On the Design of *Subly*: Instilling Behavior Change During Web Surfing Through Subliminal Priming

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Abstract. With 50% of people spending over 6 h per day surfing the web, web browsers offer a promising platform for the delivery of behavior change interventions. One technique might be *subliminal priming* of behavioral concepts (e.g., walking). This paper presents *Subly*, an open-source plugin for Google's *Chrome* browser that primes behavioral concepts through slight emphasis on words and phrases as people browse the Internet. Such priming interventions might be employed across several domains, such as breaking sedentary activity, promoting safe use of the Internet among minors, promoting civil discourse and breaking undesirable online habits such excessive use of social media. We present two studies with *Subly*: one that identifies the threshold of subliminal perception and one that demonstrates the efficacy of *Subly* in a picture-selection task. We conclude with opportunities and ethical considerations arising from the future use of *Subly* to achieve behavior change.

Keywords: Persuasive technology · Behavior change · Subliminal · Nudging

1 Introduction

Interest in technologies for behavior change has been increasing. Consider, for instance, the case of physical activity trackers. With physical inactivity becoming the fourth leading cause of death worldwide [40], activity trackers are gaining momentum both in research and practice as they can offer many benefits, including increased awareness of one's behaviors, taking agency to manage one's health, and identifying opportunities for self-regulation in daily life [19].

Many behavior change technologies have been designed to support change through *reflection*. For example, the personal informatics [26] model describes a process of collecting, integrating, and reflecting on one's personal data to develop greater knowledge about one's behaviors and, in turn, act accordingly.

One limitation of this reflection-based approach is its reliance on user motivation to explore the data (or at least pay attention to it) and identify opportunities for action. This motivation is not always there, and self-regulation does not work for everyone. Researchers have raised concerns over the long-term adoption and effectiveness of

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activity trackers (e.g., [12, 14, 19, 23, 32]). One study found a third of owners of activity trackers discard the tracker within the first six months [23]. Another study of tracker adoption found 66% of participants used the tracker longer than two days, 38% longer than a week, and only 14% longer than two weeks [14].

In response, researchers have investigated strategies that require little cognitive effort to reflect on habits and encourage behaviors [15, 30]. Implicit suggestions and positive reinforcements, or *nudges*, offer opportunities for shaping judgments through unforced recommendations when decisions take place [24]. For instance, some approaches adjust default values (e.g., step goal) to lead people to meet a higher mark [13] or attempt to encourage certain choices by providing incentives (e.g., rewards or price discounts) when people adopt the intended conduct (e.g., smoking cessation [36] or healthy eating [29]). Another approach is creating friction at moments of decision-making; for example, when someone retrieves a car key from the *Keymoment* key holder, it drops a bike key, forcing the user to interact with it and nudging them towards sustainable modes of transit [22]. Many of these approaches, however, face a notable challenge: they still require conscious attention and ultimately reflection about possible actions during the decision making moment, entailing a risk of *reactance* [9].

In the light of these challenges, how can we design technologies that subtly and instinctively influence behavior without conscious guidance? In this paper, we explore *subliminal priming* as an approach to motivate change and propose *Subly*, an open-source plugin for Google's *Chrome* browser that primes behavioral concepts (e.g., to walk) through slight emphasis on words as people surf through the Internet. Leveraging Kostakos's [21] argument for three types of contributions in HCI – *data*, *tools* and *theory* – this papers contributes an open-source research tool that allows third-party researchers to design and validate their own subliminal behavior change interventions (see Fig. 1). We present two studies that examined the threshold of subliminal perception and demonstrate *Subly's* effectiveness in a picture-selection task. We conclude with ethical considerations arising from the future use of *Subly* and present a possible scenario as an opportunity for *Subly* to encourage behavior change.

