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Perception of visually masked stimuli by individuals with aphasia: A methodological assessment and preliminary theoretical implications

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Abstract

Background—Studies of the automatic processes supporting language processing and dysfunction in aphasia often rely on priming paradigms. The ability to confidently interpret these studies in terms of understanding the relative contributions of automatic vs. controlled processing, however, depends on the ability to isolate only automatic processes. One way this may be accomplished is through the use of visual masking. The effective use of visual masking, however, depends on verification that there was no task-relevant information consciously available from the prime item.

Aims—The study reported here was designed to assess the visibility of visually masked stimuli, for both typical adults and adults with aphasia.

Methods & Procedures—This experiment involved 31 typical adults and 21 individuals with aphasia. Visual masking sequences were presented on a computer screen, with 11 different interstimulus intervals assessed. Participants made lexical decisions on the masked stimuli. The two participant groups were compared in terms of their ability to distinguish the word/non-word status of masked stimuli at the various intervals.

Outcomes & Results—Participants with aphasia showed an overall poorer ability to discriminate between visually masked words and non-words than typical adults.

Conclusions—The visual masking sequence effectively interfered with task-relevant conscious perception of some masked stimuli for typical adults and all masked stimuli for participants with aphasia. This finding, combined with preliminary data collected on a similar task that involved a simple presence/absence judgment on masked items, suggests that there may be differences in the ability of individuals with aphasia to process rapidly presented masked stimuli, even when there is minimal linguistic processing required.

The underlying deficits of aphasia have often been studied with priming tasks, which measure the effect of a prime item on the accuracy or reaction time of a response to a target item. These studies have included, among other things, investigations of the time-course of spreading activation in aphasia (e.g., Prather, Zurif, Love, & Brownell, 1997), assessments of models of the intact and impaired lexical retrieval system (e.g., Martin, Fink, Laine, & Ayala, 2004), and the potential for treating aphasic language deficits through implicit, rather than explicit, language tasks (e.g., Avila, Lambon Ralph, Parcet, Geffner, & Gonzalez-Darder, 2001).

Because priming is thought to rely on the automatic spread of activation, rather than strategic processing, these studies have begun to explicate the underlying, implicit mechanisms of language processing, and their breakdown in aphasia.

There is, however, a problem with the interpretation of priming effects as reflective of implicit processing. Most of the priming studies of aphasia reported in the literature confound explicit and implicit language processing by using tasks that allow some level of explicit processing of the prime items. If explicit processing of primes is possible in a task, then it is difficult, if not impossible, to attribute priming effects exclusively to automatic, implicit processes (Forster, 1999). One method that has been established for isolating and studying implicit cognitive processes is *masked priming*, which uses very rapid presentation of prime items combined with a visual masking sequence before and/or after the prime items. This technique precludes (or, at the very least, minimizes) conscious awareness of the primes, thereby allowing investigation of automatic priming effects ostensibly without the influence of strategic, top-down processing (e.g., Forster, Mohan, & Hector, 2003).

A central issue in masked priming research has been that of how to determine that the masking sequence has effectively eliminated conscious processing of the prime. This is because any conclusions drawn about non-conscious processing of stimuli are only valid if it can be ascertained that the stimuli were *only* unconsciously processed (Erdelyi, 2004; Snodgrass & Shevlin, 2006); that is, that there was no conscious processing of the prime items. In a recent study using masked primes with both typical adults and individuals with aphasia (Silkes, 2009), we were faced with the challenge of addressing this issue in a paradigm that systematically assessed priming at 11 different intervals between primes and targets. This paper presents our approach to determining whether visually masked primes can effectively eliminate conscious processing of primes, both in typical adults and in individuals with aphasia, at these 11 different intervals, which essentially create 11 different masking conditions.

