Exploring the Feasibility of Subliminal Priming on Smartphones

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ABSTRACT
Subliminal priming has the potential to influence people's attitudes and behaviour. Yet little research has explored its feasibility on smartphones. This paper addresses technical, ethical and design issues in delivering subliminal priming. We present three explorations of the technique: a technical feasibility study, and two participant studies. A pilot study (n=34) explored subliminal goal priming in-the-wild over 1 week, while a semi-controlled study (n=101) explored the immediate effect of subliminal priming on 3 different types of stimuli. We found that although subliminal priming is technically possible on smartphones, there is limited evidence of impact, with inconsistent effects across stimuli types. We discuss the implications of our results and directions for future research.

Author Keywords
Subliminal priming; smartphones; nonconscious behaviour change technology; mere exposure effect

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous;

INTRODUCTION
This paper explores the boundaries of subliminal priming on smartphones through a pilot, a technical feasibility study and a full study. Smartphones offer multiple opportunities for priming, with an estimated 55 uses per day [45]. Some of these uses may also be habitual [26,66]. This gives the opportunity to intervene without attracting conscious attention and risking disruption. Yet despite high smartphone ownership [47] and many successful subliminal priming experiments in psychology labs, to our knowledge this is the first research to analyse the technique on mobile platforms. Replicating subliminal experiments on smartphones may yield different results to those run in psychology labs since research shows replication is sensitive to contextual factors [83].

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Subliminal priming is the showing of a stimulus that has some effect without the participant having conscious recall of the stimulus [12,60]. *Subliminal goal priming* is showing people stimuli to increase the likelihood of the goal-orientated behaviour [69,76,92]. Our particular interest is in the use of subliminal priming techniques in nonconscious behaviour change technology [8,69,70,74]. This paper builds on our earlier preliminary exploration of subliminal priming for nonconscious behaviour change on mobile apps [69,70].

The application of subliminal techniques faces design, ethical, user acceptance and technical challenges. It is also not clear whether and under what circumstances subliminal priming is in fact possible on smartphones. The aim of this paper is to clarify these circumstances and challenges. Current subliminal research more generally in HCI has been criticised for not *systematically* exploring subliminal influences [3]. This is the focus of our paper.

We outline two quantitative participant studies (a pilot and a follow-up) that explore whether subliminal priming is possible on smartphones. The pilot is a week-long study in the wild examining the impact of goal priming messages shown at unlock time. The follow-up study in semi-controlled conditions examines the immediate impact of 3 different stimuli groups: photos, text and polygons.

Our paper makes the following contributions:

- We provide an overview of design considerations for subliminal priming on smartphones from a review of related work
- We outline the ethical and user acceptance issues.
- We determine the technical feasibility of off-the-shelf Android smartphones for showing subliminal primes (Study 2).
- We present the results of a 1-week pilot (n=34, Study 1) analysing the effect of subliminal goal primes on smartphones in the wild, and the results of an experimental study (n=101, Study 3), that together question the feasibility of smartphone-based subliminal priming.

RELATED WORK

Theoretical Background

Dual process theories (DPT, see Evans [36] for a review) help to explain the phenomenon of subliminal priming. They suggest that our decision-making processes are governed by two systems: a nonconscious system that is automatic, fast, heuristic and associative; and a conscious system that is slow, rational and has limited resources. Subliminal priming techniques aim to covertly trigger automatic responses in the nonconscious system [65]. The advantage of subliminal instead of supraliminal triggers are that they can support people during tasks with high load on the conscious system [87], potentially avoid irritation [43], be less likely to promote behaviour that is in contrast with the prime [38], and can increase authenticity in responses [76].

Mechanisms of subliminal priming

Subliminal priming aims to activate cognitive representations of stimuli outside of conscious attention [57,65]. Subliminal goal priming tries to make it more likely an individual will perform a behaviour in line with a given goal. For this to work, the individual must have a pre-existing associative network of cognitive constructs related to the goal, including the means to achieve it. Priming re-activates this network, increasing its accessibility, making goal-related behaviour more likely [1,7,22].

Priming may also increase a goal construct's reward value via the mere exposure effect [11,22,52]. The mere exposure effect is where exposure to stimuli increases subsequent liking judgements [94]. This effect has been extended into the subliminal, i.e. experiments where participants tend to prefer the stimuli they've been shown, despite not being able to consciously recall seeing them [75]. Monahan et al. [61] found that the effect of *subliminal* mere exposure (SME) effects further increased with the number of exposures of a stimulus.

A second approach to increasing liking via priming (affective priming) is subliminal affective conditioning (SAC). SAC pairs a target item with a valenced (positive or negative) affective subliminal prime to alter participant attitudes and/or behaviour towards the target [28,91]. Dijsterhuis found that participants exposed to a ~17ms exposure of the word "I" alongside a positive trait showed an improvement in levels of self-esteem compared to a control group [28].

Subliminal HCI research

In HCI, subliminal experiments have primarily focused on enhancing "just-in-time" decision making. Experiment have investigated domains including visual search tasks [3,68], performance support in 3D intelligent tutoring systems [16], memory support [27] and driving assistance [74]. Aranyi et al. [3] found some evidence that subliminal cues can support selection tasks in virtual environments, but found only larger effect sizes for trials with fast response rates (≤1second).