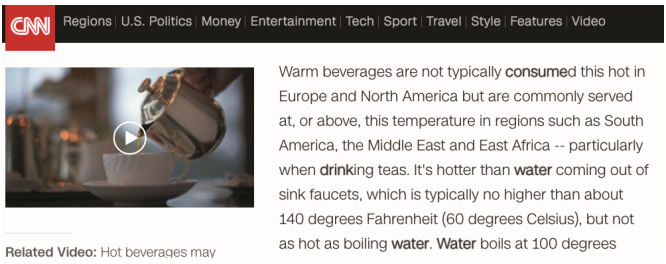

Fig. 1. *Subly* is an open-source plugin for *Chrome* browser that enables priming of behavioral concepts through slight changes in the opacity of certain words. In this example, we primed the words drink, water and consume.

2 The Dual Process Theory and the Decision-Making Process

According to Dual Process Theory [18, 33], decision-making happens through two cooperative systems: the automatic and the reflective. The *automatic* system is the principal mode of thinking. Behavioral decisions are made unconsciously and intuitively through associative inferences (i.e., prior experience), hence faster and with less effort. In contrast, the *reflective* is a knowledge-based process. Decisions are made through a conscious, rational process, and therefore, more effortful and slower.

While the two systems cooperate, one tends to dominate [18]. As we have a predisposition to reduce effort and make decisions instinctively, the *reflective system* only comes into action in situations that the *automatic* system cannot handle, overriding unconscious judgments [18]. Thus, most of our daily actions are controlled by the automatic mind, and technologies that take advantage of this can have significant impact on human behavior. Consider, for instance, the popular road sign stripes that are strategically positioned closer and closer together as the road approaches a sharp curve, making drivers believe they are speeding [34]. Such a simple but powerful intervention, tapping on the automatic mind, can decrease car accidents by 36%. Similarly, careful manipulation of plate size and color can result in a 10-15% decrease in calorie intake during meals [1].

While the dominance of the automatic mind in daily behavioral decisions seems evident, current persuasive technologies focus on the reflective mind. Mercer et al. [28] found self-monitoring to be the most commonly adopted strategy in commercial activity trackers. Also, West et al. [39] found knowledge provision and increasing awareness of one's behaviors to be the main strategies adopted by health (40% of 3336 apps). Adams et al. [1] reviewed 176 research prototypes and found only 11(6%) appealed to the automatic mind. In the remainder of the section, we delve into priming, as one way to influence the automatic mind and guide conducts.

2.1 Influencing Behavior Through Priming

Vast literature suggests that designers can leverage the automatic mind by transmitting information in a way that is not accessible to individual awareness (see [8] for a review). The exposure to a stimulus below the threshold of conscious perception is called *subliminal priming* and can be achieved either *visually* (e.g., brief duration, subtle changes in color) or *audibly* (e.g., back masking) [8]. This strategy relies on the idea that, while not affecting individual reasoning, a subliminal stimulus is still processed by the unconscious mind and may trigger action through inferences. For instance, priming the word "water" may trigger the respective mental representation and instigate drinking behavior [7].

2.1.1 Behavior Change

Research has repeatedly highlighted the effectiveness of subliminal priming in influencing people's attitudes and behaviors. For instance, Dijksterhuis [8] found that priming stimuli related with relaxation (e.g., rest and relax) lowered participant heart

rates and blood pressures, affecting their cardiovascular activity. Priming "old age" was found to make people walk slower down a corridor [3]. Légal et al. [24] found that priming the word 'trust' before reading a persuasive message about tap water consumption led to a more favorable evaluation and increased individuals' behavioral intentions in accordance with the message, possibly through the non-conscious activation of the goal "to trust." Priming the logos of certain brands was linked to heightened intention to select a drink from that brand [20]. More interesting, Veltkamp et al. [35] showed that priming certain behavioral concepts (e.g., drinking water) can be successful even in the absence of need deprivation (e.g., thirst).

