Can we use masked priming in an online setting?

The effect of prime exposure duration in online masked priming lexical decision

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Abstract

Masked priming is one of the most important paradigms in the study of visual word recognition, but it is usually thought to require a laboratory setup with a known monitor and keyboard. To investigate if this technique can be used in an online setting, we conducted two online masked priming lexical decision task experiments using PsychoPy/PsychoJS (Peirce et al., 2019). In particular, we wanted to compare our online results to the data collected by Gomez, Perea, and Ratcliff (2013), who compared masked and unmasked priming. Furthermore, we also tested the role of prime exposure duration effectively in an online experiment (33 vs. 50 ms in Experiment 1 and 16 vs. 33 ms in Experiment 2). We found that our online data are indeed very similar to the masked priming data reported by Gomez, Perea, and Ratcliff (2013). Additionally, we found a clear effect of prime duration, with the priming effect (measured in terms of response time and accuracy) being stronger at 50 ms than 33 ms and no priming effect at 16 ms prime duration. From these results, we can conclude that modern online browser-based experimental psychophysics packages (e.g., Psychopy) can present stimuli and collect responses on standard consumer devices with enough precision. In sum, these findings provide us with confidence that masked priming can be used online, thus allowing us to reach populations that are hard to test in a laboratory.

Keywords: Masked priming, Lexical decision task, Online experiments, PsychoPy, Prime duration

Word count: XXX

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Masked priming (K. I. Forster & Davis, 1984) is one of the most important techniques to study the effects of orthography, phonology, morphology, and meaning in visual word recognition(see K. Forster, 1998; Grainger, 2008, for reviews). Priming refers to the influence of a prime stimulus (e.g., *nurse*, *horse*) on a subsequently presented stimulus that the participant has to respond (e.g., "is *DOCTOR* a word?"). It is measured as the difference in a dependent variable (e.g., response time [RT]) between two conditions (e.g., unrelated: *horse-DOCTOR*; related: *nurse-DOCTOR*). In masked priming, the prime stimulus is presented very briefly (for less than 60 ms) and is itself preceded by a mask (e.g., #####) for a much longer duration (typically 500 ms). The rationale of the procedure is to make participants unaware of the identity of the masked prime (K. Forster, 1998; K. I. Forster & Davis, 1984), thus minimizing the role of participants' strategies. Indeed, masked priming experiments do not show the strategical effects that occur with visible, unmasked primes (e.g., Grossi, 2006; Perea & Rosa, 2002).

The masked priming paradigm has been used in a large number of studies over the last decades. For instance, a search of the expression "masked priming" in Google Scholar in March 2021 produced nearly 10,000 hits. Virtually all masked priming experiments have been run in a laboratory setting, often using the DMDX software developed by K. Forster and Forster (2003)). The issue we examine in the present paper is whether masked priming experiments can safely be conducted in an online setting. Even before the current exceptional situation due to the COVID pandemic, in which many labs around the world have been closed (or with minimal activity) for many months, online data collection has shown its many advantages: 1) easy access to a much more diverse population than that accessible at the typical university research laboratory; 2) independence from laboratory space constraints, and, often, lower costs as participants only need to be compensated for their time on the experiment; 3) no time spent commuting, waiting for the experiment to start, etc. Indeed, researchers in decision making and economics have been using online paradigms for several decades now (e.g., Birnbaum & Birnbaum, 2000; Paolacci, Chandler, & Ipeirotis, 2010).

However, cognitive psychologists have been much slower in taking up online paradigms (Cai et al., 2017, for some exceptions; Eerland, Engelen, & Zwaan, 2013; Rodd et al., 2016; see Vandeberg, Eerland, & Zwaan, 2012), often due to concerns about the validity of the results. Such concerns are not limited to cognitive studies (see Aust, Diedenhofen, Ullrich, & Musch, 2013), but they are exacerbated by the reliance on precise presentation times in cognitive psychology. Indeed, in the masked priming technique, it is critical for the onset of the mask, the prime, and the target to occur at the nominal times. In particular, presenting the masked prime for longer than intended would counteract the effect of the mask, making the prime consciously visible to the participant and possibly altering the processes of interest.