Subliminal scepticism

Researchers have expressed scepticism about both subliminal perception and subliminal priming [62,71], partly due to lack of replicability and the weakness of the effect [41,42]. The existence of subliminal *perception* is less controversial since neuroimaging techniques have shown activation in reward areas of the brain in response to subliminal presentation of meaningful stimuli [18,67,88]. However, subliminal *priming* remains controversial, with ongoing discussions including how to demonstrate a lack of awareness of stimuli, methodological issues and how to establish reliable and replicable subliminal priming experiments [17,31,41,77].

The technique is not universally accepted as effective in HCI: Pfleging et al. [68] found no evidence that subliminal cueing on desktops can improve visual search tasks, compared to supraliminal cues, despite tailoring subliminal cue presentation to individual participants' perception thresholds. Similarly, Reiner & Thaller's research [74] into the effect of subliminal lane change requests on steering behaviour found no significant effects compared to a control group.

Design considerations

Prime Modality

Riener et al. [73] identified four possible channels of subliminal communication: visual; auditory; olfactory and tactile. We selected visual as the most suitable channel for research on smartphones: auditory signals may not be attended to and phone sounds are often disabled; there are few tactile opportunities on a static touchscreen; and research into olfactory HCI on smartphones is in its infancy [53].

Stimuli Type

Visual stimuli have additional design considerations, in particular around whether to use words or images as stimuli. Although there is evidence that images activate meaning faster than words [15], it is more difficult to select an unambiguous image than an unambiguous word. Single words are thought to maximise the likelihood of activating related concepts, because they are easier to parse than phrases. However, subliminal word primes should avoid ironic effects. For example, Earp et al. found that "no smoking" is unsuitable as a prime because it activates concepts related to smoking [33]. Our Study 3 explores the question of stimulus type by comparing the impact of photos, text and polygons.

Prime Delivery

Subliminal priming is often delivered by displaying the stimulus for a period of time that makes people unable to consciously recall the stimulus. Yet there is some debate about appropriate timings. Previous studies have used durations ranging from 4ms [64], 5.55ms [27], 16.67ms (i.e. 1 frame at 60 frames per second, fps) [28,46,81], 30ms [84] and 33ms (2 frames at 60fps) [3,95], while fMRI studies suggest a subliminal threshold of ~20ms [59]. For our studies, we selected a target stimulus exposure time of 1 frame, approximately 17ms at 60fps [39]. Study 2 is a series of experiments to confirm these times.

Masking

Subliminal priming cannot be done on smartphones without users being aware that *something* is happening, for example at least seeing flickers related to stimuli exposure, since humans can detect flickers at rates over 500 Hz [23]. Smartphones also cannot replicate the precise millisecond or sub-millisecond exposure times of tachistoscopes [79]. Smartphone interventions may be able to use *masking*: the use of additional images shown in the same location as a target within a brief time period in order to reduce the target's visibility [35]. Masking is a common technique in psychophysics to limit or remove the ability of participants to consciously recall a target, particularly when there are technical constraints on target exposure times [6].

However, choosing an appropriate masking method, duration, and mask type is not trivial. Firstly, a mask may be presented both before and after a target (sandwich masking), just afterwards (backward masking) or just before (forward masking) [35,89]. Secondly, mask durations are also varied across experiments, from 50ms [78] to 200ms [3]. Thirdly, masks may be a pattern (e.g. random dots [43]), a similar image (e.g. a neutral face mask shown after a stimulus of an emotive face [54]), a bright-field energy mask [75] or a composite of all stimuli [3].

Greenwald et al. showed that sandwich-masking targets shown for 50ms meant that most subjects could not consciously recall them, while they could identify unmasked targets [42]. To avoid having the stimuli visible, we also selected a sandwich-masking technique with the stimulus itself being shown for 17ms.

Affective primes

Researchers have used smiling and angry faces as affective primes, with random polygons as "non-affective primes" [91]. Murphy & Zajonc found that subliminal priming non-affective items with smiling faces improved liking of those items compared with those primed with angry faces [64]. The results show evidence that emotions can be elicited outside of awareness. Winkielman et al. [91] suggest that affective priming is more effective with unfamiliar targets, compared with trying to change pre-existing affect for familiar ones.

Subliminal priming in mobile apps

Several commercial subliminal apps are available. However, some have features that make them unlikely to be able to deliver subliminal priming effectively. Megabit [58] presents primes for 300ms, whereas the threshold of sensory awareness is commonly taken to be 20ms [59]. iSubliminal [48] presents long phrases as stimuli, which are unlikely to be processed in subliminal display times.

ETHICAL CONSIDERATIONS

Priming as a dark design pattern

Using subliminal techniques to influence consumer behaviour is highly controversial [29], even though the original claims of a successful subliminal marketing in the US in the 1950s were vastly exaggerated [71]. Concerns about the potential for malicious use of commercial subliminal messaging persist [37]. The controversy is partly fuelled by the "considerable creativity" the media uses to report results—or lack of results—in subliminal research [86] and by conspiracy theorists who try to incite "moral panic" about the possible effects of the phenomenon [93].

