Who notices object repeats? Individual differences in inner experience influence repetition priming

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Abstract

Category labels such as 'dog' and 'green' appear to induce more categorical representations–highlighting category diagnostic features and helping to distinguish category members from non-members. Here we investigate whether covert language use has a similar effect by taking advantage of natural variation in people's reported use of inner speech. To measure categoricality, we use a repetition-priming task in which people make a semantic judgment of repeated images. We find a robust repetition effect of categories such that people are faster to respond to a cat if they have seen a previous image of a cat. These differences in inner speech are not associated with differences in repetition priming, but interacted in complex ways with differences in visual imagery and susceptibility to a verbal interference task.

Keywords: Language; Categories; Repetition Priming; Inner Speech; Visual Imagery

Introduction

Language facilitates category learning. Labels cue us to the existence of a category (Waxman & Markow, 1995) and prompt learners to more effectively attend to between and within category similarities (Sloutsky, 2010). In the universe where we only know one category, "dog," a new label, "cat," both indicates the existence of a new category "cat," and prompts us to investigate what makes a dog, a dog and not a cat.

One consistent finding is that the use of category labels induces more categorical mental representations (Lupyan & Thompson-Schill, 2012; Edmiston & Lupyan, 2015; Boutonnet & Lupyan, 2015). A more categorical representation of a dog is one that highlights category-diagnostic features of dogs; increasing contrast with non-dogs and simultaneously increasing similarity to other dogs (Boutonnet & Lupyan, 2015; Forder & Lupyan, 2019; Lupyan, 2012). For example, Forder and Lupyan (2019) found that hearing a color label (e.g., "green") helped people to discriminate between greens and non-greens in a way that was consistent with the label temporarily warping the ordinarily more continuous color space into a more categorical form. This is similar to the perceptual magnet effect found in speech perception (Feldman, Griffiths, & Morgan, 2009).

Here, we investigate whether endogenously produced language has similar effects by taking advantage of natural differences in people's propensity to use inner speech and visual imagery. Like many other individual differences in human cognition, people vary in the vividness of visual imagery they habitually experience (with the lower-end called 'aphantasia') (Cavedon-Taylor, 2022; Keogh & Pearson, 2018). People similarly vary in their experiences of inner speech (with the lower-end being recently termed 'anendophasia') (Nedergaard & Lupyan, 2024; Roebuck & Lupyan, 2020a, 2020b). Contrary to a common misconception that these two trade off (e.g., that there are 'visual' people and 'verbal' people) (Kraemer, Rosenberg, & Thompson-Schill, 2009; Amit, Hoeflin, Hamzah, & Fedorenko, 2017), researchers have measured these experiences on separate factors and found that this is not the case. In fact, the two measures have a moderate positive correlation such that people with more vivid (object) imagery tend to also experience more inner speech (Roebuck & Lupyan, 2020b).

Researchers have found preliminary evidence that these varying levels of inner speech and visual imagery may predict individual differences in category representation (Nedergaard & Lupyan, 2024; Roebuck & Lupyan, 2020a, 2020b). For example, visual imagery scores predicted interference effects of stimulus similarity in a picture-word matching task when a word was presented first and the participants had to select the matching image (Roebuck & Lupyan, 2020b). Participants with high levels of visual imagery were quicker to select the correct image (Roebuck & Lupyan, 2020b). Researchers also found that when asked to draw a superordinate category of, e.g., "reptiles," people with high levels of inner speech drew more typical exemplars compared to people with lower levels of inner speech (Roebuck & Lupyan, 2020a), consistent with the idea that inner speech evokes more categorical representations.

One way to measure what object representations encode is by measuring how much easier it becomes to process repeated objects. When presented with repeated stimuli, preserved activation of certain features allows us to process the stimulus more quickly over time (Druey, 2014). This decrease in response time across presentation times can act as a measure of representational similarity. This phenomenon is known as repetition priming. For example, to measure whether object representations are spatially invariant, one can compare repetition priming to the same object presented in the same location to the same object presented in different location. A reduction in repetition priming indicates a lack of true position invariance (Kravitz, Kriegeskorte, & Baker, 2010; Kravitz, Vinson, & Baker, 2008). Similarly, measuring the change in

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repetition priming from replacing one category exemplar with another (e.g., a German Shepard with a Rottweiler) allows us to see the extent to which the object representation is encoding category-level information (Druey, 2014).

