A three-minute test of implicit language processing for large sample sizes: Proof-of-concept application in a public science event

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Declarations

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Abstract:

Research into human language processing is made challenging by the implicit nature of processes, the short time-window in which they take place, and heterogeneity within the population. We used a word monitoring task to measure implicit sensitivity to grammar, semantics, and the strength of word collocations, when listening to natural spoken sentences. We report substantial and novel adjustments to the paradigm, which allowed a participant to be tested in about three minutes, and data from a proof-of-concept study for which we recruited 125 visitors of different backgrounds to a science event. Linear mixed-effects models suggest that participants' response time to target words was slower when words were less predictable in their grammatical, semantic, or collocational context, with no significant difference between trial conditions. However, in non-native speakers, grammatical manipulation was numerically less effective than manipulations of semantics and word collocations, and the effect was close to the significance boundary.. There was no significant effect of age on language sensitivity. Findings either replicated previous studies using standard word monitoring methods, or were compatible with theories on language processing, suggesting that the novel adjustments can be applied in situations where participants' time is limited, e.g. at events, in schools or online.

Keywords: Psycholinguistics; Implicit processing; Word monitoring; Public event

1. Introduction

1.1 “Predicting language”

The London Bloomsbury Festival is a yearly arts, literature, performance and science event celebrating the district’s “pioneering diversity”. University College London (UCL) is located in that area and a regular contributor. 2016’s festival had “Language” as its theme and we contributed with a public science installation with the aim of engaging the public, raising awareness to language as a cognitive process, and testing sensitivity to different aspects of linguistic information in a larger public sample which is more heterogeneous than is common in psychological studies. To accomplish this, we made substantial modifications to an established empirical paradigm, shortening the protocol from typically half an hour or longer for each participant to three minutes in order to lower the barrier to participation.

Language processing is a subject critical to a range of disciplines. It informs linguistic theory, but also applies to branches such as education and clinical science, for example to track early development or profile and detect neurological disorders. However, research on language processing faces three basic challenges: First of all, much of language processing happens implicitly; speakers have no intuitive insight to the processes that underlie lexical or grammatical interpretation (Ellis, 2008), meaning that measures of implicit processing may be more informative than explicit data such as from questionnaires or grammaticality judgments. Second, processing happens within fractions of a second: Event-related EEG potentials show that many language-related effects, such as of the acceptability of a word within its context, or of effort in syntactic processing, take place at around half a second after onset of the critical stimulus (Kutas, van Petten, & Kluender, 2006), which should be regarded as a call for more sensitive measures of linguistic performance. Third, there are considerable

individual differences within populations (which have long been underestimated), meaning that experimental data from homogeneous groups, such as university students, should be generalized only with caution (Kidd, Donnelly, & Christiansen, 2018; Street & Dąbrowska, 2010, 2014).

The Bloomsbury Festival was an opportunity for us to carry out a study that addresses these three issues, and at the same time offer an engaging experience which encourages participants to think about the cognitive processes underlying language use. The design of the installation was based on the idea that listeners implicitly form predictions about incoming information based on what they hear at a given moment (Clark, 2013; Ferreira & Chantavarin, 2018). These predictions determine anticipatory activation, and linguistic stimuli which correspond to these predictions are easier to process, while stimuli that violate predictions require greater effort. We focused on three levels of language processing: (1) Grammatical processing, which we use to make predictions about incoming structure and word types; e.g., the word combination *I want to* makes the listener expect a verb or adverb. (2) Lexical-semantic processing, which we use to make predictions about the possible meaning of the next words; e.g., *For dinner I would like* makes the listener expect a reference to food or drinks. (3) Processing of collocation patterns in language, which helps us make predictions about specific words; e.g., the words *salt and* can lead to the pre-activation of *pepper* (Conklin & Schmitt, 2012; Siyanova-Chanturia, Conklin, Caffarra, Kaan, & van Heuven, 2017). Fittingly, we named our installation “Predicting Language”, a title which can be interpreted in two ways: Individuals predicting language input while listening, and the language system itself being predictive in nature.