Yet media outrage, moral panic and legislation lag behind advances in technology. Apps exploiting subliminal techniques exist in a grey area since they are neither broadcasters nor advertisers, both of whom were prohibited from using such techniques in countries like the UK [96,97]. In theory, unscrupulous designers could use subliminal priming methods as a "dark design pattern" [14,40] to try to influence users. For example, app designers might want to prime users to prefer a particular product over others without their consent. Again, the evidence for effective malicious subliminal applications is mixed. Strahan et al. [81] argue that subliminal priming is only possible where the priming involves a goal that the recipient is already motivated to achieve. Conversely, Vewijmeren et al. [85] show evidence that subliminal advertising can increase consumption of a brand over and above their habitual brand. This research opens the possibility of apps successfully priming alternatives to ingrained habits, which are difficult to overcome by conscious strategies such as self-monitoring [80,44], but also opens up ethical concerns.

Clarity for users and study participants around what is being shown subliminally and why is key. For our own research, we made the general outline of the task clear to participants. We told them they would be shown items for a short space of time. We revealed the precise aim of the experiment once they had completed it.

Acceptance towards subliminal priming techniques

A key question is whether users would accept subliminal priming techniques, even with informed consent. In a separate survey of users of activity trackers (n=26), we asked: "Would you consider enabling subliminal prompts on your mobile device?". People generally had fairly negative attitudes towards priming: 13 said "Definitely not", 7 "neutral", 1 "Definitely" and 5 people provided no rating.

The participant that responded "Definitely" said, "*Curious how and if this could work?"*. Reasons for responding "Definitely not" included scepticism over effects ("*Don't think it's useful*"), a rejection of the idea of subliminal prompting ("[prompts should] *be obvious or not at all*"); and possible fear about the technique ("*subliminal prompts sounds like it could scar[e] people*"). Neutral respondents also expressed possible fear ("*it does make me aware of the fact that anyone could [p]ut any sort of subliminal message in my devices and I wouldn't like that*"), and wanted subliminal prompts that would comply with their conscious goals ("*the messages should comply with my other […] goals and not conflict with them*").

We therefore suggest that any app employing subliminal techniques should ensure they address user fears and misunderstandings at the outset. It is the responsibility of researchers and app designers to ensure that interventions are delivered in an ethical, transparent fashion [50].

STUDY 1: PILOT

This in the wild pilot measured the impact of one week of goal-related subliminal primes, shown at unlock time, on measures of direct and indirect goal activation. An intervention group were shown goal-related primes on their own phones at unlock time. The pilot used both SAC techniques by associating a goal word with a smiley ":)" and SME effects in the form of many repetitions of the goal word.

Participants

A sample of 38 participants (24 female, Mean age = 28.8 years, SD 8.22 years) took part. All participants were adult native English speakers who owned Android devices and used a PIN unlock, recruited at a UK university. 34 participants were included in the final analysis: 17 in a control group, 17 in an intervention group. 1 other participant in the intervention condition was excluded because they reported they saw the prime on unlock. 3 other participants were excluded because they did not use their phones during the week. This study has similar sample sizes to related work that has found effects [3,28,74,81].

Recruitment material asked for people who wished to be more active, to address Strahan et al.'s evidence that participants need to be motivated to pursue a goal for subliminal goal priming to be effective [81]. All participants gave consent to participate in an experiment that "may prompt you to be more active", but were naïve to the subliminal nature of the experiment until the end.

Prime Conditions

The experiment had two between subjects prime conditions: 1) an *intervention* group that received a goal prime at smartphone unlock time and 2) a *control* group that did not receive this prime at unlock. Participants were randomly assigned, balanced for gender, to either the intervention group or the control group.

Priming procedure

For both conditions, all experiment materials (adverts, emails, surveys, instructions) repeatedly contained the prime "*active :)*". Participants were also asked to form a specific active goal for the duration of the experiment. They were advised that the goal should be clear, specific and somewhat hard to achieve, in line with Goal Setting Theory (GST, [55]). For both conditions, when participants unlocked their phones, after a short 500ms pause, a sandwich-masked stimulus was shown in black font on a white background in the centre of the screen.

For the *Intervention* condition (Figure 1), participants were shown the *active :)* stimulus for one frame (~17ms at 60fps), masked by a non-word pre- and post- for 3 frames (~51ms at 60fps). The non-word was chosen to mask each character of the stimulus including the smiley characters. *Control* participants were only shown the non-word masks for ~100ms (Figure 2).

For the *Intervention* condition we used a simple word, *active*, as a goal prime. This was chosen as it was relevant to the recruited participants' goal (i.e. to be more active) ensuring that it was goal-relevant [81]. It is also commonly understood to form part of a general action goal [2]. We used text rather than a potentially faster-parsed image because of the difficulty of selecting an image that would be meaningful to a large group of people. The smiley was included to add affective conditioning for the goal prime [21,22]. This is based on evidence from neuroscience that smileys provoke similar brain responses as smiling faces [19], and evidence that smiling faces can be effective subliminal affective conditioning cues [43].

At Android target rates of 60 frames-per-second, we expected the prime to be shown for ~17ms [98]. We selected a sandwich masking technique, using a non-word to conceal the prime with a pre- and post-mask target duration of approximately ~51ms (3 frames) in line with [78].