So, to the extent that language elicits more categorical representations, do people who report experiencing more inner speech have object representations that are more categorical? We aim to evaluate the effect of internal experiences, such as inner speech and visual imagery, on various types of repetition priming. If overt language affects the categoricality of our representations due to labels acting as categorical "magnets" in a continuous space (Feldman et al., 2009; Forder & Lupyan, 2019), then we venture to explore whether this categoricality is also predicted by levels of inner (covert) speech and visual imagery.

In the following two experiments we investigate repetition priming in two conditions: 1) identity priming where the exact same object is repeated and 2) category priming where the same category of item is repeated with varying exemplars. If someone is activating a representation that is highly categorical in nature, the priming effect for category repetition should be stronger than for someone who has a less categorical representation. We hypothesize that to the extent that inner speech and visual imagery are associated with activating stronger categorical representations, people with higher levels of inner speech and higher levels of visual imagery will show a larger category repetition priming effect than people with lower levels of inner speech.

Experiment 1

Methods

Participants were asked if an object on the screen could easily fit in a microwave. This task was designed to require participants to access some semantic representation of the object without requiring the use of language. Any linguistic effect on categorical representation was left to individual internal tendencies of the participants.

This was a within-subjects design with three object conditions. The first was an identity repeat where participants saw repeats of the exact same object. The second condition was a category repeat where categories of objects repeated with varying exemplars. The rest of the trials were fillers where participants saw each object only once. These were included to evaluate baseline response times throughout the experiment. We were particularly interested in individual differences between these priming effects and whether those differences can be predicted by variations inner speech. The critical objects – either an identity or a category repeat – were interspersed with the filler objects to mitigate anticipation of repeated items. Following the repetition priming experiment, we evaluated participants propensities to experience inner speech and visual imagery by administering the Internal Representations Questionnaire (Roebuck & Lupyan, 2020b).

Participants We recruited 163 participants through the University of Wisconsin - Madison SONA pool of psychology students (74 women, 58 men, and 1 person who preferred not to report gender). The median age of participants was 19 (mean = 18.83, sd = 0.86) years old. We received ethical approval from the University of Wisconsin - Madison IRB. Thirty participants were excluded for missing attention checks.

Materials We adapted a preexisting image set from a previous study (Brady et al., 2008) as our stimuli. These images cover a wide variety of everyday objects and categories including both animate and inanimate objects. We supplemented this image set with a selection of free images from the Internet as needed to properly balance the images according to the task (ensuring an equal number of images that did and did not fit in a microwave). Researchers in the Lupyan lab provided responses to the task question for all stimuli. We only included stimuli with inter-rater agreement between five or more of the six researchers (i.e. at most one person disagreed). We excluded any poor-quality images and any objects that people would most likely not be familiar with in today's environment, for example, pixelated images of old scanners.

The final stimuli set consisted of 430 images. 30 images were selected for the practice phase that were deemed to be unambiguous in the answer to the task question. These images were fixed across participants and shown in a random order. The test phase contained 400 total items, 50 of which were critical stimuli. These critical objects were split into our two conditions: identity repeats (10 images total, each repeated 4 times) and category repeats (10 total categories with 4 exemplars per category, totaling 40 images). The remainder of the stimuli set were filler images, all belonging to unique categories. All subgroups of images were balanced based on whether they could or could not fit in a microwave.

We evaluated propensities for inner speech and visual imagery using the Internal Representations Questionnaire (Roebuck & Lupyan, 2020b). This questionnaire is comprised of 36 statements where participants rate their agreement on a 5-point Likert scale. These statements load onto four separate factors of internal experiences: visual, verbal, orthographic, and manipulation (the ability to mentally rotate objects). The main factors we are interested in are the verbal and visual factors as these represent people's experiences of inner speech and visual imagery. Crucially, this questionnaire focuses primarily on evaluating peoples' propensity to experience these types of inner representations, rather than describing details of the phenomenology.