Methods

Participants

Control participants were 31 adults over the age of 21 who reported no history of neurological disorders, substance abuse, or significant psychiatric disorders. Inclusion criteria were a score of at least 20/36 on the Raven's Coloured Progressive Matrices (RCPM; Raven, 1976), which is sensitive to impairments typical of right hemisphere lesions, and at least 50/60 correct on the Boston Naming Test (BNT; Kaplan, Goodglass, & Weintraub, 2001), which is sensitive to impairments typical of left hemisphere lesions. Control participants scored no more than 4/5 on the Depression Intensity Scale Circles (DISC; Turner-Stokes, Kalmus, Hirani, & Clegg, 2005), to rule out severe depression. Vision for all participants was normal or corrected to normal, as per participant report and observed performance on screening tasks. One participant scored 49/60 on the BNT but was still included as a participant because it was determined, on further questioning, that a number of the test stimuli were simply not part of his experience or vocabulary, and he had no other evidence or history suggestive of left hemisphere lesion. Vision for all participants was normal or corrected to normal, as per participant report and observed performance on screening tasks. Control participants ranged in age from 21-84 ($M=57.1$, $SD=15.26$), with an average of 15.97 years of education (range=12-22, $SD=2.48$).

Participants with aphasia were 21 adults over the age of 21 with a diagnosis of aphasia and/or anomia following a unilateral neurological lesion (if there were multiple neurological events, lesions were restricted to the left hemisphere, as per neurology reports). All were at least 9 months post-onset, and native speakers of American English. Participants with aphasia ranged in age from 29-82 years old ($M=60.95$, $SD=13.28$; not significantly different from control participants, $p=.34$), with an average of 16.33 years of education (range=12-20, $SD=2.15$; not

significantly different from control participants, $p=.59$). Inclusion criteria for the RCPM and the DISC were the same as for control participants and, as with the control participants, individuals with aphasia had no prior history of neurological disorders, significant psychiatric history, or substance abuse, by participant or family report. Diagnosis of aphasia/anomia was made by an experienced, certified speech-language pathologist based on performance on the Western Aphasia Battery (WAB) and the BNT, and/or free conversation (in the case of some participants with mild anomia), in conjunction with otherwise intact cognitive skills, as shown on the RCPM. Aphasia severity ranged from mild to severe (Mean WAB Aphasia Quotient = 62.99/100, range = 7.4-98, SD=28.77; Mean BNT score = 32.95/60, range = 2-59, SD=17.5). The BNT could not be conducted with two participants due to severe apraxia of speech. None of the participants had a significant limb apraxia, as measured with the Apraxia Battery for Adults (Dabul, 2000). Participants with aphasia also completed the first four subtests of the Reading Comprehension Battery for Aphasia (LaPointe & Horner, 1979) for descriptive purposes only. This showed combined single word reading scores from the first four subtests ranging from 7-40 ($\bar{X}=34$, SD=8.16). Vision for all participants was normal or corrected to normal, by participant or family report, and no participants showed functional evidence of visual neglect on any of the consent or evaluation procedures.

All testing was done in a quiet room, with participants seated at a comfortable distance from a computer screen. Stimuli were presented visually on a 20" CRT computer screen with a 100 Hz refresh rate, connected to a personal desktop computer running Microsoft Windows 98, using E-Prime for stimulus delivery (E-Prime version 1.1.4.1, Psychology Software Tools, Pittsburgh, PA). Responses were made using one of two color-coded keys on a serial response box (Psychology Software Tools, Pittsburgh, PA) interfaced with E-Prime, which collected and recorded response time and accuracy data. Participants wore noise-cancelling headphones (Bose QuietComfort 2) to reduce distraction by ambient noise.

Stimuli

Masked stimuli for this task were either real words, pronounceable non-words, or strings of alternating x's and g's. All stimuli were 3-8 letters in length, presented in 30-point, lower case, black, Arial font, and were forward and backward masked by strings of twelve hash marks (48-point, black, Arial font). Pronounceable non-words were all phonotactically and orthographically legal in English, and were created by changing each real word used in the study by no more than two letters. Each participant saw only one item from each pair (i.e., either the real word or its derived non-word) over the course of the experiment. In addition, no masked item was presented more than once to a participant. The masking sequence was followed by an unrelated real word, presented in 48-point, upper case, black, Arial font.

Procedures

The visibility task involved participants making lexical decisions on the masked stimuli, with responses given by button press when the upper-case real word appeared at the end of the visual presentation sequence (described in detail below). For the participants with aphasia, verbal instructions were simplified and/or supplemented with writing, gesture, and demonstration as needed to maximize comprehension. Participants were given an opportunity to practice this task as many times as they needed to feel comfortable with it. In some cases for participants with aphasia, additional practice runs were specially created with reduced masking or longer stimulus exposure durations to assist them in learning the task. In these cases, once they had learned the task in these special circumstances, they then practiced in the standard practice condition (which used the same task parameters as the first run of the experiment, as described below) before beginning the experimental conditions.