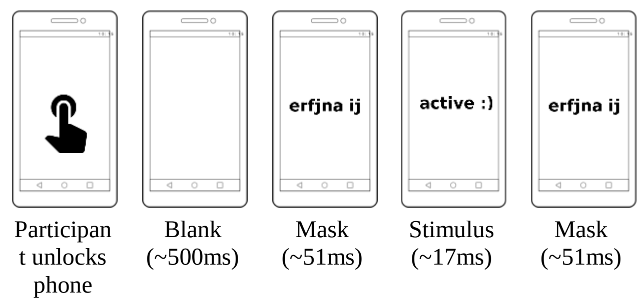

Figure 1. Unlock procedure – intervention

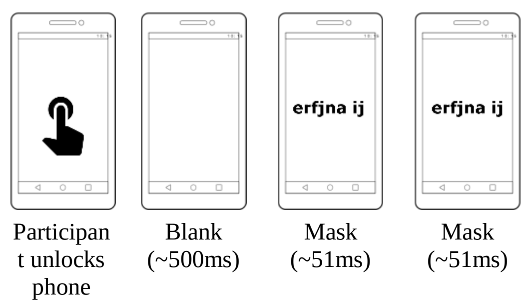

Figure 2 Unlock procedure – control

Measures

To measure the accessibility of the goal we used an implicit measure (reaction time in a modified Stroop task [63,90]) and an explicit measure (HWK scale) of goal activation. Each measure was administered before and after experiencing the week of priming (forming the independent variable *Session* in the analysis below).

The modified Stroop task in our study measured reaction times in a colour naming task. This task is used to measure processing bias towards different categories of words.

Following Berry & Spence [10], we measured reaction time in colour naming for three word types: *active, inactive and neutral* related words (forming the independent variable *Word Type* in the analysis below). The neutral words used were matched for length and frequency with the active and inactive words using the British National Corpus [99]. The set of words is given in the supplementary material.

The HWK subscale [44] (explicit measure) is a 5-item self-report measure using 1-5 Likert scales from Strongly Disagree to Strongly Agree. The measure has been validated by previous work [25]. HWK items are listed in the supplementary material.

An additional post-test dependent variable was a measure of *reactance*, computed from a set of 8 explicit attitude statements towards the app. Reactance, where users react adversely to a perceived loss of freedom of behaviour [13], is important because any app that generates the feeling runs the risk of being uninstalled. Dillard & Shen show that reactance can be measured using anger (anger, annoyance, irritation and aggravation) and negative cognition components [30]. We used a set of semantic differentials to gauge anger and a series of positive/negative differentials about the app to gauge negative thoughts towards it. Reactance items are listed in the supplementary material.

Procedure

Participants were recruited via social media across a UK University. They received a link to a demographics survey to start the experiment, after which they were prompted to form and declare an active goal, and completed the HWK measure. They were then randomly assigned to one of the two conditions, balanced for gender. Participants received a download link to the relevant Android experiment app. After installing the app, the first task was to complete the modified Stroop task

Figure 3. Modified Stroop task example

The modified Stroop task is shown in Figure 3. Following a short practice, participants were shown each word from the stimuli list at random in each of four colours, with the restriction that two words of the same colour should not appear at adjacent times. The participant task was to select the correct colour as quickly and as accurately as possible. We recorded reaction time and whether the participants selected the correct colour.

The app then primed each group (intervention and control) for a week at unlock time as outlined below. At the end of the week, participants were asked to complete a second modified Stroop task, and received a link to an online survey to measure Reactance and the HWK measure. Once the survey was completed, participants were asked whether they had seen any words on unlock, and which ones if any. Participants were finally given a confirmation code to claim their £5 voucher.

Results

App usage

We calculated actual usage for each full experiment day for each participant. Mean daily unlocks (and therefore stimulus exposures) was 49.0 (*SD* 28.0). A Chi-squared test of independence investigating unlock usage between the intervention and control groups showed no evidence of a difference X^2 *(1, N=34) = .06, p=.80*.

Goal commitment

Mean goal commitment HWK scores are shown in Table 1.

Intervention	*Session*	*N*	*Mean*	*SD*	*95% CI Lower*	*95% CI Upper*
Control	*Pre*	17	1.88	0.52	1.61	2.15
	Post	17	2.07	0.48	1.82	2.32
Intervention	*Pre*	17	1.58	0.34	1.40	1.76
	Post	17	2.03	0.63	1.71	2.35
Total	*Pre*	34	1.73	0.46	1.57	1.89
	Post	34	2.05	0.55	1.86	2.24

Table 1 HWK scores

An ANOVA showed no interaction effects between intervention group and session on the HWK measure (*p*=.28), nor a significant main effect of group (*p*=.17), but showed a significant main effect of session [$F(1,64)=6.81$, $p=.01$, $\eta p^2=.19$)]

Modified Stroop

One participant was removed from the data because of a high error rate (27.5%) and another participant's second Stroop session data was lost, so the final sample for analysis included 32 participants (16 in each condition). In line with common procedure, colour-naming errors (1.98%) and reaction times more than 2 standard deviations from the mean (0.48%) were removed [32].

		Word Type		
Condition	*Session*	*Active*	*Inactive*	*Neutral*
Control	*Pre*	994 (±387)	969 (±370)	997 (±382)
	Post	917 (±306)	935 (±328)	926 (±299)
Intervention	*Pre*	988 (±402)	1014(±456)	1001 (±423)
	Post	985 (±430)	986 (±409)	1001 (±457)

Table 2. Stroop colour-naming reaction times (ms *mean* ± *s.d.*)

Table 2 shows the remaining mean reaction times for each intervention group, session (pre or post) and word type. If the intervention is successful, correct reaction times to active-related words should increase in session two for participants in the intervention condition. This is because as exposure to the *active :)* prime activates their goal-related associations, active words become more salient and interfere more in the colour naming task. Reaction times to neutral words should not change, and inactive word reaction times may decrease as inactivity becomes less salient relative to activity.