There have been attempts to address these concerns. For example, a Web version of DMDX (webDMDX) was developed and showed promising results in a trial experiment (Witzel, Cornelius, Witzel, Forster, & Forster, 2013). However, webDMDX is a self-contained Windows executable file that participants have to download and run rather than a "true" online programming script that could be run inside of a browser. A downside of this format is that participants often are (and should be) understandably skeptical about downloading and running executable files from the Internet. Additionally, many participants may not have access to a Windows PC, or may be discouraged from participating by the extra work it takes to deploy the experiment on their computer. As a consequence, the use of webDMDX has been rather limited so far (CITE somebody who has employed it)

Fortunately, in recent years, there have been significant improvements in how content can be presented on the World Wide Web. Most notably, the HTML5 standard now makes it possible to use Javascript in order to draw stimuli interactively and monitor participant responses with remarkable flexibility inside the browser. Participants do not have to install any software, and the HTML5 standard is supported by a wide variety of devices, including mobile phones and tablets (Reimers & Stewart, 2015). There is now a variety of software packages taking advantage of the new capabilities to present experimental stimuli and collect data, both commercial, e.g., Gorilla (A. L. Anwyl-Irvine, Massonnié, Flitton, Kirkham, & Evershed, 2020) or Testable (Rezlescu, Danaila, Miron, & Amariei, 2020) and open-source, e.g., jsPsych (de Leeuw, 2015) or PsychoJS (the Javascript version of Psychopy 3, Peirce et al., 2019). In addition, online setups allow researchers to target any individual with an internet connection as a participant, from very different countries and backgrounds. Indeed, various on-line platforms (e.g., Prolific, Amazon Mechanical Turk) offer the possibility to recruit participants for on-line experiments based on various specific characteristics set up by the experimenter not necessarily in the country's lab (e.g., native French speakers, not older than 30 years old, not currently in college).

Of course, despite the technological advances, many cognitive psychologists still have concerns about timing and measurement precision. While Javascript-based experiments run on the participants' devices and thereby avoid any lag due to connection issues (e.g., to avoid delays, all stimuli are usually downloaded before the start of the experiment), experimenters have little control over which devices the experiment is run on beyond the option of explicitly preventing the experiment to run on specific device types such as mobile devices. Moreover, experimenters have no control at all over what other applications are running on the device, screen size and resolution, viewing distance, properties of the keyboard/touchscreen, etc., as all of these are determined by the device or the participants' preferences. As Reimers and Stewart (2015) point out, there are two ways of testing whether timing and response issues are problematic: (1) comparing a Web-based experiment directly with an established lab-based version by measuring presentation timings (using a photodiode) and response timings on various device configurations and (2) attempting to replicate existing lab-based findings using a Web-based paradigm. If the results of the Web-based study are comparable to previous lab-based results, this suggests that whatever the deviations in stimulus and response timing are, they are not severe enough to affect the overall findings in the paradigm in question.

The first approach has the advantage that differences in presentation timings can be objectively recorded and evaluated. A very thorough recent example of this approach is the "timing mega-study" by Bridges, Pitiot, MacAskill, and Peirce (2020), who compared the timing in experiments run in lab-based setups with the timing in online packages run in different browsers. The very similar study by A. Anwyl-Irvine, Dalmaijer, Hodges, and Evershed (2020) compares only online packages and browsers with regard to timing. Overall, Bridges, Pitiot, MacAskill, and Peirce (2020) found that online packages were capable of presenting visual stimuli with "reasonable" precision, although the lab-based packages were slightly better in this regard. This first approach is important in order to establish that a certain level of precision and accuracy can be achieved at all. If this is not possible, there is no point in moving forward to the second approach and replicating specific paradigms. However, it is of course impossible to test every possible device and configuration that participants might use. On the other hand, some of the differences in precision and accuracy between setups that can be observed using a photodiode may be too small to have an influence on actual participant performance.