Procedure Participants were seated in a booth in front of a monitor on which the stimuli were presented. Each participant saw a total of 30 practice trials plus 400 test trials broken into 4 blocks of 100 trials each. Participants saw 20 critical trials in each block (10 identity repeats and 10 category repeats). This ensured that each critical item was repeated once every block. Participants were not made aware of existence of the block structure; they simply saw a stream of trials.

Each trial began with the presentation of a fixation cross in the center of the screen for 500ms after which the stimulus was presented in the same spot. The participants were asked to press the 'z' or '/' key to indicate their answer to the task question ("Can this object easily fit into a microwave?"). The keys assigned to each answer were counterbalanced across participants. In the practice phase, once the participant pressed the key, the stimulus was immediately removed from the screen followed by 500ms of blank screen. In the test phase, regardless of when the participants pressed the key, the stimuli remained on the screen for the total allotted response time of 1500ms to ensure equal presentation time for every stimulus.

The order of the critical and filler objects was randomized across fixed trial slots in the first block. For example, trials 3 and 7 were always critical trials, but the order of objects was randomized across participants. Future critical trials were randomly jittered to be ±3 slots away from their original. For example, if participant 1 saw cat1 on trial 3 (in block 1), the next repeat of this item would be 100 ±3 trials in the future (in block 2). We introduced this jittering to discourage participants from anticipating repeats while maintaining a similar lag length between repeats.

After the test phase, we measures self-reported levels of inner speech by having participants respond to the Internal Representations Questionnaire (Roebuck & Lupyan, 2020b). We also included a short demographics survey that contained questions about gender, age, and native language. We chose to supply this questionnaire at the end of the task in order to avoid hinting to the participants that we were evaluating inner experiences such as visual imagery and inner speech. We did not wish to encourage participants to use inner speech or visual imagery if they were not normally prone to using it.

Results

All data and analyses for both experiments can be found here.

Participants reached close to ceiling accuracy throughout the experiment in all three conditions (baseline M = 0.95, identity M = 0.971, and category M = 0.973). Because of this near ceiling accuracy, we continue with response times as the primary dependent variable for our models.

What predicts response times? We fit a linear mixed-effects model including the interaction between block number and condition with random slopes by participant. We found a significant repetition priming effect (the interaction term between block number and condition) for each critical condition (see Figure 1). Participants showed greatest repetition priming for identity repeats compared to baseline ($b = -25.895$, $se = 2.58$, $t = -10.038$, $p < .001$) and also significant repetition priming for category repeats ($b = -10.485$, $se = 2.572$, $t = -4.077$, $p = .0038$). Identity repetition priming effects were significantly greater than category repetition priming ($b = 15.546$, $se = 3.107$, $t = 5.003$, $p < .001$).

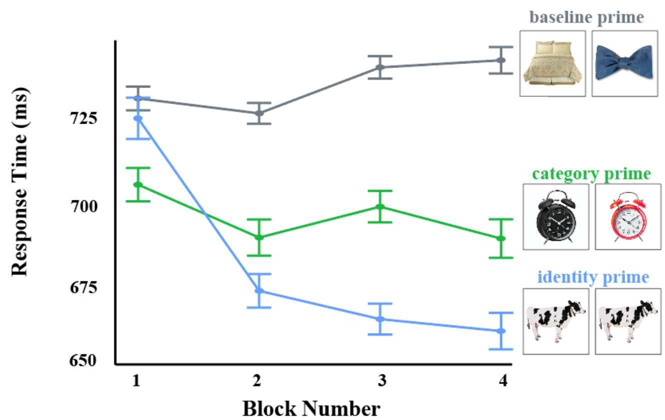

Figure 1: Experiment 1 repetition priming effect by condition. There is one repeat for each object (identity) or category of object (category) per block. Error bars show standard errors.