The public event allowed us to investigate effects of age, gender and native language (English as native (L1) or non-native (L2) language) on sensitivity to the three features of language described above, namely (1) grammatical structure, (2) lexical-semantic information, and (3) word collocations. We were interested in whether results from the new WMT task were consistent with previous observations as well as language processing theories, in order to validate the methods. We also observed participants' reactions to the event as an indicator of engagement.

1.1 The Word Monitoring Task (WMT)

We designed a word monitoring task (WMT; Kilborn & Moss, 1996; Marslen-Wilson & Tyler, 1975, 1980), a response time measure of implicit spoken language processing. The paradigm tests how recognition of a single word is affected by word context. In a typical WMT, a target word (e.g. *city*) is presented to the participant. Then, a sentence is presented which contains the target word, and the participant has to press a response button as quickly as possible when they recognize the word in the sentence. Response time (RT) is measured. Test conditions typically differ in whether the target word occurs in a context that makes it predictable, e.g. *You can reach the city in little time*, or less predictable, e.g. *You can arrive the city in little time*. In this example, *city* appears in a grammatical context in first condition (the verb *reach* takes a direct object) and in an ungrammatical context in the second condition (the verb *arrive* does not). Typically, increase in processing effort results in a RT increase, such as when the target word is presented in a position that makes it less predictable or a violation. Sensitivity to linguistic information in processing is measured by subtracting the RT from the less predictable condition from the RT of the predictable condition. According to the definition of "implicit processing" offered by Shanks (2005), WMT is a measure of implicit

processing because participants following the instructions are not aware of the critical processes while they take place. By focusing on pressing the button as soon as the target word appears, they are engaged in something other than reflecting on the properties of the stimulus sentences. Suzuki and DeKeyser (2015) found that language sensitivity measured in a WMT correlated with performance in a serial reaction task, an implicit measure of non-verbal sequence learning.

Sensitivity varies depending on the cognitive system of the individual. There are striking deviations in clinical cases, such as developmental language disorder, aphasia (a language impairment caused by brain injury or degeneration) or schizophrenic thought disorder (Baum, 1989; Haarmann & Kolk, 1994; Kuperberg, McGuire, & David, 1998; Montgomery & Leonard, 2006). However, the WMT is also used to investigate language processing in second language speakers (Granena, 2013; Kilborn, 1992; Suzuki, 2017; Suzuki & DeKeyser, 2015) and aging (Tyler et al., 2010; Waldstein & Baum, 1992).

In order to motivate participants to engage with the experiment, we told them that they would see their average RT at the end of the task. After the task, we gave each participant a button with a logo and the phrase “Language Predictor”, and offered to write their average RT on it. We expected participants to be motivated and respond as quickly as possible, and to compare the average RT with friends. To further increase engagement, the installation had an animated PowerPoint presentation about predictive language processing, included one offline activity involving predicting words (a variation of the cloze task), and displayed the cumulative results from one of the test computers on a screen (see Methods section). Researchers were present to discuss language processing with visitors.

1.2 Methodological innovations

One major hurdle in applying the WMT in a public science event is the duration of the task. The ‘Predicting Language’ installation would run for six hours on one day and we expected hundreds of visitors. We had two test computers available and were aware that participants would not want the activity to be longer than a few minutes. WMTs have always been designed for smaller subject groups, and contained dozens of trials: for example, Marslen-Wilson and Tyler (1975) had 81 sentences for each participant, Baum (1991) 150 sentences, Haarmann and Kolk (1994) 160 sentences, Kuperberg, McGuire and David (1998) had 76 sentences and Granena (2013) 120 sentences. For the current study, we decided to present 12 sentences to each participant.

