The influence of intrinsic reward on word learning in oral and written contexts

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Abstract

Previous studies show that word learning can be intrinsically rewarding, even the absence of external feedback or incentives. Intrinsic reward activates the brain's reward-memory circuit, leading to enhanced memory for words people enjoyed learning. However, existing studies have tested word learning through encountering written word forms (i.e., through reading). In this study, we investigate whether word learning triggers intrinsic reward across modalities, focusing on listening, reading, and listening and reading in combination. We find that when words are successfully learned, people report greater levels of enjoyment, regardless of modality. Across modalities, we also find that words with higher enjoyment ratings were remembered better than those with lower enjoyment. Our results demonstrate the relevance of the reward system for language learning, and suggest that the link between words and reward operates on higher-level word representations, rather than on modality-specific ones.

Keywords: vocabulary, reward, pleasure, long-term memory, word learning

The influence of intrinsic reward on word learning in oral and written contexts

As we encounter new texts and converse with people, we expand our vocabulary, continually extracting and refining our understanding of word meanings from the contexts in which we encounter new words (Nagy et al., 1985). But *why* do we engage in such learning? Recent empirical studies probing incidental word learning in written contexts –using behavioural, physiological, neuroimaging and pharmacological approaches– indicate that we find the process of extracting word meaning intrinsically rewarding (Ripollés et al., 2014, 2016, 2018). This fits with theoretical accounts postulating a link between the brain's reward and language systems, and may have been crucial for the evolution of human language (Syal & Finlay, 2011). Given that we learn new words from both oral and written contexts, one notable omission is that this relationship between reward and word learning has not been studied using auditory stimuli. Early language acquisition typically occurs through spoken language, and this would strengthen the argument for this link being important throughout language development, including in pre-literate stages. Additionally, finding a link between reward and word learning using auditory stimuli would indicate this link operates on higher-level, modality-independent representations of words. In this study, we address this question, and investigate whether the relationship between intrinsic reward and word learning is observed across both oral and written language modalities. We also assess whether the experience of intrinsic reward is associated with enhanced memory for words across modalities, building on existing findings demonstrating this link in written contexts (Ripollés et al., 2014, 2016, 2018).

To study the link between intrinsic reward and word learning, we use a contextual word learning paradigm (Mestres-Missé et al., 2007). In these paradigms, participants must decipher word meaning from the context that the words occur in. For instance, when encountering the novel pseudoword *jedin* in these sentences, "Every Sunday the grandmother visited the *jedin*" and "The man was buried in the *jedin*", readers infer that *jedin* probably refers to a graveyard or cemetery. An advantage of this paradigm is that this type of word learning is extremely naturalistic. The majority of words are learned incidentally in this manner, rather than through direct instruction, and without explicit feedback (Akhtar, 2004; Henderson et al., 2015). Some authors even suggest that each word's mental representation has its own contextual history, shaped by the person's language and reading experience with that word, and that contexts can be used to shape learning (Mak et al., 2021). Previous work using the contextual word learning paradigm has established that even in the absence of explicit feedback, learning of new word meanings is intrinsically rewarding (Angwin et al., 2019; Bains et al., 2020; Ripollés et al., 2014, 2016, 2018). Across this set of studies, subjective ratings of pleasure were higher when participants successfully extracted novel words, relative to when they were not able to extract meaning. Importantly, effects of effort and novelty were controlled for by contrasting pleasure for a set of sentences where participants encountered novel words but could not extract meaning, i.e., incongruent sentences. The aforementioned effects of increased pleasure did not hold for this set of control sentences. The pattern of effects observed for pleasure ratings was not observed in the case of other subjective ratings such as confidence and arousal. This indicates that behavioural ratings of pleasure can selectively index intrinsic reward. The same paradigm has also been used in an fMRI study, which offered a more naturalistic experience as participants did not have to actively rate pleasure. In that study, in line with the behavioural evidence, activity in reward-processing regions of the brain such as the ventral striatum was greater when words were correctly extracted (Ripollés et al., 2014). Providing further evidence for the involvement of the dopaminergic system in this form of learning, the administration of a dopaminergic precursor (levodopa) and a dopaminergic antagonist (risperidone), increased and decreased, respectively, both the learning rate and pleasure ratings experienced by the participants in this word learning paradigm (Ripollés et al., 2018).

Across multiple studies, the reward system has been linked to improvements in long-term memory (Adcock et al., 2006; Murayama & Kitagami, 2014). For instance, in a classic study, participants were much more likely to remember scenes presented after high-reward cues, relative to low reward cues. High-reward cues were also associated with activation in the ventral tegmental area, nucleus accumbens, and hippocampus (Adcock et al., 2006). Mechanistically, this is thought to be due to the role of dopamine in mediating long-term potentiation processes via a memory loop formed mainly by the hippocampus, the ventral striatum and the dopaminergic midbrain (i.e., the ventral tegmental area and the substantia nigra). Recent studies indicate that it is not only extrinsic reward, but also *intrinsic* reward that can facilitate the entrance of items into long-term memory. In the domain of language, using the contextual word learning paradigm, Ripollés and colleagues (2016) demonstrated that subjective ratings of pleasure were higher for words that were successfully remembered 24 hours after learning. A recent functional imaging study from this group also supports the idea for a link between reward and memory systems, demonstrating that brain activity and functional connectivity between the main regions forming the aforementioned memory loop (hippocampus, ventral striatum, and dopaminergic midbrain) were enhanced for words that were successfully remembered, relative to those that were not (Ripollés et al., 2016). Finally, a dopaminergic precursor (levodopa) and a dopaminergic antagonist (risperidone), increased and decreased, respectively, the number of words remembered (using the same contextual word learning paradigm) after a 24-hour consolidation period (Ripollés et al., 2018).

