers who are in the early stages of designing an interaction that presents information to users below the subjective threshold of awareness. After considering the necessity of the procedure and the associated processing requirements, it may be clear that subliminal techniques are warranted. In this case, it becomes important not only to present the stimuli below the subjective threshold, but also

measure participant awareness of those stimuli. We provide three recommendations for capturing this information. The first recommendation – measuring participant awareness immediately – could be considered a best practice, while the other two recommendations provide practical alternatives.

Recommendation 1: Measure Awareness Immediately

It is not uncommon for participants to be asked at the end of the study or at the end of an interaction with a device whether or not they noticed anything unusual. The hope is that participants who were aware of the subliminal information will report that awareness. By leaving the question vague, researchers, presumably, avoid unintentionally contaminating participant responses. Simply including a direct measure of stimulus awareness at the end of the study may not be enough to reliably measure participant awareness. The assessment of self-reported user awareness of a stimulus provides an excellent case in point. As discussed, there are numerous pitfalls associated with self-report (e.g., response bias), but an additional pitfall concerns memory. Many stimuli that are presented near the subjective threshold of awareness have "weak" signals and can be forgotten rapidly if other competing stimuli are present (Potter, 1976). Thus, participants may be briefly aware of a stimulus, but if they do not focus attention on that precept, the memory of it may be lost. If participants are only asked at the end of the experiment about their experience, they may truthfully say that they did not notice the stimulus, when in fact they were aware of it at one point and simply forgot (e.g., Dewar, Cowan & Sala, 2007). To get the most out of subjective reports of awareness, it is important to probe the participant very soon after the presentation of the stimulus. The longer the delay, the larger role memory will play in self-reported awareness.

If we were to implement this recommendation in Riener's (2012) driving and vibrotactile feedback study, this would mean asking participants whether or not they notice a vibration while they are completing the driving task. Granted, questioning participants while they drive could affect their performance, but if this is done in each of the diving conditions (e.g., drivers asked about awareness three times during each of the driving segments), the effects would be equally detrimental preserving the validity of the measure. Another concern one might have about asking participants about the presence of a "subliminal" stimulus is that their behavior would change as they wonder why they are continually questioned about vibrations. One way to accommodate possible behavior change is by counterbalancing the order of driving conditions so that the cumulative effect of continued questioning is experienced in each of the driving manipulations across participants. Another way to counteract participant strategy changes is to disguise the purpose of the questioning by asking irrelevant questions as well. For instance, ask about other sensations "did you hear any high-pitched noises?", "did you see any lights flash?" Not only would these questions diffuse participants' focus on the vibrations, but they could also serve as a measure of participant bias. Specifically, as sounds and flashes were not presented, participants' spurious responses give a general indication of how likely they are to report something that was not present.

In some cases, it simply may not be possible to test for stimulus awareness during the experiment, or interaction, itself. An alternative could be to perform an objective test of stimulus awareness immediately following the experiment. Cetnarski, Betella, Prins, Kouider, and Verschure (2014) did just that in their study investigating the use of subliminal cues on virtual maze navigation. During the navigation task, participants were presented with a masked picture of an aversive stimulus (i.e., a spider) or a masked picture of a neutral stimulus in front of/on one

arm of a Y-junction. The researchers hoped that participants would be less likely to select the path that had been primed by the image of the spider. In their Experiment 2, Cetnarski et al. administered a prime visibility test after the navigation task. In this test, participants were presented with a series of negative and neutral masked primes – using the same display parameters as the experiment – and were asked to indicate whether or not the image was the spider (negative prime). Their analysis indicated that participants did not detect the spider above chance level (50%) suggesting that participants were not aware of the prime during the experiment. Aranyi et al. also used a forced choice visibility test at the end of their study to ensure participants were not aware of the subliminal information. This awareness post-test is valuable as it could be used to exclude the data from specific participants who were able to identify the prime above chance level (c.f., Gómez Maureira, Rombout, Teernstra, Speek, & Broekens, 2015). It is worth mentioning that this is a conservative measure; participants are likely to become more sensitized to the stimulus with repeated presentations. Therefore, even though these post-tests do not index real-time visibility, they do represent a less-intrusive method for indexing awareness without compromising the validity of the awareness measure.