In contrast to how WMTs are typically designed (see Marinis, 2010, for a review of methods), this restriction made a number of deviations necessary. It is normal for each target word to be presented to each participant in both predictable and less predictable conditions, e.g. *city* in grammatical and ungrammatical sentences. This enables a contrast of each item pair at a within-subject level, offering more robust data. To avoid participants becoming aware of the manipulation, trials with the same target word are spaced out across sessions or trial blocks. The brevity of our study made such a design impossible, and we therefore presented each target word only once to the participant. Half of the participant sample encountered it in the predictable, and half in the less predictable condition. As a result, the effect of the predictability manipulation was dependent on between-subject comparisons.

The other important deviation is the omission of filler and catch trials. Filler trials contain a target word but are not relevant to the hypotheses and are included to keep participants from becoming aware of the task manipulation. Catch trials contain no target word and therefore

require no response. These can be included to raise participant alertness, and to avoid participants pressing the button purely mechanically, without listening to the linguistic content of the task. Our experiment, however, contained only hypothesis-relevant trials. Based on our experience designing and running WMT tasks, we expected that the brief duration of the experiment would keep participants from losing focus, and that this short duration in combination with presenting each target word once would limit participant awareness of the task manipulation. In making changes to the paradigm, we saw an opportunity to contribute methods which could be used not only in public events, but also in other settings where participants' time could be limited, such as schools or online, where we expect individuals will more likely participate and complete a task if it is short. For instance, Hartshorne, Tenenbaum and Pinker (2018), who recruited more than 650,000 participants for their vocabulary quiz, highlighted that in order to go viral, a test has to be entertaining, motivating and quick to complete.

The project had ethical approval from the UCL Department of Language and Cognition Ethics committee (ID: LCRD.2016.06). We had permission to include people younger than 18, but had no permission to use their data and therefore removed them before analysis.

2. Methods

2.1 Installation

We designed an interactive 'Predicting Language' installation as part of a one-day public event, on Saturday, November 22nd 2016, from 11am to 5pm in the UCL Main Quad Marquee. We shared the event space with other installations. Figure 1 shows the setup of the installation which included a scientific slideshow presentation about prediction in language,

a sentence completion (cloze) task, and a WMT with real-time display of results. The sentence completion task was not set up as an experiment, but rather, as a way for visitors to further engage with the topic of the installation. We describe the task and the results in the Appendix. Moreover, each visitor could take a badge with a logo of our installation.

Figure 1

Design of the Predicting Language installation.

The event was widely publicized in London through press and social media. Organizers advertised the Predicting Language installation with “take part in cutting edge research” in the festival brochure (2016), and the program described it as: “Take part in a live experiment, with researchers from the Department of Language and Cognition”. Visitors who stopped at the installation were approached by a researcher and asked if they were interested in taking

part. Some participants had heard about the experiment already and approached us. They were given an information sheet, had time to ask questions about the study and, if they agreed to take part, gave written consent to storage and use of their anonymized data for research purposes. The experimenter would then wait for a test computer to become available and lead the participant to the machine.

2.2 Participants

We collected data from 136 volunteers between 7 and 79 years (mean = 39.8; SD = 17.9). For analysis, we only included participants who were 18 years or older since we did not have approval to analyze data from minors. Our final sample consisted of 125 volunteers between 18 and 79 years (mean = 42.2, SD = 16.6). Of these, 83 were native speakers of English; 74 were male, 50 were female and one participant was non-binary. No participant reported a history of language or hearing impairment, stroke or other brain damage.

2.3 Materials

The WMT consisted of 12 sentence pairs, divided into three experimental conditions: grammatical, lexical-semantic, and word collocations. We split stimuli into two lists of 12 sentences, with equal numbers of predictable and less predictable items from each condition. Table 1 presents the stimuli. Each condition comprised four sentence pairs. For each pair, there was one sentence where the appearance of the target was more likely given its context (i.e., semantically / syntactically correct sentence, common word collocation) and a counterpart sentence with violated semantic or syntactic context, or with a less common collocation.