2.1.2 Intelligent Tutoring Systems

To escape from purely cognitive approaches of teaching that often lead to disengagement [27], subliminal cues have been employed to accelerate the learning process. Chalfoun and Frasson [5], for instance, demonstrated the impact that subliminal priming has on challenging tasks. They asked participants to construct a magic square in an on-screen 2D puzzle that required applying three successive tricks to be solved. By flashing the tricks needed to infer the solution, they reduced mistakes and moves by 44% compared to the control condition. Beyond supporting task execution, subliminal stimuli were found to generate positive emotions such as increased enjoyment of the activity and increased levels of motivation. Jraidi et al. [17] found that the subliminal priming of words that had the capacity to increase individuals' self-efficacy and self-esteem (e.g., 'smart') had a positive impact on their problem-solving abilities and led to positive emotional reactions and higher scores in the quiz.

2.1.3 Task Support

The complexity of digital tasks, combined with people's lack of motivation to engage with task-support applications, has encouraged researchers to study subliminal cueing as a means of assisting novice users during interactions with computing. Wallace et al. [37], for instance, explored how subliminal cues may be used to support the use of a text-editor by novices, through displaying use instructions. They found users seek help less frequently when they displayed required task-information visibly but not too briefly for participants to notice.

2.1.4 Boosting Creative Processes and Generating Emotional Experiences

Positive priming has further been found to increase individual performance in creative tasks, such as brainstorming and creative writing. Lewis et al. [25] explored the impact of positive, negative, and neutral images, presented subliminally during a creative writing task, on people's affective state and writing performance. Positive affect images (e.g., a laughing baby) positively influenced the quality of people's ideas. Through a different path, Dijksterhuis et al. [8] presented pairs of positive and self-related words subliminally and found they increased individual perceptions of self-esteem. Fitzsimons et al. [11] and Wang et al. [38] studied how subliminal priming may affect individuals' creativity during brainstorming, and found that visually priming the logo of well-known

creative brands (e.g., Apple) made participants feel and reason more creatively and boosted the diversity of ideas during the brainstorming task.

3 Study 1: Threshold of Subliminal Perception

In our research, we sought to examine and develop the capability to prime certain messages by manipulating the opacity of certain words in text people are already reading. Our first study aimed to determine the threshold of subliminal perception. In other words, how much can we vary the opacity of primed cues so that the reader does still not perceive the difference?

We recruited a total of 25 participants (mean age = 25, 17 male). All were native English speakers, the language we used for the study. None of the participants had any known form of visual impairment. Participants were brought into a control room without prior awareness of the purpose of the study. They were seated about 70 cm from the screen, a *Retina LED IPS 13.3"* display at resolution *1440* × *900* px.

Following a procedure similar to that of Pfleging et al. [31], we presented two words at the screen (font-style Times New Roman, 16 px). Both words were presented at full opacity. For one of the words, we started decreasing the opacity at a rate of 1% every 0.5 s. Participants were asked to look at the screen and to press the space bar once they noticed a change. This was performed five times. We repeated the same procedure in four conditions to understand how the threshold of subliminal perception would vary based on the *type of vision* (*foveal*, if participants would gaze at the word, or *peripheral*, if participants would gaze at a distance) and the color of the word presented in *webpages* (*black*, for standard text, versus *blue*, for hyperlinks). To simulate the foveal and peripheral conditions, we varied the distance between the two words. In the foveal condition, both words were placed next to each other. In the peripheral condition, words were placed at a distance and participants were asked to gaze at one of the words (the one with constant opacity). Each participant went through all four conditions, in random order, thus performing a total of twenty trials.

3.1 Findings

The visibility thresholds were set based on the value of the opacity at the time the participants pressed the space bar key. We then computed an overall opacity value for each font color, black and blue, taking into account both the foveal and the peripheral vision condition, using the following formula:

$$\alpha_d = \alpha_{\text{foveal}} + \frac{d}{d_{\max}} * (\alpha_{\text{peripheral}} - \alpha_{\text{foveal}})$$

where α_f and α_p are the opacity values for the foveal and the peripheral vision conditions respectively, d is the distance between the two words being displayed (which reflects

the distance between the word whose opacity was changing and participants' gaze position, as participants were asked to gaze at the non-changing word), and $d_{\max}$ denotes the fixed value of the screen diagonal (=1510).