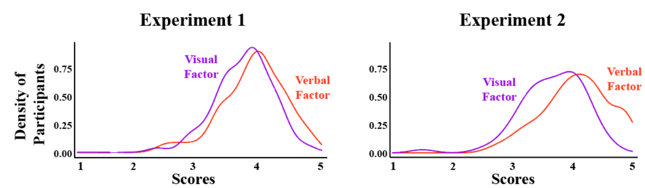

Figure 2: Distribution of Internal Representations Questionnaire Verbal Factor Scores (in orange) and Visual Factor Scores (in purple) for both Experiment 1 (n = 133) and Experiment 2 (n = 73). The y-axis shows density of participants.

Inner Speech and Visual Imagery We hypothesized that individual differences in category and identity repetition priming may be predicted by level of inner speech. We first analyzed the responses from the Internal Representations Questionnaire (Roebuck & Lupyan, 2020b). In a similar method to that completed by Roebuck and Lupyan in 2020, we averaged participant ratings for all statements per factor to calculate participants' individual visual, verbal, orthographic, and manipulations scores. All scores were appropriately corrected for reverse-coded items. The final scores on all factors were on a scale from 1 – 5, 1 indicating the lowest propensities and 5 indicating the highest propensities. As seen in the distribution of the scores in Figure 2, the experience of very low levels is much less common in this sample than higher levels of both inner speech and visual imagery ($M\_Verbal = 3.94$, $sd\_Verbal = 0.49$; $M\_Visual = 3.79$, $sd\_Visual = 0.44$). This is similar to the distributions found in previous work (Nedergaard & Lupyan, 2024; Roebuck & Lupyan, 2020b). These scores were used in a continuous form as a predictor in the following analyses.

To evaluate inner speech as a predictor of repetition priming effects, we ran a linear mixed-effects model with the three-way interaction between condition, block number, and

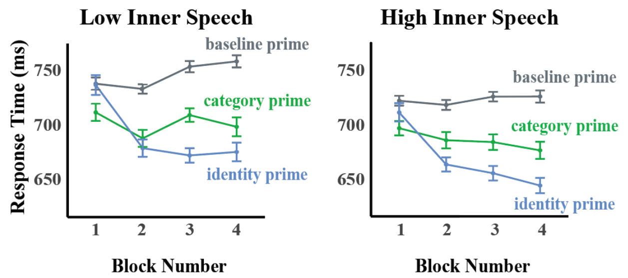

Figure 3: Median split of inner speech interacting with block number and prime condition. Note that the median split is for visualization purposes only. Model analyses were run with inner speech as a continuous variable. Error bars show standard errors.

inner speech predicting raw response times (see Figure 3). We saw no significant interaction between block number, category condition, and inner speech (b = 3.382, se = 5.236, t = 0.646, p = .518), nor between block number, identity condition, and inner speech (b = 2.510, se = 5.261, t = 0.477, p = .633). We also evaluated visual imagery in these models (rather than inner speech) and found no interaction with category repetition priming (b = -9.864, se = 5.875, t = -1.679, p = .093), nor with identity repetition priming (b = -3.225, se = 5.912, t = -0.545, p = .586). That is, neither inner speech nor visual imagery predicted variations in patterns of category or identity repetition priming.

Discussion

As we expect, participants begin with average response times that are relatively similar for all conditions. As the objects are repeated (either exactly or with varying category exemplars), we see that participants respond significantly quicker over time. We also see that people become quickest when the exact object is repeated (the identity condition) and participants still experience a significant repetition priming effect for category exemplars. This may be because instances of identity repeats are not changing, allowing us to represent objects similarly from one time to the next without needing to adjust for variation. Conversely and critically, category repetitions require some variation in representation as details of exemplars fluctuate. However, representing objects categorically allows us to quickly notice the aspects of the stimuli that are not changing. This in itself allows future quicker processing compared to evaluating unique new objects.