Therefore, we consider replication of previous key lab-based effects a more important test of online paradigms than photodiode measurements. Based on the results by Bridges, Pitiot, MacAskill, and Peirce (2020) and A. Anwyl-Irvine, Dalmaijer, Hodges, and Evershed (2020), modern Javascript-based stimulus presentation systems are capable of sufficiently fast and precise stimulus presentation. To establish whether masked priming studies can be successfully run online, the next step is now to follow the second approach and implement the masked priming paradigm in one of the online experiment packages tested by Bridges, Pitiot, MacAskill, and Peirce (2020) and A. Anwyl-Irvine, Dalmaijer, Hodges, and Evershed (2020). After evaluating their results, we decided on Psychopy/PsychoJS (Peirce et al., 2019) as it combines relative ease of use with high precision and accuracy across the great majority of platforms. COMMENT: Was there something better (more precise)? It needs better rationale (we want to say it is the best). Possible reviewers' comments:

- Have you checked in different platforms?
- What does it mean "ease of use"?
- How precise is it?

In the present study, we were interested in whether we could replicate, and extend, a key phenomenon in laboratory masked priming lexical decision using an online setup: masked identity priming reflects a savings effect. As first suggested by K. Forster (1998), for a masked identity prime, "the lexical entry is already in the process of being opened, and hence the evaluation of this entry begins sooner," whereas for an unrelated prime, "the entry for the target word would be closed down (since it fails to match the prime), and no savings would occur" (p. 213). Thus, according to the savings account, a target word like *DOCTOR* would enjoy an encoding advantage when preceded by an identity prime such as *doctor* than when preceded by an unrelated prime such as *pencil* (i.e., a head-start). One implication of such benefit is that the RT distributions of the unrelated and identity pairs should reflect a shift rather than a change in shape. Furthermore, this shift should be approximately similar in magnitude to the prime-target stimulus-onset asynchrony. Empirical evidence supporting this view has been obtained in several papers not only with skilled adults but also with developing readers (Gomez & Perea, 2020; e.g., Gomez, Perea, & Ratcliff, 2013; Taikh & Lupker, 2020; Yang, Jared, Perea, & Lupker, 2021). Moreover, this pattern of results fits very well with the diffusion model (Ratcliff, Gomez, & McKoon, 2004). This model proposes that, when making a two-choice decision, the resultant RT can be explained as the sum of non-decision parameters, which are the encoding time and response execution (T_{er}) and decision parameters, which refer to the process of accumulation of information until a decision criteria is reached. Importantly, in the decision process, the information gathered from the stimulus can vary in noise, depending on its quality, which modifies the rate at which information is accumulated (i.e., the *drift rate*). With regards to RTs from masked priming tasks, Gomez, Perea, and Ratcliff (2013) found that the difference between identity and unrelated conditions could be accounted by a change in the T_{er} parameter, while there were no differences across conditions in the parameter that corresponds to the quality of evidence gathered (i.e., drift rate)–note that changes in drift rate would necessarily produce a skewer RT distribution in the slower, unrelated condition.

Critically, the above pattern is *specific* to masked priming. When primes are visible (i.e., unmasked priming), identity priming effects are stronger in the upper quantiles of the RT distribution than in the lower quantiles (i.e., a change in shape rather than a shift in RT distributions; see Gomez, Perea, & Ratcliff, 2013). Fits from the diffusion model show that this result corresponds to changes in both the T_{er} parameter and the drift rate (see Gomez, Perea, & Ratcliff, 2013). Hence, when the prime is visible, it does influence the quality of the information accumulated of the target word. Clearly, this dissociation between masked and unmasked priming reflects qualitative differences in the way primes affect the processing of the target: purely encoding in masked priming (with an expected effect close to the prime duration) vs. both encoding + information quality in unmasked priming.

In the present paper, we took advantage of the above marker to examine whether online masked priming studies follow the same pattern as in-lab masked priming studies. Specifically, we manipulated prime exposure duration in identity vs. unrelated primes: 33.3 vs. 50 ms in Experiment 1, and 16.6 vs. 33.3 ms in Experiment 2—note that targets were presented immediately after the primes (i.e., prime exposure duration was equal to the prime-target SOA). The rationale of Experiment 1 is that if the actual exposure duration of the primes is the nominal exposure duration, then we would expect the typical shift between the identity and unrelated response time distributions, which according to the savings hypothesis (K. Forster, 1998) would be greater for 50-ms than for 33.3-ms exposure duration (i.e., the head-start would be greater for 50-ms identity primes than for 33.3-ms identity primes). This outcome would indicate that the on-line masked priming studies reproduce a characteristic signature of laboratory masked priming studies. Alternatively, if the actual exposure duration is greater than the nominal one (e.g., approximately 20-ms longer on average) then, the 50 ms primes could be consciously perceived. If this were the case, the effect of the prime could affect not only the encoding but also core decision processes (i.e., drift rate parameter), which would be reflected as a stronger priming effect in the upper quantiles (i.e., the two RT distributions would have a different shape). In this scenario, one should be very cautious when running online masked priming experiments—at least with the settings currently available.