A relationship between intrinsic reward and memory is also consistent with a parallel literature on the roles of curiosity and satisfaction upon learning (Gruber et al., 2014; Kang et al., 2009; Marvin & Shohamy, 2016). In this research, states of intrinsic motivation, assessed using measurements of curiosity or satisfaction, are associated with better learning. Drawing on this research, we recently demonstrated that people were willing to wait to receive the meanings the words when they were curious, with curiosity predicting memory for words (Garvin & Krishnan, 2022). Taken together, these studies strongly indicate that people place intrinsic value on learning the meanings of words, and point to an enduring link between reward and memory.

All the aforementioned studies have probed the link between reward and learning of word meanings using written stimuli. However, we hypothesise that links between reward processing and semantics operate on higher-level language representations, and are independent of modality (oral/ written). We consequently postulate that a facilitatory link between reward and language learning should also be observed in the oral domain. Thus far, there is no empirical assessment of this link. Observing this relationship in the oral domain would open up new lines of investigation, allowing us to study the link between reward and language processing in younger children who do not read, adults who are illiterate, or individuals who struggle to read.

Here, we investigate the relationship between reward and word learning using the paradigm of contextual word learning in three modalities: reading, listening, or reading and listening. The last modality condition was included as word learning appears to be fostered when both reading and listening contexts are jointly provided (Valentini et al., 2018), akin to providing subtitles on videos. Our primary hypothesis was that we would observe higher enjoyment ratings when word meanings were successfully extracted in all three modalities: reading, listening, and reading and listening. We also hypothesised that across modalities enjoyment ratings would be higher for words that were successfully remembered 24 hours later.

Methods

Ethics

This study received approval from the Central Ethics Committee at Royal Holloway, University of London. All participants provided written informed consent.

Pre-registration

This study was not pre-registered on an open repository.

Participants

Our inclusion criteria were being a native English-speaking adult between the ages of 18-40 with normal or corrected-to-normal vision. Exclusionary criteria were the presence of a history of any known neurological disorder, developmental disorders, or speech, language, or hearing disorders. Participants who did not complete the experiment had their data removed and were replaced by other participants. Participants were assigned at random to one of the three modalities: reading, listening, or reading + listening.

Our power analysis was based on an ANOVA similar to previous studies (Ripollés et al., 2016, 2018), which suggested we needed a minimum of 30 participants in each modality to detect the key interaction of congruency (M+/M-, see detailed methods below) and accuracy (correct/ incorrect) on enjoyment ratings, taking into account an effect size of $\eta^2 = 0.06$ with 90% power. Previous studies using this paradigm have also used similar sample sizes. We therefore aimed to recruit 90 participants between the ages of 18-40. We stopped data collection when we achieved N=30+ in each group; because of random assignment to group our final sample size was 104 (Listening N = 36, Mean Age = 22.6 years (SD=4.3), 28 female, 1 undisclosed; Reading N = 42, Mean Age = 23.1 years (SD=5.4), 32 female; Listening and Reading N = 34, Mean Age = 21.9 years (SD=4.9), 31 female).

Stimuli

The stimuli comprised 40 pairs of sentences ending in a novel pseudoword. The pseudoword stood in for a noun. All pseudowords respected the phonotactic rules of English, were between 1-2 syllables, 5-7 letters in length, and were generated using Wuggy (Keuleers & Brysbaert, 2010). The sentences were developed for a previous study (Angwin et al., 2019), and slightly adapted for British speakers (for further details, see Bains et al., 2020). Auditory versions of these stimuli were recorded by a native southern British-English speaker using audacity and a Rode NT1A microphone with a Focusrite Scarlett 2i2 USB audio interface. Recordings were made at 44,100Hz with 32bit quantization in a quiet room using a Marantz Professional Tabletop Sound Shield.

During the experiment, in half of the sentence pairs, the meaning evoked by the pseudoword was congruent and, therefore, it was possible to extract the meaning of the new word (M+ condition; e.g., sentence 1: ‘‘Few countries are now ruled by a cyche’’; sentence 2: ‘‘In the palace lives the king and the cyche’’. Cyche means *queen* and was congruent with both the first and second sentence). For the other half of the sentence pairs, the second sentences were scrambled so that they no longer matched their original first sentences. In this case, the new-word could not be associated with a congruent meaning across the sentences (M- condition; e.g., sentence 1: ‘‘John needed a battery for his bemble.’’ - watch was one possible meaning of bemble. Sentence 2: ‘‘The teacher wrote the date on the bemble’’- Blackboard was now another possible meaning of bemble, but this was not congruent with the first sentence). These pairs constituted the M- condition in which meaning acquisition was not possible. The M- condition was used as a control for novelty, task structure, difficulty and cognitive effort (e.g., working memory constrains; see Mestres-Missé et al., 2007, 2014; Ripollés et al., 2014, 2016, 2017, 2018). Sentence assignment to M+ and M- was counterbalanced. In other words, the 20 pairs of sentences that served as M+ in one version of the experiment were part of the M- condition in the other version.

Design

After providing informed consent, participants were told that they would be exposed to new words that they were expected to learn. Specifically, before they started the learning phase, they were informed that they would be tested on their learning performance on the following day.