So why might this repetition priming effect not be explained by variations in inner speech or visual imagery? One possible explanation is that our sample distribution of scores for these factors did not capture much of the lower end of the spectrum (see Figure 2). Though this is consistent with the population levels researchers have found so far (Nedergaard & Lupyan, 2024), one possible way to more accurately evaluate the effect of inner speech is to attempt to block it. If, for example, repeating a phrase out loud interferes with inner speech, people with high levels of inner speech may experience a larger change in their repetition priming. We may be able to artificially engineer the case where our participants experience less inner speech by introducing verbal interference to the task. We would expect that to the extent that inner speech is blocked by verbal interference, people with high levels of inner speech may show a larger interference effect on their repetition priming. If these repetition priming effects are, in fact, being driven by high levels of inner speech, we would predict that the addition of verbal interference may selectively block them for people with high levels of inner speech.

Experiment 2

In this follow-up, our goal was to evaluate whether the category repetition priming effect would hold up to the addition of verbal interference. Prior work has found that the addition of verbal interference during visual tasks often increases response times (Pérez-Moreno, Conchillo, & Recarte, 2011). We wanted to evaluate whether different profiles of inner speech and visual imagery predict the intensity of an interference effect on this repetition priming. Our expectation was that the addition of verbal interference may inhibit the use of inner speech during this task, possibly lessening the category repetition priming effect.

Methods

The key difference between experiment 1 and experiment 2 is that we introduced verbal interference blocks. We used a within-subjects structure where each original block of trials from experiment 1, was further split into an interference sub-block and a no-interference sub-block. Participants saw the same stimuli under the same three conditions as in experiment 1 and were asked the same question about whether the object could fit in a microwave.

Participants The participants in this study were undergraduate students from the University of Wisconsin – Madison SONA pool. We recruited a total of 80 participants (50 women and 23 men) with a median age of 19 (m = 18.94, sd = 1.19). Seven participants were excluded because they did not pass attention checks during the primg study and/or during the questionnaire.

Materials The materials for this experiment were identical to those in experiment 1.

Procedure The procedure for this experiment was identical to experiment 1, except for two key adjustments. We introduced alternating sub-blocks of verbal interference and no verbal interference. We also adjusted the length of the response window. We decreased the response window from 1500ms to 1000ms, after very few participants responded slower than 1000ms in the first experiment, and those that did, failed attention checks.

Participants were shown four blocks of items (with one object repeat in each). In experiment 2, each block was broken into two sub-blocks. Participants started with either an interference sub-block or a no-interference sub-block (counterbalanced across participants) and continued to alternate through experiment, with two sub-blocks per repeat block. Participants saw 50 trials in each sub-block, with 10 critical items and 40 filler trials per sub-block. The 10 critical trials were balanced to have 5 category objects and 5 identity objects.

Before the no-interference sub-blocks, participants were shown a screen that prompted them to remain silent during the subsequent trials. Then they were presented with the same experiment structure as in experiment 1. This was intended to act as a control against the verbal interference condition. Any effect of language in this case would come from natural tendencies to use inner speech, as in the first experiment. Before each interference sub-block, participants were presented with a message asking them to begin repeating 'abcabcabc' out loud at a consistent pace. This is a relatively "light" form of verbal interference that makes minimal demands on memory and lexical retrieval that has nevertheless been previously found to affect object categorization (Lupyan, n.d.). At the beginning of the experiment, participants were given a demonstration of the expected repetition pace and volume – a typical speaking pace and volume. Voice recordings were obtained to ensure that participants followed the instructions. Finally, after the participants completed the experiment, they completed the Internal Representations Questionnaire (Roebuck & Lupyan, 2020b).

Results and Discussion

Our main question in this experiment was whether the addition of verbal interference selectively blocks category repetition priming for certain inner speech and visual imagery profiles. Based on previous findings that verbal interference can affect repetition priming, we evaluated how both inner speech and visual imagery predict the magnitude of these interference effects. As we come to find, the interaction between these types of habitual thinking is predictive of variations in verbal interference effects.