Recommendation 2: Support Claims of Awareness with Multiple Measures

With the challenges of using and assessing the impact of subliminal techniques, it can be helpful to reframe the question of participant awareness of a stimulus in terms of behavioral outcomes. Instead of focusing on whether or not a stimulus is detectable, consider whether or not a set of tasks or conditions produce dissociable effects (DeVaul et al., 2003; Jacoby, Lindsay, & Toth, 1992; Merikle, 1998). Merikle and Reingold (1992) recognized the difficulty in "proving" the existence of pure processes and measures of perception without awareness and recommend instead, for instance, that direct and indirect measures be used together to infer the underlying

processes at work. For example, in addition to asking a participant whether or not they detected a word (a direct measure of perception) one might also ask them to complete a lexical decision task (an indirect measure of perception). Detection tasks (was anything presented), recognition tasks (was this specific thing presented), and recollection tasks (what was presented, if anything) are all direct measures of perception. There are a wide variety of indirect measures of subjective awareness as an indirect measure is really any measure that is impacted by exposure to the stimulus but does not require the participant to report on their awareness of the stimulus. Some common indirect measures include lexical decision tasks and evaluative ratings (e.g., how much a stimulus is preferred). In Merikle and Reingold's (1990) Experiment 4, perception without awareness was demonstrated when participants failed to detect the stimulus, but performed above chance level (with bias considered) on the lexical decision task. Although indirect measures do not offer a direct examination of participants' awareness of a stimulus, they can be valuable.

For example, Riener (2012) presented vibrations below the threshold of awareness in an attempt to encourage individuals to adopt energy saving driving strategies. At the end of the study, participants were asked whether or not they noticed the vibrations; this is a direct measure of stimulus awareness. All but two participants (15%) reported being aware of vibrations at some point during the experiment. Participants said the vibrations were not distracting or annoying and they did not intentionally change their driving behavior in response to the vibrations. During the experiment, researchers monitored participant driving behavior; this is an indirect measure of the influence of the stimulus. In this experiment, the indirect measure of driving behavior is just as important – if not more so – than participants' self-reported awareness of vibrotactile notifications. Additional indirect measures could be obtained in this hypothetical study by asking

participants how much they were enjoying their driving experience under conditions when they were receiving vibrotactile feedback and conditions when they were receiving no vibrotactile feedback.

Beyond providing evidence that a stimulus was presented below the subjective threshold, using multiple measures could provide differential sensitivity to subliminal information. Gómez Maureira et al. (2015) used this strategy in their experiment designed to examine the impact of various subliminal cues on the affective responses of users playing a computer game. In their experiment, stimuli with negative affective valences were camouflaged by presenting them briefly (33 ms) and masking them with the game scene and a lightening flash. The subliminal stimulus could be a picture of a spider, a picture of a face depicting a fearful expression, the word *panic* appearing in several locations across the screen, or a "blank" screen with no prime. At the end of the experiment, participants were asked if they had seen anything unusual. Of the 60 participants in the study, 16 said they had noticed something. Of those 16, six mentioned something about the primes that were actually used in the study while the other 10 did not. In addition to open-ended responses, participants completed a forced-choice task where they indicated how confident they were that they had seen a set of images. The results of the forced-choice task were used to determine that the 10 participants' whose awareness was in question were unlikely to have been aware of the subliminal stimuli (selection performance was at or below chance level). In this case, the forced-choice task was a more sensitive index of participant awareness than the open-ended question about seeing anything unusual. It is also worth mentioning that the six participants who were clearly aware of the prime were excluded from their statistical analyses.

Researchers can consider whether one measure is more sensitive than another similar measure (e.g., a recognition task compared to a recall task), but it is also worth considering sensitivity across measures that are less similar. For instance, Gómez Maureira et al. (2015) measured participant heart rate and galvanic skin responses along with participants' subjective experience playing their computer game. Although they did not find a reliable impact of subliminal presentation, the physiological measures would likely have provided a more sensitive measure of fear than a subjective report of fear. Neuroscience measures are also sensitive to subliminal stimulation: ERP (e.g., Kiefer & Brendel, 2004; Kiss & Eimer, 2007) data are particularly useful when temporal precision is needed, for instance, when using briefly-displayed stimuli, while fMRI (e.g., Brooks et al., 2012; Luo et al., 2004) data are more useful when particular brain areas or neural circuits are of interest.