To measure RT to target words, it is essential to accurately determine the onset time of target words in the sound file. Target words beginning with plosives (/p/, /t/, /k/, /b/, /d/, /g/, affricates /tʃ/, /dʒ/ or fricatives /s/, /z/, /f/, /v/ are easiest for determining word onset (Cruttenden, 2008; Brekelmans & Meitanis, 2016). With the exception of one target word (*icing*), all began with a plosive, affricate or fricative. Each target word appeared at the same sentence position in both sentences of the pair.

Auditory stimuli were recorded by a female native speaker of Standard Southern British English in a sound-attenuated booth. We determined the onset points of target words in each sentence, using Praat (Boersma & Weenink, 2019). This allowed us to determine monitoring latencies by subtracting a participant's RT by the onset point.

Table 1

WMT stimulus conditions, targets, and sentences.

Condition	Target	Sentential context	Predictable / less predictable
Semantic violations	crawl	I saw a <i>spider</i> that was very big, crawl under my bed.	P
		I saw a <i>fish</i> that was very big crawl under my bed.	LP
	cucumber	For my <i>salad</i> , I should buy some cucumber from the market.	P
		For my <i>guitar</i> , I should buy some cucumber from the market.	LP
	crowded	The <i>room</i> is very small and crowded in my opinion.	P
		The <i>mouse</i> is very small and crowded in my opinion.	LP
	tree	On Sunday, we will <i>plant</i> a small tree with Alex.	P
		On Sunday, we will <i>bake</i> a small tree with Alex.	LP
	city	You can <i>reach</i> the city in little time.	P

Syntactic violations		You can <i>arrive</i> the city in little time.	LP
	books	John <i>loaded</i> the table with books .	P
		John <i>put</i> the table with books .	LP
	icing	Helen <i>covered</i> the cake with icing .	P
		Helen <i>spread</i> the cake with icing .	LP
	cushions	She got ready to <i>sew</i> some cushions for her new home.	P
		She got ready to <i>sleep</i> some cushions for the new home.	LP
Common noun pairings	groom	I don't like this picture. The <i>bride</i> and groom both look tired.	P
		I don't like this painting. The <i>horse</i> and groom both look tired.	LP
	chips	It's a great place. I love the <i>fish</i> and chips served in this pub.	P
		It's a great place. I love the <i>bread</i> and chips served in this pub.	LP
	pepper	That's unbelievable. I forgot the <i>salt</i> and pepper for our breakfast.	P

		That's embarrassing. I forgot the <i>juice</i> and pepper for our breakfast.	LP
	dogs	It's common sense. <i>Cats</i> and dogs should not be kept indoors for too long.	P
		It's common sense. <i>Birds</i> and dogs should not be kept indoors for too long.	LP

2.4 Procedure

Before starting the experiment, participants gave informed consent to take part. They were then allocated to the next available laptop. On the laptop, they filled out a short questionnaire which asked for their age, gender (male, female or non-binary), whether they were a native or non-native speaker, had a history of neurological illness or had a hearing impairment. They then saw instructions of the task displayed on the laptop screen (Figure 2) and started the experiment. Stimulus lists alternated on each machine and researchers did not know which would run next. Items in each list were presented in randomized order. Participants listened to the stimuli using noise-cancelling headphones and responded to the target by pushing the space bar on the laptop keyboard. There were no practice trials. Filling out the questionnaire, reading the instructions and carrying out the task took about three minutes for most participants.

After the experiment, participants saw their mean RT (in ms) displayed on the laptop screen. They picked up their button and one of the researchers offered to write their mean RT on it with a permanent marker. Real-time results were displayed on a separate computer screen,

visible to all visitors (see Figure 1). The screen presentation cycled through three graphs with the following headings. The first was “How sensitive are we to unexpected words?” and displayed a bar chart showing average RT difference for predictable versus less predictable targets in each condition. The second had the heading “Does age matter?”, and displayed a scatterplot of average RT difference between unpredicted and predicted targets by age, with a correlation line. The third screen was titled “Are native or non-native speakers of English more sensitive to unexpected English words?” and displayed a bar chart showing average RT difference across all conditions for native versus non-native speakers of English.