Across all conditions, we obtained a 3% higher value in the opacity threshold for text displayed in black ($\alpha_d = 0.76$) than for text displayed in blue ($\alpha_d = 0.73$). This difference between blue and black text was not statistically significant.

4 Study 2: Efficacy of Subliminal Cueing

In this study, we wanted to examine the efficacy of subliminal priming while reading text online. The task consisted of reading a short sentence, which referred to at least three concepts (e.g., "A *bird*, a *cat* and a *bear* were standing on a tree"). After reading the sentence, participants would be asked to quickly select one of three images, each reflecting one of the concepts presented in the sentence. We wanted to see whether priming one concept would make individuals more likely to select the relevant image.

4.1 Method

4.1.1 Developing the Material

We first crafted sentence-image pairs so that all three concepts were equally represented. To do so, we selected a total of twenty-seven short sentences from literature, which embraced at least three different ideas, where each idea was easily reflected in one image (e.g. a bear). Out of the twenty-seven sentences, we wanted to select the nine that had the most equal representation of the three concepts and posed the least challenges to participants during reading. We invited a total of 95 participants (mean age = 40, 43 male, 52 female, all native English speakers) through Mechanical Turk, and compensated them $0.30 for their participation. To avoid participant fatigue, we presented a random set of 14 out of the 27 sentences to each participant. During the task, participants were asked to read each sentence, and without re-thinking, to select one of the three pictures presented, horizontally aligned in random order. After completing each selection task, they were asked to rate how difficult it was to make the selection, on a 5-point scale. We also logged the time spent in each task, both for the sentence reading and the image selection. We removed from our sample sentences that participants reported as confusing or difficult (e.g., uncommon or ambiguous), or ones in which participants spent substantially more time in reading them, given their text length (we measured the median time spent and removed the phrases where the values were sorely larger). From the remaining pool, we selected the nine sentences that displayed the most balanced selection distribution, so that all three concepts were equally represented in the text.

4.1.2 Study Procedure

We recruited a total of 30 participants on campus (mean age = 29, 13 male, 17 female, all English native speakers). We used the properties of subliminal priming suggested by the first study (0.76% opacity, font color black). Participants were presented with the nine sentences in random order and were asked to select one of the three pictures

counterbalanced presented. The prime of each sentence was randomized. We asked participants to read out loud, so that we better understood their comprehension of the text and any impact the priming had on their reading. We video-recorded users' tasks.

We used a *Tobii Pro TX300* eye tracker to monitor participants' eye gaze while reading the text and logged the time spent in each task, both for the sentence reading and the image selection. At the end of each sentence and image selection task, participants were asked to rate how difficult it was to make the selection, on a 5-point scale, and elaborate verbally on the reasons for any challenge experienced. At the end of the study, we asked participants if they noticed something unusual and if there was anything that disrupted their reading and how.

4.1.3 Conditions

All participants experienced three conditions: *subliminal*, *supraliminal* (referring to a stimulus that can be consciously perceived if attention is directed to it), and *no-cue* (control condition), the order was block randomized. The nine sentences were randomly distributed across the three conditions (three sentences per condition), and the order of the nine sentences was randomized. In the subliminal condition, the primed words were presented at opacity level of 0.76, while the remaining text was presented at 100%. In the supraliminal condition, the text value was further decreased to 0.66 (see Fig. 2) and the primes were presented with full opacity. In the control condition, all words were presented in full opacity.

"Their blades crashed together twice, then slipped past
each other only to be blocked by upraised shields, but
the bigger man gave ground at the impact."

Fig. 2. Subly priming the words "blocked" and "shields" supraliminally with opacity levels of 66% and 100% (primes).

4.2 Findings

4.2.1 Did Priming Disrupt the Reading Process?

To understand whether priming disrupted the reading process, we looked at two aspects: the total *reading time*, and the *number of pauses* people made while reading. An analysis of variance revealed no significant effect of condition on reading time, $F(2) = 0.04$, $p = 0.96$, and no significant interaction between condition and the sentence, $F(16) = 1.43$, $p = 0.13$. As expected, a significant effect of the sentence on reading time was found ($F(8) = 9.14$, $p < 0.001$).