During the learning phase on Day 1, participants encountered 40 trials. Trials were presented in blocks of four sentence pairs (see Figure 1 for schematic). Each block comprised 2 pairs of M+ sentences and 2 pairs of M- sentences in a random order. First, participants were shown a screen with the first sentence from a sentence pair and were prompted to click the next button to continue (making the task self-paced). They then saw three more "first" sentences from three other sentence pairs. Once all first sentences were presented, participants were shown the second sentences in a random order. After encountering the second sentence of a pair, they were prompted to enter the meaning of the pseudoword or type the word "reject", which would indicate that they believed the two sentences did not have a congruent meaning. After they typed an answer, participants rated their enjoyment (and other behavioural responses) using 9-point visual scales. In this work, we focus only on enjoyment.

A recognition test followed a consolidation period of at least 24 hours. Regardless of the modality they had encountered, participants encountered the pseudowords from the previous day presented both aurally and visually (for both M+ and M- conditions). They were then provided with three options (two meanings and the option to reject; as in Ripollés et al., 2014, 2016, 2017, 2018). For the M+ condition, these included the real meaning of the word (correct), a meaning consistent with another pair of sentences presented during the experiment (incorrect), and an option to reject (i.e., to incorrectly identify the trial as a non-congruent M- trial in which meaning cannot be extracted). For the M- condition the options were the meaning evoked by the second sentence just presented before (incorrect), the meaning consistent with another pair of sentences presented during the experiment (incorrect), and an option to reject (i.e., to correctly identify the trial as a non-congruent, M- trial in which meaning cannot be extracted). After each response, participants rated their confidence using a 9-point visual scale.

Procedure

Participants completed the experiment online using the Gorilla platform www.gorilla.sc (Anwyl-Irvine et al., 2020). After giving informed consent and completing a short demographics questionnaire, all participants completed a quick sound check to ensure that they had functioning headphones or speakers (they were played a word and had to type it in). Participants had to pass this screen to continue. They were then automatically randomly assigned to a modality: reading, listening, or reading and listening. When participants started the word learning task, they were given six practice trials with feedback, following which they completed the task without any feedback. Finally, participants were asked to fill in the BIS/BAS scales, which assessed their sensitivity to reward (Vervoort et al., 2015).

At the end of the task, participants were prompted to enter their email addresses, to continue the second part of the experiment the next day. Twenty-four hours later, they were emailed a link to the second part of the experiment. If participants did not complete the entire experiment within 2.5 days, their data was automatically rejected by the Gorilla experimental platform. Most participants were recruited as part of an undergraduate project and offered the chance to win a £50 Amazon voucher. A subset of participants (N=45) who completed the task for course credit also completed a short reading fluency task on the second day.

Exclusion criteria

We planned to exclude participants if their learning performance was below 25% for words encountered on Day 1 for M+ trials (as in Ripollés et al., 2014,2016,2018). However, no participants were excluded on this basis. For the Day 2 memory test, correct answers that had a very low confidence rating (<1) were treated as a guess and were not included in the analysed trials.

Data, materials, and code

All data and code have been made publicly available at the OSF and can be accessed at https://osf.io/e57u3/

Analyses

All models were implemented in R (R Core Team, 2020) using the lme4 package (Bates et al., 2014). We established significance of factors using likelihood ratio tests, implemented using the mixed command of the afex package (Brown, 2020; Singmann et al., 2015). We mean centered continuous variables (e.g., enjoyment ratings) prior to model fitting.

Planned analyses.

Testing hypothesis 1: Successful extraction of word meanings will be predicted by enjoyment

To test hypothesis 1, we conducted a logistic mixed effects model with learning accuracy (correct/ incorrect) as the dependent variable. We included fixed effects of learning condition, i.e., congruency (M+/M-), modality (reading, listening, or reading and listening), and enjoyment ratings, as well as all interactions between these variables. We also included random intercepts for participant and item (accounting for random slopes of the counterbalanced list participants to which were assigned, i.e., list 1 or 2). The models took the form:

Correct ~ Congruency*Enjoyment*Modality + (1 | ID) + (1+List | Item)

We expected to observe a significant interaction effect of sentence congruency and enjoyment on accuracy, with enjoyment modulating accuracy positively, and more strongly in M+ relative to M- trials. We planned to the direction of these differences using the emtrends function from the emmeans package.

Testing hypothesis 2. Memory for word meanings will be predicted by enjoyment.

To test hypothesis 2, we conducted a logistic mixed effects model with memory (correct/ incorrect) as the dependent variable. We included fixed effects of sentence congruency (M+/M-), modality (reading, listening, or reading and listening), and enjoyment ratings, and all interactions between these fixed effects. We also accounted for random intercepts of participant and item, including random slopes of counterbalanced list. We only included trials where word meaning was successfully extracted on day 1, and those where confidence on day 2 exceeded 1. The models took the form:

Memory ~ Congruency*Enjoyment*Modality + (1 | ID) + (1+List | Item)

Again, we expected to observe either a significant main effect of enjoyment, or an interaction between sentence congruency and enjoyment on memory, with enjoyment modulating memory positively, and more strongly in M+ relative to M- trials. We planned to the direction of these differences using the emmeans or emtrends function from the emmeans package.

Exploratory analyses.

Memory for word meaning will be boosted in the reading + listening modality.

Previous studies have indicated that reading + listening could confer an advantage for word learning (akin to providing subtitles on a video). We therefore examined if there was a main effect of modality on memory, predicting that memory for items in the reading + listening modality would be greater than in the reading or listening modalities alone. We conducted these contrast comparisons using the emmeans package (Lenth, 2017), using the memory model as described above:

Memory ~ Congruency*Enjoyment*Modality + (1 | ID) + (1+List | Item)

The relationship between reading ability and intrinsic reward.