Figure 2

WMT instruction screen.

Press SPACEBAR to start the experiment.

3. Results

3.1 WMT

3.1.1 Analysis methods

We applied generalised linear mixed effects models (Baayen, Davidson, & Bates, 2008), using lme4 (Bates, Mächler, Bolker, & Walker, 2015) and knitr packages (Xie, 2018) for the R environment (R Core Team, 2019). Graphical representations were created using ggpirate (Braginsky, 2018). Reliability was calculated using the psych package (Revelle, 2021).

The experimental factors were *age* (a continuous variable), *native language* (native/non-native English speaker), *predictability* (high/low predictability for the target condition), and *manipulation type* (semantic/syntactic/collocations in the language manipulation condition). We included all experimentally manipulated variables and their interactions as fixed factors in the models, regardless of whether their contribution was significant. *Participant* was included as a random effect with as full a random slope structure as would converge (in this case only the interaction of *native language* by *predictability*, without the *manipulation type* or *age*) as recommended by Barr, Levy, Scheepers, & Tily (2013). *Item* was included as a random effect with random intercepts only. Additionally, we included *list* into the model as a fixed factor for the randomised stimuli list which was part of the experimental manipulation. However, *list* was considered a control factor not relevant to our hypotheses. We, therefore, included it as a main effect, but did not interpret it. Predicting variables were centred to reduce collinearity effects between main effects and interactions, so that the intercept corresponded to the grand-mean (in log odds space) and main effects were evaluated as average effects over all levels rather than having a baseline level for each variable. For *manipulation type*, which has more than two levels which are not naturally

ordered, we used a centred contrasts coding instead. To assess whether performance was above chance, data were compared to the intercept. All reported models converged using the Bound Optimization by Quadratic Approximation (BOBYQA optimization; Powell, 2009). Since all models had a continuous outcome variable (RTs, standardized RTs or RT differences) we calculated *p*-values using the lmerTest package (Kuznetsova, Brockhoff, & Christensen, 2017) and Satterthwaite approximation for degrees of freedom.

The full model included the *age by native language by predictability by manipulation type* interaction and any lower level interactions within that. Since *manipulation type* has three levels, and our method of centring only shows two levels at once, we ran the same model with a different manipulation type as the baseline to get to the third level. *Gender* was not added into the final model, as it did not significantly improve the model fit. The final model structure is as follows:

$$RT \sim age * native\ language * predictability * manipulation\ type + list + (native\ language : predictability || participant) + (1 | item).$$

3.1.2 Effects

Although we ran models including all of the experimentally manipulated variables and their interactions, we only report statistics for the key effects relevant to our hypotheses. The

dataset, code and analyses are available here:

https://osf.io/jy4zr/?view_only=3312962cdabe4f348f7d46f8b4d9c523

Table 2

Model results for the analyses of effects of age, native language, predictability, and manipulation type on RT on a WMT.

Effect	β	SE	t	p
<i>Age</i>	1.639	0.357	4.591	< .001
<i>Native language</i>	34.528	13.169	2.622	.010
<i>Predictability</i>	42.547	20.010	2.126	.048
<i>Age by predictability</i>	-0.410	0.444	-0.923	.358
<i>Native language by predictability</i>	-28.906	16.751	-1.726	.089
<i>Predictability by manipulation type</i>				
<i>Collocations vs semantic</i>	2.297	48.497	0.047	.963
<i>Collocations vs syntactic</i>	-24.038	48.593	-0.495	.627
<i>Semantic vs syntactic</i>	-26.335	48.583	-0.542	.595
<i>Age by predictability by manipulation type</i>				
<i>Collocations vs semantic</i>	0.507	0.987	0.513	.608
<i>Collocations vs syntactic</i>	-0.738	1.005	-0.734	.463