We ran a linear mixed-effects model (LMEM) using lme4 [9] in R (version 3.1.2) [72] to identify the effect of condition, session and word type on reaction time. LMEM models are a good alternative to ANOVAs for this type of data because they remove ANOVA's averaging across participants and stimuli [4,5]. The model that converged included within-item random slopes for intervention and within-participant random slopes for session and word type. The model showed no statistically significant main effects of condition, session, or word type (p>.05) or interaction effects (p>.05). Full results from the model are given in supplementary information.

Reactance

Mean reactance scores (averaged over reported anger and negative feelings towards the app) for the intervention group was 0.34 (95%CI [-0.02, 0.34]) and 0.56 (95%CI [0.24, 0.88]) for the control group. A Welch Two Sample t-test showed no evidence of an effect of intervention group on mean reactance scores t (31.63) = 0.90, p = .374.

DISCUSSION

There is some evidence from the goal commitment HWK score that *any* reminders shown at unlock time, regardless of meaningful content, tend to increase goal commitment over 1 week. The modified Stroop results from our pilot show no evidence that our intervention had any impact on goal activation. We therefore conducted two follow-up studies to disambiguate these non-significant results. Study 2 addresses possible technical issues with delivering image-based primes on smartphones by measuring precise frame times for primes on particular experiment phones. Study 3 uses these phones to addresses possible issues arising from 1) a failure to instil a primeable goal, 2) participants not attending to primes at unlock time, and/or 3) an inability of the Stroop task to detect changes. Study 3 therefore used 1) immediate reaction tests, 2) semi-controlled conditions where users were asked to concentrate, and 3) direct measures of visibility and likeability.

STUDY 2: TECHNICAL FEASIBILITY

Our first step was to rule out technical issues with displaying primes on smartphones. We constrained our testing to a set of same-batch Android smartphones that we later used in Study 3. The study investigated the technical limitations of these phones for showing sandwich-masked subliminal primes.

Method

Apparatus

We ran our experiment timings app on a set (n=4) of Samsung Galaxy Nexus smartphones running Android 4.3. Android smartphones are capped at 60 fps or ~16.67ms per frame and use vertical sync to align the software's refresh rate with the display hardware refresh rate [98].

Procedure

We built an Android app to test frame durations for showing short-lived stimuli. We used the sandwich-masked stimulus exposure (mask-stimulus-mask) shown in Figure 6 using 3 different types of stimuli (text, polygons and photos, see Figure 5). We ran multiple sessions on each of 4 experiment phones. Mask duration was set at 3 frames (50ms at 60fps), while the stimulus duration was set at 1 frame (~16.6ms at 60fps). No images were preloaded. We used Android's Choreographer functionality [100] to log precise frame times for stimulus animation on our experiment phones. We recorded a "dropped frame" where the frame time exceeded 25ms, the mid-point between frames at 60fps.

Although we can measure exact frame durations, this is not the same as a length of the stimulus actually appearing because each pixel takes time to update once it receives the signal: the pixel transition rate. Analysis of LCD television screens pixel response rates show rates of approximately 1 frame duration or longer [34], but we were unable to locate any stated pixel response times for manufacturers of LCD or AMOLED smartphone displays for comparison. To investigate further, we filmed our experiment on our Samsung Galaxy Nexus' AMOLED display using a GoPro Hero 4in WGVA in 240fps mode, equal to 4.17ms per frame.

Results

Frame timings

The results are shown in the first row of Table 3. Although there were some dropped frames, 0.09% of total (n= 89714), all dropped frames we found occurred during the first or second frame captured. This suggests that the animation object may in some circumstances take some time to initialize, and may therefore not be ready by the first VSYNC, but that subsequent frames appear at around 60fps.

Wi-Fi state	*Dropped frames*	*Length of non-dropped frames in ms*				
		Median	*Max*	*Min*	*Mean*	*SD*
Off	0.09%	16.97	17.97	15.99	16.98	0.17
On	0.32%	16.97	18.64	15.25	16.97	0.19

Table 3. Frame timings

As a comparison, we also ran the timing app with Wi-Fi connected as a proxy for extra load on the devices. The results are shown in the second row of Table 3. A Kruskal-Wallis test showed no significant differences between frame lengths between our devices with Wi-Fi off [$X^2(3)$ = 1.42, p=.70], but a significant difference with Wi-Fi on [$X^2(3)$ =

18.38, $p < .001$]. The higher number of dropped frames with Wi-Fi on (0.32%) occurred in multiple positions, not just the first frame. We therefore disabled Wi-Fi in our semi-controlled experiment (Study 3) so that. a 1-frame stimulus duration would be ~17ms, the 3-frame mask duration would be ~51ms and there would be no dropped frames.

Pixel transition rates

Figure 4 shows the transition between mask and stimulus from an example filming session. The stimulus is clearly discernible for ~16.7 ms (8.3ms—25ms), although we can also see transitions between the stimulus and mask before and after the stimulus is fully visible.