Visibility was assessed in 11 interstimulus interval (ISI) conditions: 1500, 1000, 750, 500, 250, 200, 150, 100, 70, 50, and 30 msec between the offset of the masking sequence and the onset of the uppercase real word (unrelated to the masked item) signaling the response period. The unmasked real word at the end of the visual sequence had the potential to serve as an additional backward mask to the prime, but its effectiveness as a mask was likely to be reduced at longer ISIs, yielding the possibility that masked items in the longer ISI conditions would be more visible than those in shorter ISI conditions. Thus, assessment of this wide range of intervals (with fixed prime exposure and mask durations) was undertaken to determine whether masking effectiveness varied across the range of ISIs likely to be used in implicit priming paradigms with individuals with aphasia.

Each ISI condition was assessed in a separate run of 16 masked stimuli: eight real words, four XG strings, and four pronounceable non-words. Participants were not told about the two different non-word conditions. They were instructed to make a lexical decision on the masked stimulus in each trial, but not to respond until the unmasked word at the end of the sequence appeared. Responses to the visibility task were made by pressing color-coded buttons on the serial response box. The control participants were encouraged to respond within 650 msec from onset of the unmasked word, whereas the individuals with aphasia, who had greater difficulty with rapid response, were encouraged to respond within 1000 msec. Every participant began this experimental task with the 1500 msec ISI condition and continued with progressively shortening ISIs. This sequence of presentation, with the easiest-to-discern conditions presented first, was used to maximize the chances of participants being able to detect the masked stimuli so as not to underestimate their visibility.

All visual elements for the masked priming task were presented in the center of the computer screen, on a white background. The stimulus presentation sequence (see Figure 1) involved a forward mask (##### in 48-point, black, Arial font) for 500 msec, the masked stimulus (either a real word, a string of alternating x's and g's, or a pronounceable non-word, in 30-point, black, Arial font, all lower case letters) for 20 msec, a backward mask (##### in 48-point, black, Arial font) for 20 msec, a blank (white) screen for the duration of the interstimulus interval being assessed, an unmasked word (48-point, black, Arial font, all upper-case letters) for up to 650 msec for typical participants and 1000 msec for participants with aphasia, and (assuming a response was obtained by the end of this interval) a blank (white) screen (2000 msec for typical participants and 5000 msec for participants with aphasia) for an inter-trial interval. If a participant did not respond by the deadline (650 or 1000 msec), an additional screen appeared, containing the same unmasked word in red font. This was a signal to the participants that they had not responded quickly enough. The smaller font size for the masked item compared with all other stimuli in the sequence was used to assure that the masked stimuli were completely covered by the forward and backward masks. The entire protocol took most participants 30-45 minutes to complete.

Data collection and processing

Each participant completed 16 trials in each of the 11 ISI conditions, for a total of 176 possible responses per participant. Accuracy and reaction time data from the button-press responses in the visibility task were downloaded from E-Prime. All targets were analyzed for response accuracy. Responses that were made beyond the response deadline for either group were counted as incorrect, under the assumption that a significant delay was likely to be an indication of difficulty deciding which response to make, which would reflect poor conscious perception of the masked stimulus.

Results

All control participants successfully learned the experimental task, and completed the entire protocol. Of the participants with aphasia, three (participants 123, 138, and 170) were unable to learn the task adequately, even with extended training periods modified extensively to encourage comprehension and success. Therefore, results presented for participants with aphasia are based only on the 18 who successfully learned the task. The one exception to this is the analysis for the 30 msec ISI, in which only 17 participants with aphasia were included due to computer error with data collection for one participant. For ANOVA analysis, the missing data point for this participant was replaced by the group average for that ISI.

Visibility of the masked stimuli was assessed using the signal detection measure of d' (Green & Swets, 1966), based on the proportion of accurate responses and the proportion of false alarms. For each participant, two d' values were calculated at each ISI: one to quantify how well the participant discriminated between real words and XG strings, and one to quantify how well the participant discriminated between real words and pronounceable non-words. A d' value of zero indicates no discrimination between groups, whereas higher numbers indicate greater degrees of discrimination.