We obtained literacy scores in a subset of participants (N=45, 35 of whom met our inclusion criteria). In this group, we examined the relationship between literacy score and enjoyment experienced during successful extraction of word meaning. For each participant, we calculated the mean of all enjoyment ratings in M+ conditions where words were correctly extracted, and the mean of enjoyment ratings in the M+ condition where words were incorrectly extracted. We then calculated the difference between these means for each participant (enjoyment in M+ correct – enjoyment in M+ incorrect). We assessed if reading ability was correlated with enjoyment ratings in the M+ correct condition, or this change in enjoyment, using Pearson's correlations.

Results

Overall performance

For words embedded in the congruent M+ sentence pairs, participants were able to successfully extract meaning 63.2% (SD=15.5%) of the time (listening, 66.8%, SD=15.0%; reading, 60%, SD=16.6%; listening + reading, 63.2%, SD=14.2%). This is fairly consistent with previous studies (Ripollés et al., 2014, 2016, 2018). In the incongruent M- pairs, participants correctly rejected 36.0% (SD=24.77%) of words (listening, 28.5%, SD=21.3%; reading, 37.5%, SD=23.4%; listening + reading, 42.1%, SD=28.21%).

On day 2, participants remembered 39.5% (SD = 15.70%) of words encountered in the M+ condition (listening, 44.0%, SD=18.3%; reading, 34.6%, SD=13.1%; listening + reading, 40.7%, SD=14.4%). In the M- condition, participants correctly rejected 42.3% (SD = 20.7%) of words (listening, 43.5%, SD=23.3%; reading, 39.4%, SD=18.9%; listening + reading, 44.7%, SD=20.0%).

Planned analyses.

Testing hypothesis 1: Enjoyment ratings will be higher when word meanings are successfully extracted.

Sentence congruency (M+/M-) significantly influenced accuracy, $X^2(1)=56.20$, $p <.001$, and there was a trend for a main effect of enjoyment, $X^2(1)=2.71$, $p = .099$. We did not observe a significant main effect for modality, $X^2(2)=3.65$, $p=.16$. Our predicted two-way interaction between congruency and enjoyment, $X^2(1)=77.35$, $p<.001$ was significant. In addition, interactions between congruency and modality (listening, reading, reading and listening), $X^2(2)=32.38$, $p<.0001$, and enjoyment and modality, $X^2(2)=9.20$, $p=.010$, were also significant, and we also observed a significant three-way interaction between modality, congruency, and enjoyment, $X^2(2)=6.19$, $p=.045$.

Given the presence of this three-way interaction, we examined if we could establish a congruency and enjoyment interaction in each modality independently. In all modalities, we observed a significant congruency *enjoyment interaction (see Table 1 and Figure 2).

Examining trials in each congruency type (M+/M-) independently allowed us to assess the drivers of the observed three-way interaction. We focused on the effects of modality and enjoyment, constructing separate models for the M+ and M- trials. As predicted, in the M+ congruent condition, enjoyment was predictive of accuracy across all modalities, $X^2(1)=62.62$, $p<.001$ (Figure 3). We used the emtrends function within the emmeans package to compare the difference across slopes, there were no significant differences ($p>.29$). In the M- trials, we observed a significant effect of enjoyment, $X^2(2)=31.69$, $p<.001$, and a significant interaction between enjoyment and modality, $X^2(2)=14.71$, $p<.001$. We tested the slopes of the relationships using emtrends. In the Reading + listening modality, the relationship between enjoyment and accuracy was significantly flatter than the other two modalities, listening, $p=.008$, and reading, $p=.0114$ – this drove the three-way interaction. Enjoyment was negatively associated with accuracy in the reading modality and the listening modality (Figure 2).

Testing hypothesis 2: Memory for word meanings will be predicted by enjoyment.

In our omnibus model for memory (Figure 4), enjoyment, $X^2(1)=6.75$, $p=.009$, and modality, $X^2(2)=8.48$, $p=.014$, emerged as significant main effects. We did not observe a significant main effect for congruency, $X^2(1)=0.04$, $p=.85$, or any other significant interactions (*p*

>.12). Enjoyment was positively associated with memory for words (B = 0.169, SE = 0.11). With respect to modality, people were most likely to remember words in the listening modality (see exploratory analyses below). Given the absence of any interactions, we did not decompose the data any further.

Exploratory analyses.

Memory for word meaning will be boosted in the reading + listening modality.

As reported above, we found a main effect of modality on memory for words. We used the 'emmeans' function to compare estimates for these modalities, predicting that reading + listening would be associated with better memory for words. However, our results revealed that people in the listening modality outperformed those in the reading modality, p=.005, but not the reading + listening modality p=.326. The contrasts between reading and reading + listening was not significant, p=.188.

The relationship between reading ability and intrinsic reward.

The relationship between reading ability and average enjoyment on successful M+ trials (r=.15, p=.38), or the uplift in enjoyment between correct and incorrect M+ trials (r=.10, p=.57), was not significant.

Discussion

In line with our hypotheses, we found that intrinsic reward, assessed through behavioural ratings of enjoyment, predicted word learning in all three modality conditions: reading, listening, and the combination of reading and listening. Further, the relationship between successful extraction of word meaning was strongly linked to sentence congruency, with this relationship being faciliatory in nature, and stronger for the congruent (M+) sentence pairs in which meaning can be successfully extracted. This is the first demonstration of the link between intrinsic reward and word learning in the oral domain, and this opens exciting new lines of investigation, especially in the developmental domain where language acquisition mostly occurs in oral contexts. Crucially, across the three modalities, we find that enjoyment is associated with memory. This indicates that the link between intrinsic reward and memory is robust, exists across sensory modalities, and deserves further attention.