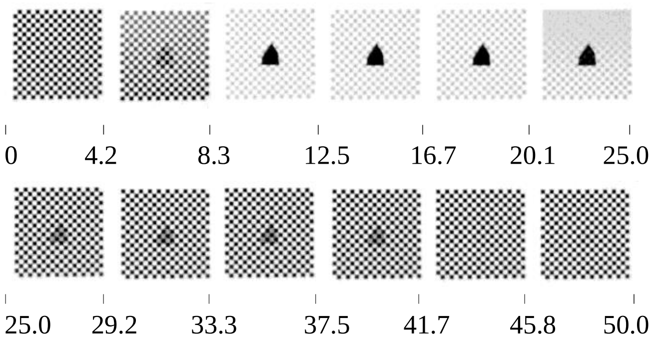

Figure 4. Mask - polygon stimulus - mask at 4.17ms intervals

The study app was filmed on our experiment phone under the same conditions as Study 3 (WiFi off, no other apps running) several times (n=10) on different occasions, with similar results.

STUDY 2 DISCUSSION

Our timings show that a 1-frame item appears for ~16.7 ms and a 3-frame mask appears for ~51ms on our experiment phones when Wi-Fi is disabled. A future task is to confirm whether these results generalise to different types of display hardware.

STUDY 3: STIMULI PRIMING EXPERIMENT

This study built on subliminal priming experiments from psychology [11,52,75]. To demonstrate subliminal priming, we need to satisfy two conditions: participants cannot consciously recall the stimulus (direct effect); and the same stimulus has some measurable indirect effect [29,31]. A common measure of the indirect effect is participant liking of the primed stimulus [61].

We selected three different types of stimuli: polygons, photos and text. The stimuli were non-affective (non-smiling faces, abstract polygons and text) to focus the study on exploring the effects of subliminal mere exposure effects.

We conducted this study in semi-controlled conditions: participants used our experiment phones and were asked to concentrate for the duration of the session, thus reducing the issues identified in Study 1.

Method

Participants

101 participants (36 female, Mean age = 25.9 years, SD age = 8.22 years, 1 participant declined to give their age) completed the experiment. Participants were recruited in person and via posters at our institution and in social and work situations within our social networks. They were offered a small non-monetary reward at the end of the experiment and could choose to enter a prize draw for a £30 voucher.

Conditions

There were 2 independent variables in the experiment:

1. Repetitions - how many times the prime was shown to participants [3 levels: 0xRepetitions (Control, N=29), 1xRepetitions (N=32) and 3xRepetitions (N=40)]
2. Stimulus Type - the type of stimuli shown to participants [3 levels: polygon, photo and text].

Repetition was varied between subjects with Stimulus Type varied within subjects. For Repetitions conditions, participants were unaware of which condition they were allocated to until they were debriefed at the end of the experiment. Experimenters were also unaware of the precise allocation of participants.

Task

The experimental task involved participants completing a series of trials, during which participants were shown a single masked *prime* stimulus (Exposure Phase). The priming procedure is shown in Figure 6. Participants were exposed to the primes as follows:

1. A focus dot for ~1003ms;
2. A mask for ~51ms;
3. A stimulus for ~17ms (prime);
4. A mask for ~51 ms;
5. A blank screen for ~204ms.

The prime exposure procedure varied depending on the Repetitions condition people were in:

- *0xRepetitions* (*control*) condition: steps 1-5 where the stimulus in step 4 was a blank image.
- *1xRepetitions* condition: steps 1-5 repeated once.
- *3xRepetitions* condition: step 1-5 repeated three times.

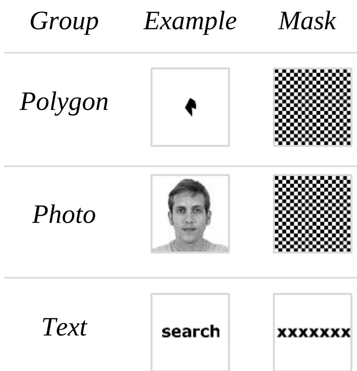

Figure 5. Stimuli groups, examples and masks

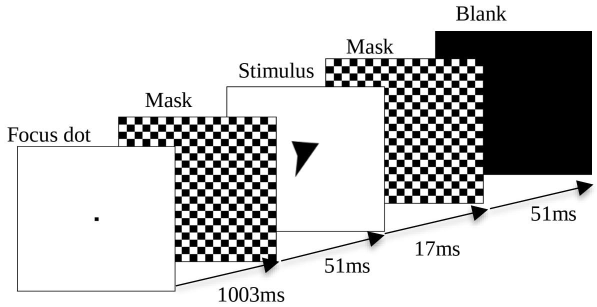

Figure 6. Exposure Phase (1x condition trial)

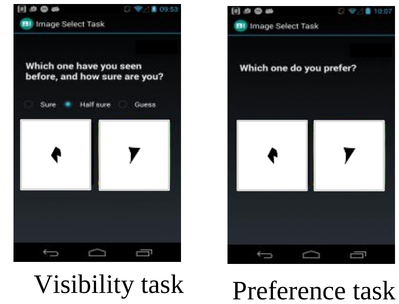

Figure 7. Selection Phase example (polygons)

After priming, participants were immediately given two 2-alternative forced choice tasks in sequence to measure 1) whether they had seen the stimulus (Visibility Task) and 2) whether they preferred the stimulus they had been primed with (Preference Task). These are described in more detail below. After answering both questions, participants switched back to the exposure phase to start another trial and until they had been shown all the primes in each stimulus type group. The order of type groups and order of pairs within the type group were randomised between participants. The order in which items were shown as primes were also randomised within participants and between stimulus types.