Interference Effects on Repetition Priming Firstly, we evaluated whether verbal interference affects repetition priming based on condition. We ran a linear mixed-effects model with a three-way interaction between condition, block, and interference with random intercepts for participants (see Figure 4). We did find a significant main effect of verbal interference (b = 14.207, se = 3.655, t = 3.887, $p < .001$), but we did not find any significant interaction between verbal interference and category repetition priming (b = -7.621, se = 4.510, t = -1.690, p = .100).

We then evaluated two other models including visual imagery and inner speech (individually) to evaluate whether either of these types of habitual thinking significantly interact with repetition priming based on condition. We did not see any interaction between verbal interference , category repetition priming, and either of these habitual thinking patterns. That is, contrary to what we hypothesized, when evaluating repetition priming by block, neither inner speech (b = 4.432, se = 8.248, t = 0.537, p = .592) nor visual imagery (b = -7.637, se = 8.477, t = -0.901, p = .368) significantly predicted the interference effect on category repetition priming versus baseline.

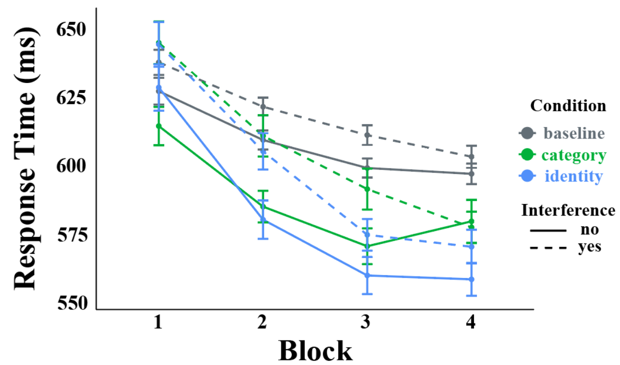

Figure 4: Verbal Interference effects by condition across block number. Error bars show standard errors.

Interaction Between Inner Speech and Visual Imagery The lack of interaction between inner speech and interference on category priming was contrary to what we predicted as we hypothesized that verbal interference might selectively block category priming. However, given the correlation found in previous work between high visual imagery and high inner speech (Roebuck & Lupyan, 2020b), we added the interaction between inner speech and visual imagery to our model. That is, rather than running independent models with each form of habitual thinking interacting with block and condition, we included both visual imagery and inner speech in the interaction. So, as a final adjustment to our model, we collapsed the category and identity conditions to evaluate interference effects on repeated stimuli in general and removed block from our model. Because we did not find a significant interaction between verbal interference with repetition priming by block, we excluded block number from this model. By removing block 1 responses, that is, removing the first instance of all objects, we can evaluate response times that would emerge as a result of repetition priming without including the by-block effect (see Figure 1). For this final model, we fit a linear-mixed effects model on the interaction between stimulus type (critical or baseline), visual imagery, inner speech, and interference. We included random intercepts by participant. In this case, we see a significant main effect of stimulus type (b = -11.14, se = .907, t = -12.278, $p < .001$) such that response times are quicker for critical (i.e., repeated) compared to filler (non-repeated) stimuli. We also see a significant main effect of verbal interference (b = 5.475, se = 1.574, t = 3.478, $p < .001$) such that interference increases response times.

Neither inner speech (b = 0.547, se = 0.896, t = 0.611, p = .541), nor visual imagery (b = 0.750, se = 0.895, t = 0.838, p = .402) interacted individually with verbal interference and

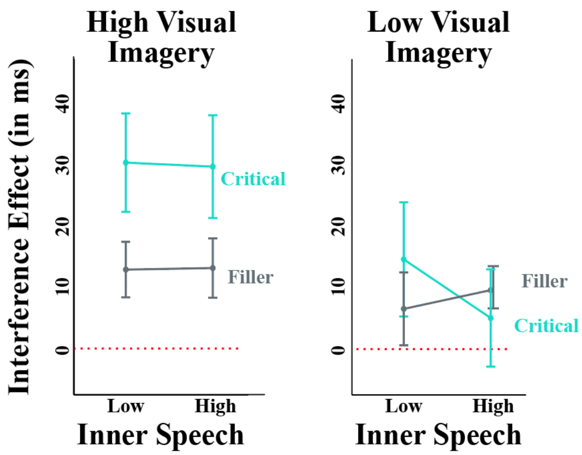

Figure 5: Average interference effects by habitual thinking scores (Inner Speech and Visual Imagery) for critical versus filler trials. The x-axis shows a median split for inner speech and for visual imagery scores. Error bars show standard errors.