The relationship between reward and successful extraction of word meaning

Our finding that intrinsic reward is linked to the successful extraction of word meaning is consistent with our previous work on reading (Angwin et al., 2019; Ripollés et al., 2014, 2016, 2018), but we have now been able to demonstrate this relationship in the auditory and auditory-visual domains. This strongly suggests that the link between reward and word learning exists independent of modality. This is in line with what we would predict for this relationship to be important through development (Bains et al., 2020), and through evolution (Syal & Finlay, 2011). This opens the door to investigating this relationship in populations that do not read, such as younger children.

It is important to note that the relationship between reward and word learning was quite specific, as it was only observed for the M+ trials, where successful extraction of word meaning was possible. For the M- trials, where it was possible to answer correctly but not to extract meaning, we did not observe a positive relationship with intrinsic reward and accuracy. This suggests that effort or novelty are not sufficient drivers of this relationship, but that this is specific to successfully extracting a meaning (i.e., learning a new item).

However, it is rather unlikely that the experience of intrinsic reward is specific to or confined to word learning. Rather, we argue that word learning benefits from a reward-seeking process that occurs across domains to aid learners. For example, Kizilirmac and colleagues (2016) have demonstrated that insight into a learning problem can benefit long-term memory. They investigated this through trying to identify objects in ambiguous black and white photos. When participants had an "aha" moment, they provided higher affective ratings, indicating a more rewarding experience. In this vein, the contextual word learning paradigm offers an excellent means to investigate this relationship for language, as it is a naturalistic means of word learning through insight that occurs in all of these modalities. This would indicate that even in real-word environments, words learned in this contextual manner do benefit from intrinsic reward. In future studies, it is important to investigate if other forms of word learning, for example, in more explicit paradigms, also show the same associations with intrinsic reward.

The relationship between reward and memory for words

Intrinsic reward, measured through ratings of enjoyment, was linked to memory for words across all three modalities. Our findings offer a convincing replication of this relationship in written contexts (Ripollés et al., 2016, 2018), and build and extend this work to suggest that the relationship between reward and memory is agnostic to the modality in which words are encountered. This link between states of intrinsically high motivation and long-term memory are also consistent with other studies that tap curiosity, where we see that states of high curiosity are associated with better memory (Garvin & Krishnan, 2022; Gruber et al., 2014; Kang et al., 2009; Marvin & Shohamy, 2016).

This association is likely to be driven by known links between reward and memory systems, wherein explicit reward cues strengthen the connectivity between striatal and midbrain dopaminergic reward regions and hippocampal memory systems even before the material to be learned is presented (Adcock et al., 2006). Ripollés and colleagues (2018) have shown that successful extraction of word meaning also activates a dopaminergic circuit which fuels memory for word learning, suggesting that intrinsic reward states activate the same circuits. In non-linguistic domains, the link between affective and memory processes that occurs when participants gain insight into a solution is recognized as the insight memory advantage (Danek & Wiley, 2020). This is thought to result from the positive affective response people receive in the moment of epiphany (Danek & Wiley, 2020; Kizilirmak et al., 2016). This speaks to the possibility that intrinsic reward could be tapped as a means of boosting learning. One way to do this might be to restructure situations to explicitly facilitate generation about the meaning of new words, rather than simply presenting meanings to participants.

It is important to highlight that our task difficulty was carefully controlled when developing this task, we aimed to reach an overall accuracy level on day 1 of around 60% for M+ trials. We therefore ensured that our block structure was complex, with novel words being presented non-sequentially (at least four sentences apart), see Figure 1. This is because some level of difficulty appears necessary to drive the activation dopaminergic systems associated with learning, perhaps as the affective response to problem solving does not appear without such difficulty (Vavra et al., 2021). This would suggest that it is not necessary for educational material to be perceived as easy, as some difficulty might be desirable.

The influence of modality on memory for words

We expected to find that providing the opportunity to read and listen would lead to the best word learning. This is in line with literature suggesting that subtitles help with learning (Linebarger et al., 2010). However, people in the reading + listening modality did not learn more than those in the reading or listening modalities. Indeed, the modality that resulted in the greatest word learning was the listening. In our study, the listening modality may have required greater attention to words, and this attentional effort may have led to better retention. However, this may also be because we focused on retention of words that were already learned when examining memory – people in the listening modality learned relatively few M- words, perhaps allowing the few M- words correctly learned to be encoded better. Further, these analyses were not repeated measures analyses, and may reflect cohort effects. They therefore need replication in independent samples.

The role of reading ability

One important question is whether people of all reading/ language abilities benefit from this reward-learning relationship. From a subset of participants, we had access to performance on a task that tapped reading comprehension and fluency. We found that there was no systematic relationship between reading ability and reward experienced. However, it is important to note we were sampling from a typical undergraduate population, collected data on reading ability only from a subset of this sample, and excluded those with reading or learning difficulties. In a previous study, we have found that adults with dyslexia did not differ in the level of curiosity they displayed, but they did show a difference in the relationship between information prediction errors and memory (Garvin & Krishnan, 2022). These may be fruitful directions for future exploration.

Limitations and future directions

In our study, we asked people to rate their enjoyment as a proxy for intrinsic reward as we conducted this work online. Previous studies have revealed that these ratings converge with other measures of the dopaminergic reward system, such as electrodermal activity, pharmacological interventions, or fMRI. In future work, it would be useful to assess whether such measures converge with our behavioural findings. MRI studies could also be helpful in establishing whether the representations that are being accessed are truly independent of modality (Evans et al., 2019).