We then looked for pauses in participant reading. A pause was inferred from a combination of participant gaze behavior and verbal protocol, being defined as *a pause in reading leading to silence, a hesitation, or a repetition in reading*. Two researchers independently reviewed all tasks by replaying the gaze and audio recordings, and were asked to note when a pause was identified in each of the tasks. Inter-rater agreement was strong (Cohen's Kappa = 0.85). Pauses in reading were exceptionally rare across conditions, possibly due to the short length of the sentences, with only two pauses identified

in the supraliminal condition, one in the subliminal and one in control. No significant differences existed across conditions (Fisher's exact test, $p = 0.99$).

4.2.2 Did Priming Affect Users' Image Selection?

A single image would have a probability of being selected 33% of the time, as there were three images presented for each selection task. However, this might vary with individuals or the selection task. Participants selected the primed concepts 28% of the time (25 out of 90) in the control condition, where no priming took place.

Subliminal primes were found to lead to a significantly higher chance of selecting the primed word (42%, 38 out of 90) compared to the control condition, χ^2 (1, $N = 180$) = 4.13, $p < 0.05$. In contrast, supraliminal priming did not have any impact on users' image selection, as compared to the control condition; the primed word was selected only 24% of the time (22 out 90), χ^2 (1, $N = 180$) = 0.26, $p = 0.61$.

One plausible explanation for the lack of effect in the supraliminal condition could be rooted in the *aversion effect*, which suggests negative responses to unfamiliar stimuli when presented supraliminally (consciously) [4]. All in all, these results are consistent with prior work that suggests mere exposure effects to be stronger when the stimulus is presented below the limits of perception [4].

5 Design Your Own Intervention with *Subly*

These results give reason to believe that subliminal priming during web surfing should be investigated as a possible vector for behavior change interventions in daily life. Building a tool that makes priming interventions available for use can help identify the right application domains for subliminal priming and validate its efficacy across a wider range of tasks and decision environments. *Subly* supports these goals. It consists of a plugin for Google's Chrome browser and an easy to use study setup panel that enables third-party researchers to design their own behavior change interventions and deploy them in the wild. The source code is available at https://github.com/SublyM-ITI/Subly and a detailed tutorial is available at http://subly.m-iti.org/.

Subly includes a *study setup panel* that enables researchers to define the properties of their study such as type of cueing (flashing message or emphasis using opacity), its properties (size, color or other style of the stimulus by inserting the envisioned CSS widespread style), length of exposure, exposure frequency, opacity threshold, and the list of words or phrases to be primed.

Subly distinguishes itself from existing tools that display subliminal messages (e.g., *Free Subliminal Text, SubliminalMessages* and *Subliminal Power*) in four primary ways. First, it embraces an *authentication* system that identifies each user and corresponding data and allows remote customization of cues, content, and properties for each user. Researchers may *define events* that trigger priming, either events in external applications (e.g., data from a personal device such as an activity tracker) or events in web browsing behavior (e.g., mouse overlaying a word of interest) (Fig. 3).

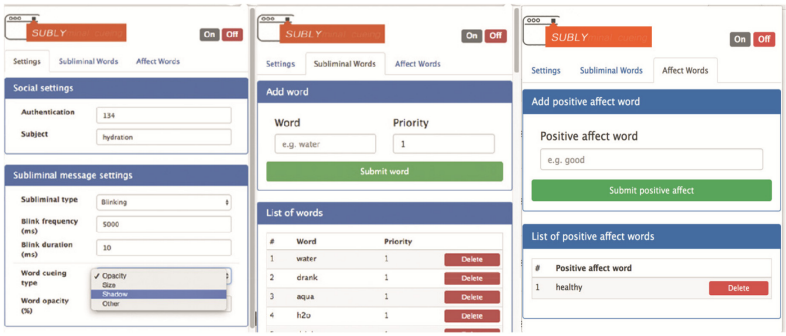

Fig. 3. The study setup panel enables researchers to define all aspects of the intervention as the cues and their subliminal properties (e.g. opacity of the cues).