To further constraint the research questions, Experiment 2 was parallel to Experiment 1, except for the use of a very short prime exposure duration (i.e., 16.6ms). Similar prime exposure durations have shown rather weak masked priming lexical decision experiments in a laboratory setting: smaller than 5 ms for a prime durations of 14 ms (Ziegler, Ferrand, Jacobs, Rey, & Grainger, 2000) and smaller than 9 ms for a prime duration of 20 ms (Tzur & Frost, 2007)—in the Tzur and Frost (2007) experiment, this difference increased to 16 ms when using a very high level of contrast in the computer screen. Thus, if prime exposure durations in online masked priming correspond to the nominal ones, we would expect a sizeable priming effect at the 33.3 but only a residual priming effect at the 16.6 ms prime exposure duration. Alternatively, if we obtain a sizeable effect at the 16.6 ms prime exposure duration (e.g., above 20-25 ms), this would indicate, again, that we should be wary of using the masked priming technique in online experiments. Keep in mind that we are using a software that has good control over the exposure duration (CITE).

ADD at some point:

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- Even with no control over many context variables, we obtain the effects (peerj:Parker)
- Hypotheses in a figure (as in Gomez & Perea, 2020).
- In addition:
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We conducted a simulation study on the impact of suboptimal response time accuracy on statistical power when varying the number of participants, the number of items/condition, and the degree of inaccuracy of the response device.

Experiment 1

In the first experiment, we tested whether we could observe reliable effects of masked priming at prime durations of 33 ms and 50 ms (roughly corresponding to two and three frames at a refresh rate of 60 Hz).

We report here how we determined our sample size, all data exclusions (if any), all manipulations, and all measures in the study.

Method

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## Warning: package 'rworldmap' was built under R version 4.0.4
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Participants. We collected data from 77 participants aged from 18 to 71 (mean age: 31.14) recruited through Prolific (www.prolific.co, 2021). Of the participants, 41 identified as male and 36 identified as female. The experiment was only shown to participants who indicated that English was their first language in the Prolific screening questions. Based on their IP addresses, 47 participants were based in the UK, 23 were based in the US, three participants were based in Canada, and two participants were based in Ireland. Two participants could not be localized in this way. Participants who completed the experiment were paid £1.25 for their participation (corresponding to £5/hour). All participants were naïve to the purpose of the experiment.

Materials.

Procedure. Participants were able to sign up for the experiment on the Prolific website. On signing up, they were redirected to the participant agreement form on the Qualtrics online survey development environment (Qualtrics, 2020). After indicating their agreement to participate, participants were forwarded to Pavlovia (Pavlovia, 2020), where the actual PsychoJS experiment was hosted. After completing the experiment, participants were redirected to a debriefing form on Qualtrics and from there back to Prolific in order to receive their participation payment.

Data analysis. We used R [Version 4.0.3; R Core Team (2020)] and the R-packages *dplyr* [Version 1.0.3; Wickham, François, Henry, and Müller (2021)], *forcats* [Version 0.5.1; Wickham (2021a)], *ggplot2* [Version 3.3.3; Wickham (2016)], *papaja* [Version 0.1.0.9997; Aust and Barth (2020)], *purrr* [Version 0.3.4; Henry and Wickham (2020)], *readr* [Version 1.4.0; Wickham and Hester (2020)], *rworldmap* [Version 1.3.6; South (2011)], *sp* [Version 1.4.5; Pebesma and Bivand (2005)], *stringr* [Version 1.4.0; Wickham (2019)], *tibble* [Version 3.0.5; Müller and Wickham (2021)], *tidyr* [Version 1.1.2; Wickham (2021b)], and *tidyverse* [Version 1.3.0; Wickham et al. (2019)] for all our analyses.

Results

Discussion

General Discussion

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