The effectiveness of this masking protocol at preventing conscious perception of the masked items was assessed by comparison of the range of d' values obtained at each ISI against an expected d' of zero, which would reflect no discrimination at all (see Figure 2). One-sample t -tests revealed significant differences from zero for the typical adults on Word/ Pronounceable Non-Word discrimination in the 30 ($t = -2.48, p = .019$) and 1500 ($t = 2.983, p = .006$) msec ISI conditions. For Word/XG discrimination, typical adults showed performance significantly different from zero, with positive t -values and all p values $< .001$, in all ISIs from 100 through 1500 msec. A significant difference was also seen in the 70 msec ISI condition ($t = 3.022, p = .005$). Participants with aphasia showed significant differences from zero on the Word/ Pronounceable Non-Word discrimination in the 50 ($t = -2.484, p = .024$), 200 ($t = -2.505, p = .023$), and 250 ($t = -3.002, p = .008$) msec conditions. For Word/XG discrimination, a significant difference from zero was seen only in the 50 msec ISI condition ($t = -2.183, p = .043$).

Analysis of individual performance of participants with aphasia was also conducted, to assess the potential impact on this task of single-word reading comprehension and overall aphasia severity. There was no significant relationship revealed with linear regression between overall aphasia severity (as measured by WAB AQ) and average d' value across all ISI conditions ($r^2 = .0004, p = .94$ for the Word/XG and $r^2 = .02, p = .57$ for the Word/Pronounceable Non-Word conditions), nor between single-word reading ability (as measured with the first four subtests of the RCBA) and average d' value across all ISI conditions ($r^2 = .02, p = .54$ for the Word/XG and $r^2 = .10, p = .20$ for the Word/Pronounceable Non-Word conditions). In addition, the average d' values obtained in both discrimination conditions by the participant with the both the lowest AQ (7.4) and the lowest score on the single-word reading subtests of the RCBA (7) were within 2 standard deviations of the mean for all participants with aphasia. Finally, when all regression analyses were repeated with the two lowest scoring participants' data removed as outliers, relationships continued to be non-significant.

Discussion

The experiment presented here serves to demonstrate two points. The first is methodological in nature, outlining a method that can be used with individuals with aphasia to assess the visibility of masked primes for the sake of verifying that they are not being consciously processed. This has practical application for future research using masked priming methods with this population. The second point demonstrated here has more theoretical than practical implications; namely, that there are significant differences between typical adults and

individuals with aphasia in their ability to perceive masked stimuli. Each of these ideas is discussed in turn below.

Methodological analysis

The primary objective in conducting this experiment was to ascertain that masked stimuli were not being processed at a level that would allow them to exert a conscious influence on lexical decision on a subsequent target. Previous research has suggested that ruling out conscious perception of all task-relevant information (if not of all information about the masked item) is adequate to assure that priming effects are not governed by conscious, controlled processing (Snodgrass & Shevrin, 2006). Although the task described here may not definitively rule out all information about masked items, we believe that it does serve to verify that no task-relevant information is being gleaned. Typical participants were largely successful at discriminating between XG strings and real words, but we suspect that their ability to do so may have been based on the conscious perception of single visual features of the XG strings, such as a diagonal line or an x and a g right next to each other. Indeed, after completing this experiment, many of the typical participants reported that they had just looked for single visual features, and used that information to make their decision – if these features were present, they called the masked item a non-word, but if they were not present they called it a word. This level of conscious processing allowed good success on this particular task, but the level of conscious awareness that it demonstrates is not likely to be enough to allow participants to consciously apply information gleaned from masked items to anticipate the lexical status of an upcoming unmasked target. The Word/Pronounceable Non-Word discrimination, however, required the processing of masked stimuli at a higher level, and the ability to do this reliably would indicate that the masking was inadequate to prevent conscious application of information from the primes to lexical decision on a subsequent unmasked stimulus. In this task, however, the ability to make judgments based on single visual features was removed. This resulted in much poorer performance, with the typical adults, as a group, showing unreliable discrimination in all but the longest (i.e., most visible) ISI condition. Participants with aphasia showed poor discrimination on both tasks (potential implications of which are discussed below), unrelated to aphasia severity. Based on these results, we conclude that the masking protocol described here was generally effective at eliminating task-relevant conscious processing of the masked primes. In addition, most of the participants with aphasia were able to learn and complete this task, with task success having no apparent relation to aphasia severity (WAB Aphasia Quotients of 34.45, 81, and 21.7 for the three participants who were unsuccessful).