Second, *Subly* connects to a database and further *logs user interactions with primes and webpages*. The tool records the webpages visited and users' active time on them (a researcher may opt to remove this for privacy reasons), the number and list of primed words and their frequency of occurrence on a web page, user interactions with primed words based on mouse activity (e.g., clicks, selections and *proximal attention* – the duration in milliseconds for which the mouse was in close vicinity to a primed word, assuming a strong relationship between mouse and gaze position [6]). Data can be used for analysis purposes, or in the creation or adjustments of event triggers for priming based on monitoring results.

Further, it allows a prioritization of stimuli (e.g., preferences for certain words or behaviors among others). For instance, in a situation were prolonged sedentary behavior is detected; the preference to prime a goal-related stimulus (e.g., *exercise*) can increase and be intensified to match the user's need.

There are still many opportunities and different techniques to be explored for integrating subliminal primes into web content. Multimedia content (e.g., images or audio) can be added to bias perception while using visual and auditory information to incite multiple senses [16, 25]. Simply manipulating text and images properties, as color, shape, size, texture or reversing the order of words might similarly go unnoticed.

Lastly, as open-source, *Subly* is readily expandable. It can be adapted for other purposes or research questions. For instance, it might be possible adapt it to predict readiness for change based on the content visited (e.g., users might search for opportunities to increase physical activity), to predict user emotional states based on content of pages visited, or to infer when individuals most need or would be receptive to the subliminal incentive.

6 Discussion and Conclusion

With prior research suggesting that subliminal priming effects last from 2 min to more than 24 h [2], and by integrating with a pervasive activity such as browsing, *Subly* enables

prolonged exposure to primed behavioral concepts, creating an opportunity for continuous behavior change support and minimizing the risk of relapses [10].

This paper makes three contributions to the exploration of subliminal priming as a behavior change strategy. Our first study helped us identify the threshold of conscious perception; the second study demonstrated the efficacy of *Subly*, by influencing people's decisions in a picture selection task consistent with our priming intervention.

While these results are promising and consonant with prior evidence of subliminal stimuli, we highlight the need to study the efficacy of *Subly* in a wider variety of domains. Subliminal stimuli remain a controversial topic, receiving surprisingly little research attention. While presenting stimuli to subconsciously shape behavior certainly presents ethical challenges, so too do prevalent behavior change techniques. Regular cognitive appeals to change behavior can limit people's attention to other tasks while failing to take advantage of people's primary means for processing information – the automatic system. With this research, we seek to inspire new discussions about the role of subliminal stimuli. We also contribute with *Subly,* a tool that can be readily used and extended by researchers and others to replicate our studies and investigate new questions. Making the tool available for widespread use can help identify and evaluate new application domains for *Subly* and evaluate its efficacy across a wide variety of prosocial domains, such as decreasing sedentary activity, coping with stress at work, reminding patients to take their medications until the behavior becomes habitual, promoting safe use of the Internet among minors, improving search task performances, reducing online bullying, encouraging people to take breaks, or conveying information while performing a task (e.g. while writing an email, subliminal priming might be used to bring users' attention to missing fields or remind them about an attachment). Given that automated processes govern much of our behavior, we envision *Subly* helping change people's attitudes and behaviors, facilitating goal enactment and engaging them during behavior change.

Finally, *Subly* poses significant ethical challenges that need to be considered before and during its use. When priming behavior concepts that may influence wellbeing and health, researchers should adhere to principles like transparent disclosure and ensure that *Subly* supports users' goals and interests and that they are aware of how it functions. Thus, using *Subly* entails signing a *Statement of Use* in which researchers agree that potential risks are minimized and appropriate considering potential benefits stemming from the use of the tool.

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