Our results suggest that eliciting intrinsic reward could help to drive novel word learning, perhaps boosting the learning of foreign language words. Here, we have focused on neurotypical English-speaking adults. The pseudowords we used followed English phonotactics, and were embedded in English sentences. It is therefore important to assess whether these findings would hold for words with different phonotactic structure, or when people were less fluent with the language that the words were embedded in. It is also important to establish whether these findings might generalize to populations with poorer word learning, such as children with developmental language disorder or dyslexia (Nation, 2014). If so, this could indicate a powerful mechanism to boost learning.

Summary and conclusions

Our results demonstrate that successful extraction of novel word meanings is perceived as intrinsically rewarding, regardless of the modality words are encountered in. Additionally, this experience of intrinsic reward fuels memory for words. This indicates a robust reward-language link which is independent of sensory modality and that has the potential to be tapped to boost word learning in educational contexts.

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Tables

Table 1
Analysis of contribution of congruency, enjoyment and congruency x enjoyment to learning accuracy in each modality on Day 1

	Chi square	Df	p-value
Listening			
Congruency (M+/M-)	62.24	1	<.001
Enjoyment	0.93	1	0.335
Congruency x Enjoyment	24.48	1	<.001
Reading			
Congruency (M+/M-)	27.73	1	<.001
Enjoyment	0.01	1	0.941
Congruency x Enjoyment	52.02	1	<.001
Reading + Listening			
Congruency (M+/M-)	30.38	1	<.001
Enjoyment	12.84	1	<.001
Congruency x Enjoyment	14.08	1	<.001

Table 2
Analysis of contribution of enjoyment and modality to accuracy on M+ trials on day 1

	Chi square	Df	p-value
Enjoyment	50.21	1	<.0001
Modality	2.7815	2	0.2489
Modality x Enjoyment	2.8104	2	0.2453

Figures

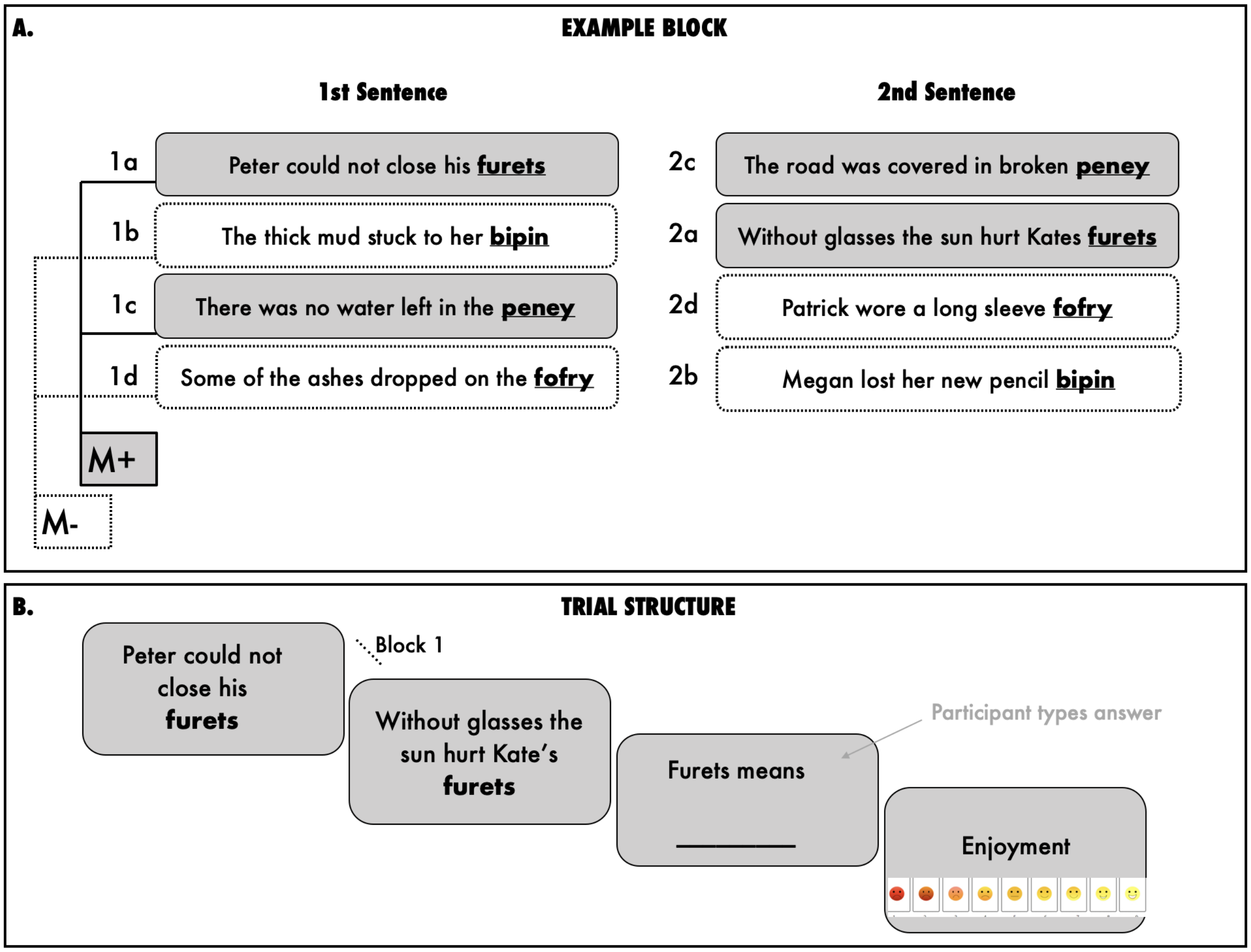

Figure 1. **A.** Schematic overview of block structure, illustrating the sentence congruency manipulation (congruent: M+, gray; incongruent, M-, white). Each block comprised 2 pairs of M+ sentences and 2 pairs of M- sentences presented randomly. Participants were presented with the 'first' sentence from all sentence pairs (e.g., 1a, 1b, 1c, 1d), before encountering the second sentence of the pair (e.g., 2c, 2a, 2d, 2b). **B.** Schematic illustration of the trial structure.