Semantic vs syntactic	-1.244	1.008	-1.235	.217
<i>Native language by predictability by manipulation type</i>				
Collocations vs semantic	-4.842	36.606	-0.132	.895
Collocations vs syntactic	-69.688	37.044	-1.881	.060
Semantic vs syntactic	-64.845	36.830	-1.761	.079

There was a significant relationship between RT and age, in that older participants were slower. Also, native speakers were overall significantly faster to respond to the stimuli ($M = 229$ ms, $SD = 128$ ms) than non-native speakers ($M = 239$ ms, $SD = 124$ ms). There was a significant main effect of the type of word monitoring manipulation, as participants responded more slowly in the low predictability condition ($M = 253$ ms, $SE = 118$ ms) than the high predictability condition ($M = 212$ ms, $SD = 132$ ms).

There was no significant interaction of WMT manipulation by trial type; WMT effects were not significantly different in the syntactic (high predictability $M = 229$ ms, $SD = 131$ ms; low predictability $M = 252$ ms, $SD = 126$ ms), semantic (high predictability $M = 231$ ms, $SD = 118$ ms; low predictability $M = 275$ ms, $SD = 116$ ms) and collocation conditions (high predictability $M = 177$ ms, $SD = 139$ ms; low predictability $M = 231$ ms, $SD = 108$ ms). There was no significant interaction of WMT manipulation with age, so older participants did not significantly differ from younger participants in their responses to predictability

manipulations. There was no significant interaction between the WMT manipulation type and native language, meaning that WMT manipulations did not elicit significantly different responses between native (high predictability $M = 206$ ms, $SD = 133$ ms; low predictability $M = 252$ ms, $SD = 119$ ms) and non-native (high predictability $M = 223$ ms, $SD = 130$ ms; low predictability $M = 254$ ms, $SD = 116$ ms) speakers of English. There was no significant interaction between age, WMT manipulation type, and trial type, meaning that older participants did not show significantly different types of reactions to WMT manipulations across the manipulation categories.

Finally, there was no significant interaction between WMT manipulation type, native language and trial type, suggesting non-native participants and native participants did not show different types of reactions to WMT manipulations across the manipulation categories, as seen in Figure 3. Note, however that the effect for the latter two interactions are close to the significance threshold, suggesting that non-native speakers may be less sensitive to syntactic manipulations.

We measured the reliability of our stimuli responses using Cronbach's Alpha. The value was $\alpha = .71$, indicating acceptable consistency of RTs.

Figure 3

RTs for native and non-native participants, comparing predictable versus less predictable contexts in stimuli that were manipulated semantically, syntactically, or by the strength of word collocations. The horizontal line in each violin indicates the mean performance with the band around it showing 95% CI.

3.2 Engagement

We did not systematically collect any data on visitor satisfaction, so this section contains our observations and impressions. Overall, visitors appeared to enjoy the installation.

Participants were keen to take part in the experiment, and from after about two hours, when more visitors appeared, until the end of the festival, the installation was crowded at all times. Most participants sought a conversation with the researchers, especially after the experiment, and having taken part in the study made it easier to communicate ideas about a predictive language system. The screen displaying WMT results helped explain the design of the experiment. Displaying individuals' average RT at the end of the experiment, and offering to write it on the badges, led to a fun sense of competition within participant groups as many visitors who arrived together enjoyed comparing their performances: e.g. one group decided that the participant with the slowest response would buy drinks. From our observation, engagement with the Power Point presentation (Figure 1, S2) was small in comparison with the engagement with the tasks and the experimenters.