Priming items

Over the task participants were primed with three stimulus types:

1. Polygons (control stimuli): Black irregular polygons on a white background, 12.5px high, adapted from [101]; chequerboard mask
2. Photos: 200x200px black and white headshots of people with neutral expressions from the Chicago Face Database [56], each pair balanced for the database's attractiveness rating, race and gender, and masked with a chequerboard mask.
3. Text: a set of words shown in 42px Verdana bold black font on a white background. We used menu items from the top 10 apps in the Android Play store, balanced for word length. The word pairs are given in the supplementary information. Each word was masked with a series of 'x's.

In total participants were exposed to 10 different polygons, 10 different words and 20 different faces, in line with [52] for polygons & words and [64] for photos, thus making 40 trials for each participant. We used an ethnically diverse range of male & female faces (10 male, 10 female).

Polygons were used as the baseline stimulus type because they have been shown to elicit SME effects in previous experiments [52,61]. We selected photos and text as comparison stimuli because they are likely candidates for inclusion in mobile behaviour change apps, and to re-examine text stimuli as a follow up to our pilot Study 1. We used the same sandwich-masking technique and mask duration as in the pilot Study 1.

Example images from each group and corresponding masks are shown in Figure 5.

Measures

As mentioned, after the prime *Exposure Phase*, participants were shown two sets of two images, in sequence, and asked to select one of the images displayed in each case (Selection Phase). These sets were made up of a *target* stimulus identical to the prime[1], and a *distractor*, a randomly chosen stimulus that was different to the prime, but of the same stimulus type. Participants were asked:

1. Which one have you seen before? (*Visibility Task)*
2. Which one do you prefer? (*Preference Task).*

The order of asking was randomised between participants. Whether participants selected the same image as the prime (i.e. the *target*, coded as a 1) or the *distractor* (coded as a 0) were recorded. Participant's selections in the Visibility Task form the binary outcome variable in the Visibility analysis and their selections in the Preference Task form the binary outcome measure in the Preference analysis, both reported below.

Procedure

Participants completed the study on our experiment smartphones from Study 2: "clean" same-batch Samsung Galaxy Nexus smartphones running Android 4.3. They completed the task in natural surroundings such as the coffee room and our atrium. Prior to the test, participants completed

[1] In the Control condition, where participants did not experience a prime, one of the stimuli displayed was randomly assigned the role of the target.

a consent form, demographics and a training session. Participants gave informed consent based on an experiment that would "show images one by one for a very short space of time" but were naïve to the subliminal nature of the experiment until the end. All participants completed a brief training session before the experiment started. The training stimuli were colour flower photos.

During the main experiment, for each trial, participants were shown a target in the Exposure Phase, followed by a two-alternative forced choice between the target and its distractor stimulus in the Selection Phase as outlined above. Once the experiment was completed, participants were debriefed and thanked. A summary of the experiment set up for a given participant is given in the supplementary material.

Results

Data analysis

As with our Stroop analysis, data with reaction times less than or equal to 200ms (3.04%) and greater than 2 standard deviations from the mean (0.94%) were removed. Our mixed effects model for the Visibility Task analysis had data from 101 participants with 3995 observations. The Preference Task analysis was on a subset of data where participants answered the Visibility Task incorrectly, with 1497 observations on 101 participants.

Our outcome variable in both the visibility and preference tasks—whether the stimulus selected was the *target* (1) or not (0)—is binary. We therefore ran a mixed effects logistic regression analysis, using the lme4 package [9] in R (version 3.1.2) [72]. This statistical approach identifies the effect of *repetitions* and *stimulus type* (termed *fixed effects*) on the log odds of participants correctly selecting the target item. We selected this approach to avoid spurious results generated by using ANOVA to analyse binary outcomes through using proportions or percentages, and because it improves statistical power compared to ANOVA [49]. It allows us to consider individual participant- and item-based variation (*random effects*) within our statistical models. Similar analysis has been used previously in HCI priming experiments [20] and in other HCI research with binomial outcomes [82]. The models used to analyse the data included random intercepts for participant and target.

Visibility Task

In the visibility task, participants were asked to select the image they thought they had seen before. Table 4 summarises the outcome of our Visibility Task model (marginal R^2=.05, conditional R^2=.11). The full model output is given in the supplementary material.

There was a significant effect of *repetitions*, yet no significant interaction effect. This means that participants in the 1x*repetitions* and 3x*repetitions* conditions, regardless of stimulus type, were more likely to correctly select the target, compared to the baseline, where they weren't exposed to a prime (*0xRepetitions*). In short, participants could see the stimuli to a certain extent.

Condition	***Visibility***	
	Wald z	*p*
1xRepetitions	3.53	<.001
3xRepetitions	3.79	<.001
Photo	2.14	.03
Text	0.98	.33
1xPhoto	0.63	.53
3xPhoto	1.43	.15
1xText	-1.75	.08
3xText	-1.00	.32

Table 4. Visibility Task analysis, summary effects

This can also be seen from the Visibility Task results shown in Table 5. There was also a significant effect of showing photos (*p*=.03) on the likelihood of a participants correctly selecting the target compared to the text and polygon conditions.

Repetitions Condition	*Total Proportion of Target Selections*
0x Repetition	.49
1x Repetition	.63
3x Repetition	.66

Table 5 Total Proportion of Target Selections in Visibility Task by Repetition condition

Preference Task

Subliminal perception is argued to exist where there is no evidence that participants are able to correctly select the target item (i.e. the item they were primed with) yet participants prefer that same item [11,24]. We therefore looked at the outcomes of the Preference Task ("Which one do you prefer?") where participants got the Visibility Task wrong, i.e. they did not correctly identify the image they'd see before. The subsequent Preference Task results are shown in Table 6.