These group data indicate the effectiveness of this protocol at identifying group patterns of visibility, but our hope was to be able to use it to determine visibility on a participant-by-participant basis. This goal arose from the recognition that there are individual differences in the ability to perceive masked primes (McCauley, Parmelee, Sperber, & Carr, 1980) and the desire to be confident that a given individual's priming results were not consciously mediated. We are encouraged that this protocol can be applied to determine visibility on an individual basis, though it was not perfect in its current implementation.

In particular, the task as reported here involved only 16 trials in each ISI condition, with eight being real words, four being pronounceable non-words, and four being XG strings. The decision to use so few trials was the result of an attempt to keep the task short, as it was being completed after a lengthy lexical decision task being used in the larger project with which this task was associated. The imbalance between the number of real words and the other two conditions was implemented because of an initial assumption that the most important analysis would be between real words and both non-word conditions combined, leading us to want an equivalent number of trials for that comparison. However, given that calculation of d' is dependent on the proportion of hits and false alarms in the lexical decision task, it became

evident that, with so few trials, small differences in response accuracy led to large differences in d' , such that random variability seemed to have undue influence on individual d' values. The results obtained on an individual basis, therefore, led to illogical patterns of performance (such as d' values reflecting high visibility at a short ISI when visibility was clearly poor at all longer ISIs) due to the large influence of random variability. In order to determine a given individual's likelihood of having consciously processed the masked items in a given ISI condition, therefore, a tripartite criterion of visibility was adopted. This criterion was based on the assumptions that the Word/XG discrimination task was easier than the Word/Pronounceable Non-Word discrimination task, and that masked items at longer ISIs are more visible than those at shorter ISIs. A given ISI condition was deemed likely to have yielded conscious perception of masked items if: 1) a d' of >1.5 was obtained for Word/Pronounceable Non-Word discrimination in that ISI condition; *and* 2) a d' value of >1.5 was also obtained for Word/XG discrimination in the same ISI condition; *and* 3) these criteria were met in all longer ISI conditions, as well. On the other hand, if large d' values were obtained without these other criteria met, it was assumed that they were erroneous.

Using this tripartite criterion allowed us to assess the visibility of the masked items in each ISI condition on an individual basis. When this criterion was applied, 6/31 control participants (19%) showed evidence of conscious perception in at least one ISI condition, but none of the participants with aphasia had discrimination performance reflecting conscious perception of the masked stimuli at any of the ISIs. We then used this information to trim data from the larger project dataset, removing data from conditions in which there was evidence for conscious processing of the masked primes. We are comfortable that this approach gave us a reasonable approximation of the visibility of the masked primes and, if anything, overestimated how visible the masked items had been during the initial task (when participants had not been told of their existence and were focused on the unmasked word at the end of the sequence). We would have preferred, however, to use the d' values by themselves, without additional interpretive criteria. In future studies using this approach, therefore, we would lengthen the task to include 8-10 trials in each of the three conditions. This increased number of trials would lessen the influence of individual responses, and would allow the d' values to be interpreted more confidently in their own right.

A further methodological limitation of the task as reported here lies in the wide variety of stimuli used. All masked stimuli in this task were controlled for number of letters (3-8), syllables (1-3), and morphemes (1-2), all pronounceable non-words were phonotactically and orthographically legal, and all real words had a word frequency of at least 100 words per million (Kucera & Francis, 1967). At the same time, however, there was no control for other lexical factors known to influence lexical decision, such as part of speech, phonological or orthographic neighborhood density or frequency, age of acquisition, or familiarity. These broad criteria for stimulus inclusion stemmed from the desire to not have any stimuli overlap with the approximately 900 stimuli involved in the larger project with which this experiment was associated, thereby significantly limiting the availability of potential stimuli. It was decided that, for this initial attempt, random assignment of the stimuli to ISI condition would serve to minimize the effects of particular lexical variables on the task outcomes. For future studies, however, it would be beneficial to more closely control the range of lexical variables that might influence performance. In addition, it would be of interest to evaluate the effect on performance of this task of systematically varying these factors.