4. Discussion

We carried out a public experiment during a local festival as a mean of public engagement, and of collecting data to investigate different levels of language processing. In order to make the test attractive as part of a public event, and to test a large number of people, we made a number of methodological innovations to the WMT paradigm which reduced the duration of each test session to about three minutes. In a WMT, the main effect is that of sentence frame, i.e. whether a target word, in a given context, is more or less predictable.

We tested words in predictable and less predictable grammatical contexts, semantic frames, and word collocations (e.g. *salt and pepper* vs. *juice and pepper*). Since we introduced substantial methodological changes, the discussion of results serves as a test of validity. Results which are either replications of previous studies, or which would be predicted by psycholinguistic theory, would suggest that the experiment measured real language processes.

We found that context had a significant effect on participants' RTs as they were slower when the word was less predictable in its frame. This serves as a replication of typical WMTs, suggesting that the adapted methods have validity. Reliability for the measure was promising for such a short adaptation of typical WMTs. To our knowledge, the effects of grammatical, semantic and collocational manipulations have not been compared in a WMT study. Nevertheless, we expected different manipulations of linguistic information to elicit different effect sizes, as they are assumed to be processed by different neurological networks. We were therefore surprised to see that differences in sensitivity across the three conditions were so small and not significant. One exception, however, was the interaction between manipulation condition and native language (see below).

Older people were overall slower but showed the same sensitivity to context, which is consistent with previous findings. Previous WMT studies on aging found no effect on processing grammatical and semantic context (Tyler et al., 2010; Waldstein & Baum, 1992). Reviews of language in aging (Burke & Shafto, 2008; James & Goring, 2018) find that age effects on language are strongest in production. In language reception or comprehension, findings differ depending on the nature of the task, with age effects being stronger when the task is off-line and explicit, for example in experiments involving recall or judgment. One

explanation may be that recall and judgment tasks pose higher demands to working memory and the ability to learn and perform a complex new task, and that both are affected by aging (Burke & Magkay, 1997; Thornton & Light, 2006).

The main effect of native language was not significant, as sensitivity to context was similar in L1 and L2 speakers across all items. This is unexpected, since previous WMT studies found differences between participants of these two populations. Kilborn (1992) found that sensitivity to grammatical context in L2 English speakers was comparable to sensitivity of L1 speakers under noise conditions. Granena (2013) also found differences between L1 and L2 Spanish speakers in a grammatical WMT. However, differences were only significant in a group of “late” learners, i.e. speakers who started learning English after age 16 and who had spent, on average, 8.4 years in Spain. Early learners, on the other hand, were not significantly different from native speakers. Similarly, Suzuki (2017) found that L2 learners of Japanese were more sensitive to grammatical violations in a WMT the longer they had lived in Japan. While we were not able to collect data on our L2 speakers’ proficiency or experience, it is possible that the weaker and non-significant main effect we found was due to our group containing more advanced speakers of English. Future research in this area should aim to include measures of participant background to explore potential differences due to variation in e.g. proficiency, age at which they started learning, or socio-economic background, to be able to tease apart the reasons behind differences in learner effects.

Despite this, we found suggestions of a possible interaction between native language and type of linguistic manipulation. When comparing the effect of grammatical, semantic, and collocational manipulation, we found no main effect, and no interaction with age. However, the interaction effect between manipulation and native language (Figure 3) was close to

significance thresholds. In L2 but not L1 speakers, sensitivity to grammatical information (verb argument structure) numerically appeared weaker than sensitivity to lexical-semantic or collocational information. While we need to restrain from generalizing from our sample, we note that the effect is in line with data from other experiments. It also seems in line with theories of second language acquisition which propose that L2 speakers are often engaged in “shallow” grammatical processing of language, with language networks paying more attention to semantic coherence than grammatical structure (Clahsen & Felse, 2006; Guo, Guo, Yan, Jiang, & Peng, 2009; Yudes, Macizo, Morales, & Bajo, 2013; Zheng & Lemhöfer, 2019). The idea of shallow processing extends to common collocations such as *fish and chips*: these are considered formulaic language, and thought to be stored holistically as a single language unit, while other combinations (e.g. *bread and chips*) rely more on processing of each individual word and its grammatical combination (Conklin & Schmitt, 2012). Future research should be conducted for replication in order to further qualify the potential difference in sensitivity to collocations between L1 and L2 speakers. .