Stimulus type	***Repetitions***	***Total Proportion of Target Selections***
Polygons	0	.20
	1	.31
	3	.25
Photos	0	.29
	1	.31
	3	.33
Text	0	.32
	1	.16
	3	.33

Table 6 Total Proportion of Target Selections in Preference Task where Visibility Task was incorrect

Table 7 summarises the outcome of our Preference Task model (marginal R^2=.03, conditional R^2=.37). The full model output is given in the supplementary material.

The results show that the main effect of repetitions is not statistically significant, i.e. there is no evidence that showing a stimulus to a participant increases the likelihood that they will prefer it when they cannot see it. The data also shows different effects across the stimuli types: when participants cannot detect a Text stimulus, showing it once (1xText) *decreases* the likelihood of it being preferred compared to the control condition (0x Repetitions) and the effect in the Polygon stimuli condition. This can also be seen in Table 6.

Condition	***Preference***	
	Wald z	*P*
1xRepetitions	0.65	0.16
3xRepetitions	0.35	0.43
1xText	-1.69	<.001
3xText	- 0.23	.60
1xPhoto	-0.34	0.43
3xPhoto	0.10	0.81

Table 7. Preference Task where Visibility Task was failed

STUDY 3 DISCUSSION

Our results indicate that subliminal priming effects on smartphones may be inconsistent, with contradictory results across different stimulus types. Using text seems detrimental to subliminal priming when primed once compared to the other conditions (a statistically significant negative impact for 1xText in Table 7).

There is evidence that stimuli are difficult to conceal. Our participants could detect target stimuli to a certain extent when they were shown the prime once and three times, compared to the control on our experiment phones. Even where participants do not correctly identify the target they've been shown, the results of the Preference Test show no evidence that showing the target increases target liking.

Limitations

As with other subliminal research on the "indirect-without-direct-effect" pattern [41], we are limited by using self-reports from participants on visibility of stimuli to indicate whether stimuli were indeed visible. For text stimuli, we did not balance our words for frequency-of-occurrence in the English language, limit participants to native English speakers (75% of participants were native English speakers), or screen for dyslexia. These factors may have a confounding effect on subsequent liking judgements, although the stimuli sets were randomised to counter this.

FUTURE WORK

Some participants commented on strategies they had developed to address the discrimination task, indicating that alternate approaches to masks and stimuli may produce different results. In line with our results from the Visibility Task showing that participants were more likely to be able to distinguish photos than polygons, some participants reported using different hairstyles of the photo faces to distinguish them. An alternative approach would be to crop the images to include facial features only and/or to use a composite backward mask (e.g. as in [51]).

This study was restricted to SME effects, i.e. the attempt to increase liking simply through repetition. A repeat study exploring the use of affective stimuli, particularly of emotional facial expressions stimuli, might yield different results. We also restricted this study to experiment smartphones with known timings in semi-controlled conditions; it would be instructive to repeat the study in-the-wild to gauge the impact of in-use devices on the results.

OVERALL DISCUSSION

We have investigated the feasibility of applying subliminal techniques to smartphone interventions outside controlled lab environments. Our pilot Study 1 was fairly broad: a week-long study in-the-wild into the effect of a repeated text prime on an indirect measure of goal activation. The pilot employed priming of the goal active to try to increase goal accessibility, and two mechanisms to try to increase goal liking and therefore accessibility: the SME effect (repeatedly exposing participants to the active goal prime) in line with Monahan et al. [61]; and SAC via the pairing of a smiley with the active goal prime, in line with Murphy & Zajonc [64]. We found no evidence of any impact of the intervention on implicit goal concept activation or on explicit goal commitment measures. Evidence for an increase in goal commitment as a main effect of session *regardless* of intervention implies the possibility that any low-cognitive-impact reminder shown at unlock time might increase explicit goal commitment.

We ran two follow-up studies: a technical feasibility study (Study 2) and a semi-controlled study of the immediate impact of a variety of primes shown at known frame rates (Study 3). Study 2 showed that it is technically possible to show stimuli at the durations similar to those in experiments that have found evidence of subliminal effects, i.e. ~17ms [28,46,81]. Study 3 used our experiment phones to run a study investigating the SME effect with a sandwich-mask technique with mask duration of ~51ms and stimulus duration of ~17ms on a variety of stimuli. This study showed that masking can partially prevent stimuli from entering conscious perception, in line with Greenwald et al. [42], but we found no evidence of a stable liking effect of stimuli in situations where subliminal priming may have occurred (i.e. where people could not correctly identify the prime). Our findings contrast with Djiksterhuis [28], but support other HCI studies that could not identify a subliminal effect [68] [74].

The statistically significant negative impact of the 1xRepetition of text primes on the Preference Task indicates that the effects of subliminal priming are inconsistent across different prime types. This is consistent with Winkelstein et al's findings that "familiar" items may be more resistant to subliminal affective priming than unfamiliar ones [91].

Based on our results, we conclude that smartphones are currently not an appropriate platform for subliminal priming, whether to increase liking of stimuli or to increase behavioural goal activation. Indeed, we expect less stable results for both visibility and preference effects in in-the-wild situations. We would therefore advise against using subliminal priming on smartphones to support nonconscious behaviour change.

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