Recommendation 3: Use Several Stimulus Intensities

We have already discussed participant biases in decision making (e.g., how much evidence does it take for an individual to say they have detected a stimulus), but it is also true that participants have different perceptual abilities. As alluded to, it is seldom the case that one stimulus intensity will fall between the subjective and objective thresholds for all participants (see figure 2). Also, as participants continue with a task, their subjective threshold may change. Typically, the threshold moves lower such that originally undetected stimuli are more likely to be detected toward the end of the experiment (e.g., Cheesman & Merikle, 1984). One way to combat these issues is to set the stimulus intensity for each participant and to update it throughout the experiment. Researchers do occasionally set the subjective threshold for each participant. But, it is much less common to update the stimulus intensity throughout the study. The increasing chance of stimulus detection is particularly problematic when the subliminal

stimuli come from a small set (e.g., color words in a Stroop task, a neutral picture vs. an affective picture). Even if only some features of the stimulus are recognized, participants may "reconstruct" those features to consciously determine the identity of the stimulus (e.g., Kouider & Dupoux, 2004).

An alternative would be to include several levels of stimulus intensity (some near the subjective and objective thresholds of awareness) in the experimental design. The most obvious benefit to using multiple levels of stimulus intensity is that each participant is guaranteed to be presented with stimuli below the threshold of awareness without varying intensities across individuals or during an experiment. When this technique is paired with the frequent probing of participant awareness, researchers can have a better understanding of participant awareness during the task and its relation to performance. This approach is particularly useful when conducting pilot studies.

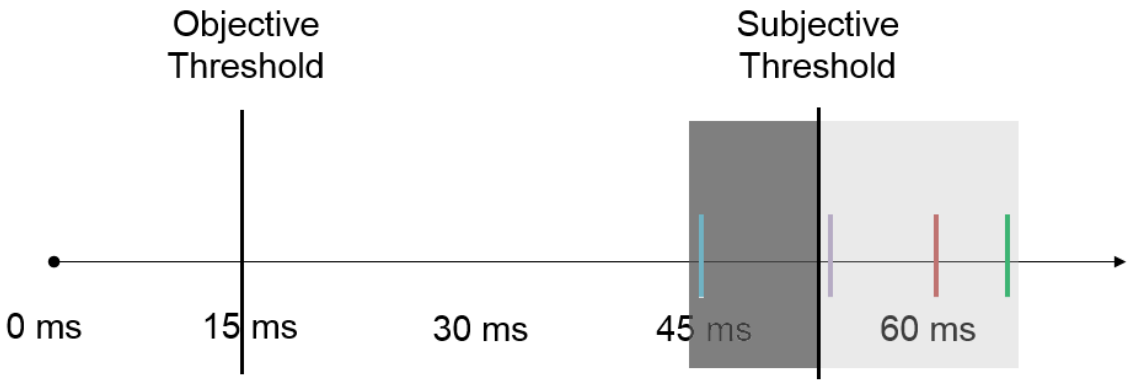

Figure 2. This figure depicts a hypothetical study with four stimulus durations – 15, 30, 45, and 60ms. The objective and subjective thresholds are based on hypothetical pretest data suggesting that the 30 and 45 ms exposure durations should be effective "subliminal" cues. The smaller, individual lines represent the subjective thresholds for individual participants. As shown in the figure, if a 50 ms exposure duration were used in this situation, the "subliminal" cue would only be subliminal for 3 out of the 4 participants. By using multiple stimulus intensities, not only will

the subjective thresholds for individuals be apparent, but it will help reveal the extent that sensitivity and bias vary in the population.

Conclusions

As we become more immersed in a highly computationally driven environment, new human-computer complexities are going to arise. One difficulty will be maintaining a calm and natural surrounding given that we are immersed in computational information sources (Weiser & Brown, 1996). One strategy would be to limit the number of devices that demand our limited conscious resources as has been an ongoing goal in Ubicomp. Another strategy is to increase understanding of stimulus processing within our natural environment. Researchers and designers have incorporated this understanding into user interface design, but some aspects of this have been a challenge. The use of "subliminal" presentation of information has presented one of these challenges, which is of major interest to designers. However, clearly, the focus of the applied work was mainly on external validity at the cost of internal validity (Still, 2011). We believe a careful examination of subliminal processing and reconsidering our goals when using subliminal techniques can lead to productive and insightful outcomes. It would be an exciting new era in human factors and human-computer interaction if designers were able to present information to users in a resource-free manner subliminally. According to Riener, Chalfoun, and Frasson (2014), subliminal information displays show great promise in both reducing cognitive workload and acting as persuasive elements. Recent evidence suggests that simple cues (e.g., a letter mapped to a "stop" response) presented below the subjective threshold can even stop or reverse ongoing motor movements (Ocampo, Al-Janabi, & Finkbeiner, 2015).