Importantly, we regard this study as proof-of-concept, and while effects are in line with the literature, a confirmatory study investigating our variables requires more participants (Brysbaert, 2019). Another limitation concerns study design, since the lexical frequency of target words was not considered, which impacts the comparability of manipulation conditions. We also note that our stimulus set was rather small. A follow-up study could take lexical frequency into account in the stimuli creation, and could include more sentence stimuli to avoid extending the duration of the experiment, by creating a larger set from which only a subset is selected for the individual participant. This would also likely be beneficial for the reliability of the measure. Note that a follow-up study with more sentence

stimuli would require an increase in participant numbers in order to ensure enough observations per item.

In a public event it is not possible to control for how much the participant knows about the task. Knowledge about the experimental design, which we discussed with participants after they completed the task, can result in more explicit processing of language as participants direct their attention to the manipulation. It is possible that knowledge about the design “leaked” to individuals who later took part in the experiment. Finally, a public event is noisy and full of distractions, and despite testing taking place behind room dividers and with noise-cancelling headphones, it was not possible to create optimally quiet test conditions.

Other limitations concern the participant sample. We note that every recruitment strategy introduces selection biases to the sample. In the case of recruiting visitors from a science-themed festival one would expect participants with higher levels of education and perhaps more proficient English skills. In the case of older participants, one would expect them to have a more active lifestyle. Therefore, while we did not limit ourselves to recruiting from a student subject pool and our recruitment addresses issues with participant group homogeneity to some degree, our sample may not be representative enough to accurately represent age effects and effects of speaking English as a second language.

In summary, we demonstrate that our version of a word monitoring task, which introduces substantial methodological changes, produces data that are compatible with other studies and views about language processing. The methods meet Hartshorne et al.’s (2018) description for a test that could be popular, as participants were entertained, motivated, and completed it quickly. We see the usefulness of the task in environments which allow testing large numbers of participants who either do not have much time, or have difficulties

being engaged in a longer task. These can be public events, but also school environments and remote online testing.

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Appendix A. Cloze task

Methods

The cloze task is a sentence completion task. Incomplete sentences were displayed on one side of a poster board (see Figure 1). We provided post-it notes for visitors to write down their answers. Visitors could put each post-it note on the back of the poster board, where each sentence was displayed again. In this way, visitors could look at all previous answers and see where there was agreement or disagreement. There were three incomplete sentences with varying degrees of contextual constraint:

- (a) When you go to bed, turn off the ...
- (b) I didn't find the key to open the ...
- (c) He was surprised to find that the large box was filled with ...

The task was unsupervised. There were no time constraints, and visitors were able to complete it in groups if they wanted.

Results

Table A1 summarizes the cloze probabilities collected throughout the day of the event. It should be noted that we did not collect demographic data of people participating in this task. The more contextually constrained sentences (a) and (b) frequently elicited the predictable targets (light(s); door, see Table 2). Some participants, however, answered with more creative variations such as “When you go to bed, turn off the brain (5) / problems (1)” or “I didn't find the key to open the heart (3) / universe (1)”. As expected, sentence (c), which had the weakest constraint context, elicited the greatest variety of answers, with a maximum cloze probability of .06 for “nothing” and “toys” (Table A1).

Table A1. Most common answers in the cloze task.

	When you go to bed, turn off the ...	I didn't find the key to open the ...	He was surprised to find that the large box was filled with ...
N	87	88	72
	light(s) (.47)	door (.36)	nothing (.06)

Most common answer (cloze probability)			toys (.06)
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