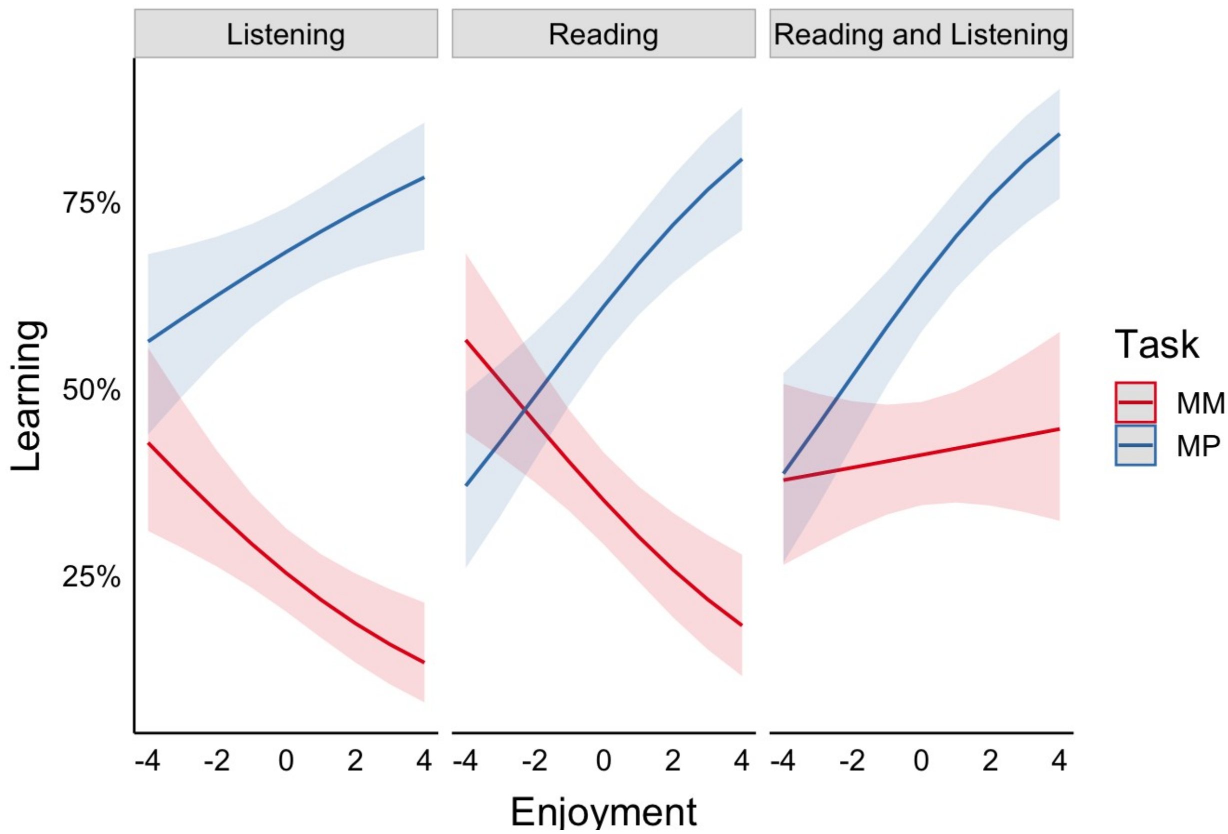

Figure 2. The effect of enjoyment on learning in M+ (blue) and M- (red) trials, in the reading, listening, and reading + listening modalities.