Before designers widely adopt the practice of influencing users below the subjective threshold of awareness, there remain a few important issues. One that we do not examine in this

manuscript is the ethical considerations associated with using these techniques. From a design perspective, the goal may be to simply improve human interaction with a device, but good intentions do not always ensure ethical behavior. If the goal is to influence users' behavior without their knowledge, designers ought to consider possible negative outcomes. For instance, in the real-world unique situations arise that require atypical responses. In these cases it is possible that a subliminal technique might actually slow the appropriate response. A pilot study by Mateescu and Bajić (2014) provides an example of this. Previous research using simple, artificial displays, demonstrated that a subliminal flicker could be used to direct attention to a specific location on the computer screen (measured via eye movements). However, when Mateescu and Bajić used a similar technique in a set of natural images, the subliminal flicker appeared to push attention away from instead of toward the location they were trying to attract attention.

However, we must determine whether subliminal perception is actually a feasible tool to use in applied settings; if it is not feasible, presumably, it is unlikely to have widespread adoption. Therefore, a second important area of research is feasibility. While several studies begin to bridge the gap between basic laboratory research and externally valid research (e.g., Aranyi et al., 2014; Cetnarski et al., 2014), "the feasibility of the subliminal perception in real settings still remains an open question" (Riener, Jeon, & Reiner, 2014, p. vi). Part of the feasibility challenge lies in practicality; for instance, how likely is it that a designer will integrate a masked prime into an interface? Will user display parameters preserve the intended experience or will cues intended to be subliminal be visible? Gómez Maureira et al.'s (2015) computer game study provides a pointed illustration of the special design considerations needed to ensure that information is presented below the threshold of awareness. Another part of the feasibility

challenge lies in the ability to use truly subliminal cues. As we have discussed, researchers often adopt multiple tasks, measurements, or stimulus conditions to check for perception without awareness. In applied situations, these additions are often of secondary concern to designers and stakeholders – and they should be of no concern to users. With lower prioritization, it is easy to see how an element such as a test for stimulus awareness would be omitted from a "real world" design. A final part of the feasibility challenge is simply finding clear evidence that stimuli presented below the subjective threshold have a meaningful impact on behavior. The influence of these stimuli often is short-lived (Cetnarski et al., 2014) and in some cases may be too weak to be useful in interface design (e.g., Aranyi et al., 2014; Gómez Maureira et al., 2015). A related element that has received comparatively little attention is the complexity of information that can, or cannot, be communicated using subliminal techniques (see Kawakami & Yoshida, 2015 for an example of subliminal influence on what is considered to be higher-level processing).

Even as we move forward testing the extent to which subliminal cues work in the real world, it will be imperative that the cues being presented satisfy the constraints of a subliminal stimulus. If they are not presented below the subjective threshold of awareness, we are merely testing the effects of weak stimuli and have learned nothing about the feasibility of subliminal influence. When the goal is to explore methods of influencing behavior without increasing cognitive load, then it may be acceptable to forgo rigorous controls of stimulus awareness (e.g., Aranyi et al., 2014). It is critical to recognize, though, that without proper controls and assessments of stimulus awareness, the science of perception without awareness in applied settings will not advance. Therefore, serious consideration must be given to the use of the term *subliminal* and serious consideration must be given to the ultimate goal of these applied research projects. In some cases, cue visibility may have little to no impact on cognitive load. From this

perspective, the use of subtle cues – just noticeable cues that still influence behavior – may be a viable alternative. For instance, Lu, Duh, Feiner, and Zhao (2014) demonstrated that a barely-perceptible opaque shape could improve visual searches across a variety of cluttered displays.

We believe an important extension of current subliminal work will examine cognitive load differences between subtle and subliminal cues. In that line of research, it will be important to look not only for resource benefits associated with the subliminal presentation, but also resource cost that may be associated with subtle or clearly visible cues. Negative use cases associated with subtle cues could prove invaluable for designers when weighing the costs and benefits of attempting to use a subliminal cue. For instance, what happens if a cue is intended to be offloaded to a non-attended channel by presenting it below the subjective threshold, but it is not subliminal all the time for all users? Would the attempt at subliminal presentation lead to unacceptable costs such as increased error rates or decreased user satisfaction?

There is a clear need for additional research examining the impact of information presented to users below the subjective threshold of awareness. The associated research findings have the potential to inform a wide variety of design decisions and, hence, real world interactions. While this area of research is by no means new, it is one that is in need of unifying approaches and conceptual frameworks. With these needs in mind, we have attempted to delineate some of the issues encountered when using subliminal techniques (e.g., the definition of *subliminal*, measuring and interpreting subliminal effects) and to provide practical recommendations and considerations for using subliminal presentation techniques.

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