stimulus type to predict RTs (when controlling for all other interactions and main effects in the model). However, there was a higher level interaction (at a significance criterion of 0.1) between inner speech, visual imagery, stimulus type, and verbal interference ($b = 1.893$, $se = .984$, $t = 1.925$, $p = .054$). A visual of this interaction is shown in Figure 5. As the right panel shows, the interaction between interference and stimulus type was different for people with less visual imagery but more inner speech (see Figure 5). We see here that low visual imagery and high inner speech may lessen the verbal interference effect for critical items.

Overall, contrary to our predictions, we did not find that verbal interference selectively reduced category repetition priming based on profiles of inner speech or visual imagery. We did, however, find an interaction between visual imagery, inner speech, and stimulus type that predicted variations in interference effects (Figure 5). In other words, though interference did not affect category repetition priming by block, we did find that certain profiles of inner speech and visual imagery do reduce the effect of verbal interference on critical trials after the first block. Given the small size of this high-order interaction we hesitate to over-interpret, but it does provide an initial hint that although significant repetition priming is shown by nearly all our subjects, self-reported differences in visual imagery and inner speech may predict differences in the dominant mechanism driving repetition priming. Further replication with a larger sample size is needed in order to explore details of the mechanisms at play and how they relate to variations in habitual thinking.

General Discussion

We find differences in repetition priming based on what features are repeated. People are most sensitive to identity repeats of objects, where objects repeat exactly, and more sensitive to repeated category exemplars than they are to unique objects. This category repetition priming effect provides further evidence that activation of category information is preserved across observations of stimuli. This category repetition priming effect is not, however, predicted by level of inner speech or visual imagery independently. This does not support our original hypothesis that people with high levels of inner speech may experience stronger category repetition priming.

Interestingly, we find that the processing of repeated stimuli is variably susceptible to verbal interference based on the interaction between inner speech and visual imagery. We find that these two factors interact such that people with lower visual imagery and high inner speech experience a sort of “protective” effect from verbal interference. The addition of verbal interference does not increase response times for repeated objects if people have low visual imagery and high inner speech as much as it does for other profiles of inner speech and visual imagery. This is contrary to our original hypothesis in experiment 2. We expected that verbal interference would block inner speech such that people with high inner speech would be more affected by verbal interference. That is, they would be unable to rely on their preferred habitual mode of thinking, making them slower to respond during interference trials. This result suggests a different story. It may, instead, be the case that high levels inner speech are not, or are minimally, susceptible to verbal interference. This may be representative of some people’s reported experiences of having an entire conversation with themselves in their head while they are conversing out loud with others (Nedergaard & Lupyan, 2024). If this is the case, verbal interference may not change anything about participants ability to use inner speech during this task. So we are left with the question: do we see no main predictive effect of inner speech on verbal interference effects for category repetition priming because inner speech is not associated with category repetition priming? Or is verbal interference simply not accomplishing the task of artificially creating lower levels of inner speech?

We plan to follow up this experiment with a replication study that includes other measures of inner speech and visual imagery. We also hope to directly recruit more participants who score lower on these factors in order to have better representation of the full span of predictive scores (as Roebuck and Lupyan did in their 2024 study).

Though inner speech does not directly affect category repetition priming as we originally suspected, the interaction between inner speech and visual imagery predicting interference effects does open doors for future research to evaluate how these repetition priming effects may be driven by mechanisms shaped partially by inner experiences. Overall, the relationship between visual imagery, inner speech, and repetition priming shows preliminary evidence that individual differences in habitual thinking affect object representation for repeated instances.

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