Finally, further evaluation of this protocol would benefit from inclusion of more detailed analysis of participants' visual acuity and function. The participants here demonstrated adequate visual function for daily activities, with no functional evidence of neglect, and the task involved all stimuli presented in a single, central location. It is possible, however, that

subtle differences in visual attention, acuity, or discrimination may impact performance on this task.

Theoretical implications

The primary purpose of this study was methodological, to ascertain accurate interpretation of priming results in another task. The results obtained, however, were surprising, and hold some suggestions for future lines of investigation.

Typical adults showed a consistent ability to discriminate between real words and XG strings at most ISIs under these masking conditions, but a relatively poor ability to discriminate between real words and pronounceable non-words. As discussed earlier, we suspect, based on participant reports of their experience with the task, that this was due largely to their ability to key into small visual features of the masked items, rather than lexical-level information. Adding to this perspective is that gained from the participants with aphasia. When questioned after the experiment was completed, most of them reported that, once they had been told that there were items “hidden” in the visual sequence, they could sometimes identify that there was something there but could not tell anything about what it was. This observation was supported by their poor discrimination not only in the Word/Pronounceable Non-Word condition but on the Word/XG discrimination, as well. In addition, many of the participants with aphasia, including the three who were unable to complete the experiment, reported that they were unable perceive anything in the masked position. In all cases, participants demonstrated understanding of the task by successfully completing it when the masked stimuli were presented for longer periods of time.

In spite of our suspicions that differences between groups in this experiment were due to processing at the level of visual perception of basic features (or, perhaps, inter-related factors associated with attention), rather than lexical processing, the task used in this experiment was inherently linguistic, both due to the use of linguistic stimuli and that the participants were doing a linguistic task (lexical decision). It is impossible, based on these data alone, to determine if the differences noted between groups was due to the expected lexical processing differences of the two groups, or whether there may be a deficit that extends beyond linguistic processing evident in the data from participants with aphasia. If we believe that the typical adults in this study were relying on basic visual features, rather than linguistic processing, for their decisions on XG strings, then it is notable that the individuals with aphasia were unable to take advantage of this same cue.

If it could be shown that this pattern of group differences persisted in a non-linguistic task, it would support an interpretation of differences outside of the linguistic processing system, per se. In fact, preliminary data from a similar investigation support this idea. In an effort to determine the prime exposure durations at which individuals show conscious awareness of masked items, we had nine typical adults and eight individuals with aphasia make simple presence/absence judgments to masked stimuli. They were asked to attend to a visual masking sequence that contained a white square on a black background, and to determine whether there was a word present in the square or whether it was empty. This task significantly reduced the need for linguistic processing relative to that needed for the experiment described in this paper, as it asked only for a judgment on whether there was anything in the square or not, rather than making a decision on the content of the square. The protocol began with the masked items being exposed for 150 msec, which was clearly visible to all participants, with a gradual reduction until a participant reached a threshold at which s/he was unable to reliably distinguish the presence vs. absence of content in the square. In this preliminary protocol, typical adults all reached threshold at 10-20 msec exposure duration, whereas thresholds for participants with aphasia were significantly different, ranging from 10-90 msec. Given that this task required no linguistic processing to complete successfully, these results suggest that there may be non-

linguistic differences involved. This would be consistent with previous research that has demonstrated non-linguistic, and particularly attention-based, impairments in individuals with aphasia (see, for example, Murray, 1999, for a discussion of these issues). We suggest, therefore, that further investigation of this phenomenon with both linguistic and wholly non-linguistic stimuli is warranted.

Conclusion

The experiment presented here provides a method for assessing the visibility of masked items in individuals with aphasia. The ability to determine visibility is a precursor to confidently using masked priming protocols for the investigation of aphasic language abilities, which is one way to tap into the automatic, implicit mechanisms underlying language function to the exclusion of explicit, controlled processing. The data presented here also indicate that both researchers and clinicians should consider the time course of basic visual perception prior to determining the temporal parameters for stimulus presentation when working with individuals with aphasia. In addition to the methodological report, the visibility results revealed differences between typical adults and participants with aphasia in their ability to consciously perceive masked items. This difference may lie in linguistic processing differences, which would not be surprising, but it may also reveal differences in broader aspects of cognitive processing, warranting further investigation.

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Figure 1.
Schematic representation of the stimulus presentation sequence.

Figure 2. Average d' values for each participant group and discrimination condition across all interstimulus intervals. Asterisks indicate values significantly different from zero.