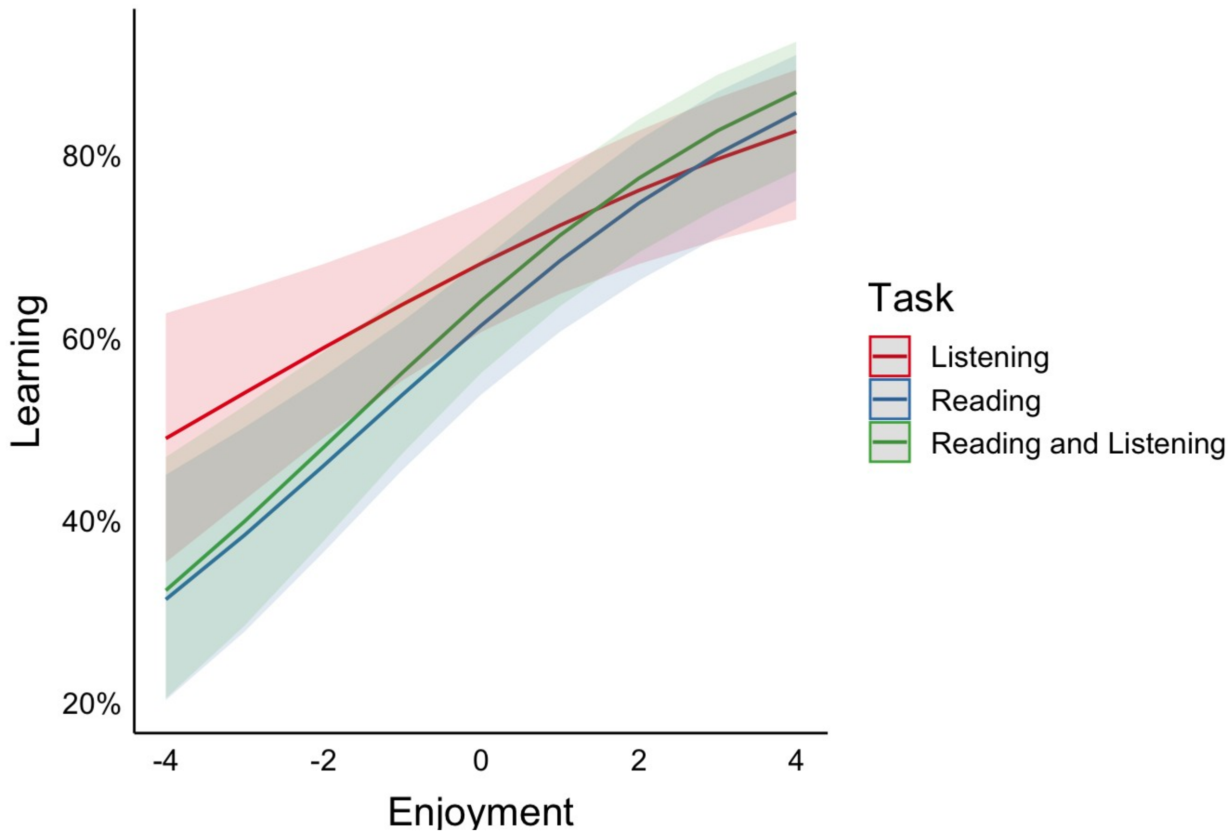

Figure 3. The relationship between enjoyment and successful learning of new words in M+ trials across modality (listening – red, reading – blue, reading + listening – green).

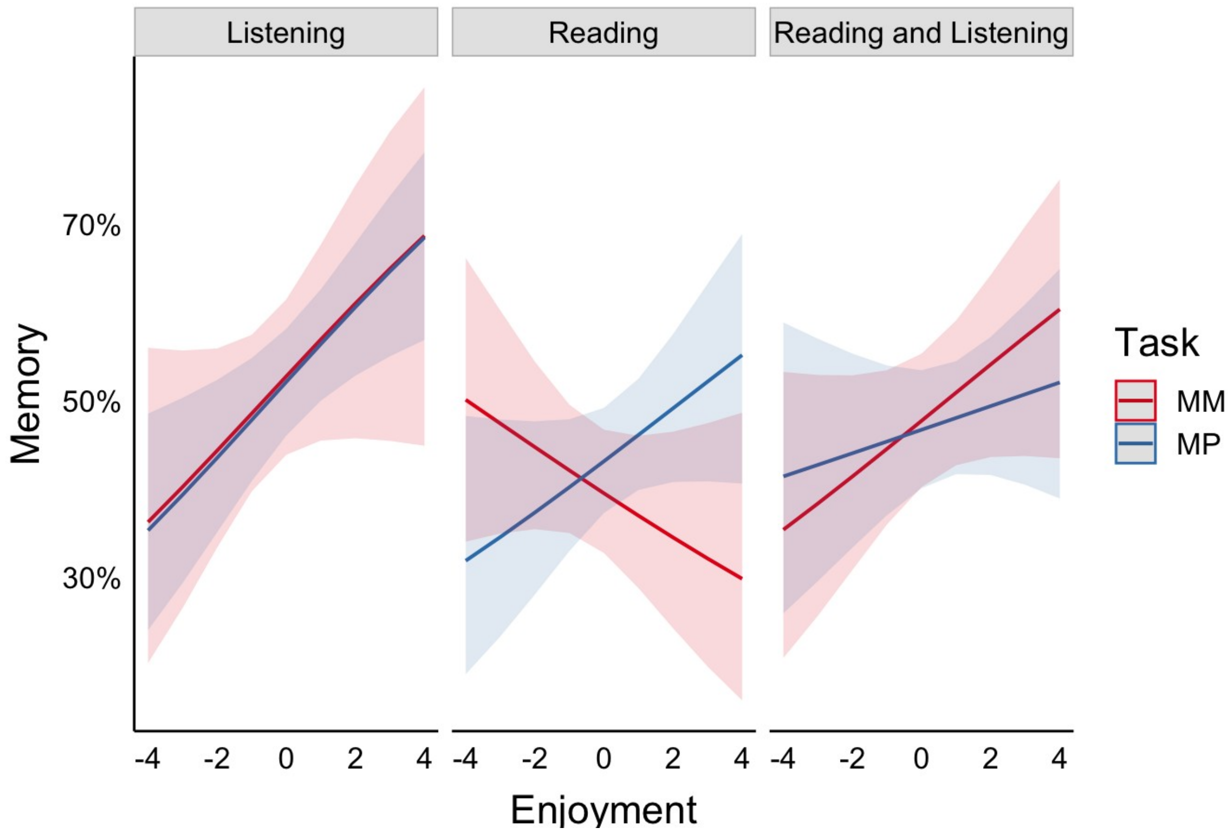

Figure 4. The effect of enjoyment on memory in M+ (blue) and M- (red) trials, in the reading, listening, and reading + listening modalities.