Activation of biographical information via picture of cultural figures during comprehension: evidence from eye-tracking during reading

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Abstract

Various types of world knowledge have been shown to be rapidly available during language processing, from well-known historical events to the colour of our local trains. Prior knowledge about well-known fictional or real-world referents, such as specific semantic knowledge of known cartoon or real-world referents, has also been shown to available during comprehension with gradient inter-individual effects correlated with fictional-world expertise. In an eye-tracking-during-reading experiment, we examined how rapidly two types of photo-sentence relations impact sentence comprehension. A first relation was between a photo of a cultural figure and a year in the ensuing sentence (the cultural figure in the photo was either alive in that year or not). This was contrasted with relations between the same photo and achievements or facts about the cultural figure (e.g., a film they had vs. had not starred in). Longer reading times were observed at the regions containing mismatching *year* or *fact* information (e.g., Emma Watson starred in the ***Wizard of Oz*** in ***1939***), with more robust effects when data were filtered to include only trials in which participants had accurate prior knowledge about the cultural figure, their accomplishments, and their lifetime. Effects of *fact congruence* were also found near sentence-end at the presentation of the cultural figure's name, but only when trials with missing relevant long-term knowledge were included in analyses, suggesting that this effect was driven by trials in which participants did not recognise the cultural figure. These findings indicate that long-term knowledge activated by a picture is rapidly available during the processing of information such as whether they appeared in a certain film and whether they were alive in a given year, and that the former, but not the latter, are available when prior knowledge about the cultural figure was more variable.

Keywords: world knowledge, eye-tracking, reading, comprehension

Introduction

Investigations into the role of high-level world knowledge in language processing have established that violations of long-term knowledge elicit processing costs. In their seminal study, Hagoort, Hald, Bastiaansen, & Petersson (2004) presented neurophysiological evidence of the influence of specific knowledge of the world on language processing, in which violations of world knowledge elicited an N400 effect which was similar in latency and distribution to semantic violations, but with a reduced amplitude (e.g., *Dutch trains are **yellow/white/sour***; Dutch trains are in fact yellow). Since this study, similar findings have been found for other types of lexico-semantic world knowledge violations of well-known historical events (Nieuwland & Martin, 2012; Rapp, 2008), traits of familiar cartoon characters (Filik, 2008; Filik & Leuthold, 2013), even knowledge specific to the Wizarding World of Harry Potter (Troyer & Kutas, 2018).

These studies have demonstrated that high-level world knowledge can influence the processing of lexico-semantic input when world knowledge is activated through linguistic contexts. Meanwhile, faces of familiar individuals can activate long-term semantic knowledge about the individual, whether they be real-world cultural figures (Abdel Rahman, Sommer, & Schweinberger, 2002; Suess, Rabovsky, & Abdel Rahman, 2013) or well-known cartoon characters (Abdel Rahman, Sommer, & Olada, 2004). Characteristics of unknown speakers have also been shown to be taken into consideration during comprehension. For example, in Van Berkum, Van Den Brink, Tesink, Kos, & Hagoort (2008) an N400 effect was elicited when participants heard statements that violated stereotypes of the speaker based on their voice (e.g., an adult male vs. female voice: *If only I looked like **Britney Spears** in her latest video*). Meanwhile, inferences about speaker nativeness, based on physical features of unknown faces and accompanying native or non-native accented speech, can additionally influence on-line processing of linguistic input, as well as well-formedness judgements (Xu, Abdel Rahman, & Sommer, 2019). The rapid effects elicited by physical referent or speaker attributes indicate that what we believe to be true about an individual is rapidly available during language comprehension. This seems to be the case whether these beliefs are based on long-term information of a known individual, or stereotypes based on demographic assumptions, like gender. Though a variety of types and sources of long-term knowledge have been investigated, such investigations have thus far focused on lexico-semantic violations activated by linguistic contexts establishing expectations based on real-world knowledge. Less is known about how long-term knowledge influences the processing of morphosyntactic relations, and how this long-term knowledge may be activated by non-linguistic contexts, such as pictures of cultural figures.

In an eye-tracking during reading experiment we examined whether high-level information about well-known cultural figures, such as politicians and actors, is activated via a picture and available during subsequent language processing. Namely, we explored to what extent knowledge of a cultural figure's lifetime influences the processing of a given year, and whether high-level knowledge of their professional accom-

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plishments is activated by a picture and available during sentence processing. We explored to what extent these two types of information, temporal ('year') and factual ('fact'), are activated by a photograph of a given person and subsequently available during processing. Sentences presented information that either matched or mismatched the lifetime of the cultural figure via a year, and matched or mismatched their professional accomplishments, such as appearing in a certain film. One might assume that a speaker's face could be a strong cue to factual information associated with that speaker (e.g., what films an actress has starred in and whether she has won awards or not). Further, given the subtlety of tense effects observed in eye-tracking experiments (e.g., Knoeferle, Crocker, Scheepers, & Pickering, 2005, Exp 1; Altmann & Kamide, 2007, 2009), it may be that associations between seeing a speaker and facts about that speaker would be more influential in comprehension than associations that implicate time and perhaps lifetime status, following previous findings of referential processing preferences in clipart scenes (Knoeferle & Crocker, 2007). Alternatively, factual knowledge (e.g., the books an author wrote, the films an actor starred in) is more probabilistic in its association with language than the arguably more binary life status information associated with a speaker's face. When seeing Emma Watson, one may start to think of multiple associations, among them Harry Potter, and wands, but also of "The Beauty and the Beast", and "The Perks of Being a Wallflower". Given the many facts an individual may know about a certain cultural figure, each specific fact may be less readily accessible and thus less influential during processing. For life status, by contrast, the associated information is likely binary (alive or not in a given year). If the uniqueness of a cue matters, then accessing information based on a face cue should be easier for binary cues like dead versus alive than facts that are part of a larger category of information (e.g., all the films someone has starred in). Evidence of rapid effects of prior long-term knowledge from previous studies (e.g., Hagoort et al., 2004) suggest that, in the presence of long-term knowledge about the cultural figures, violations of such prior knowledge should elicit processing costs. The present study therefore extends the previous findings of rapid effects for violations of high-level world knowledge (e.g., Hagoort et al., 2004) to violations of prior knowledge about a given well-known figure (activated by their picture) and temporal lifetime and factual accomplishment information.

Experiment

We investigated the influence of high-level long-term knowledge about well-known individuals in an an eye-tracking during reading study, and directly contrasted the influence of temporal knowledge of the cultural figure (when they were born or died) and biographical knowledge (e.g., whether they were elected the Prime Minister of the United Kingdom or the President of Russia). Pictures of cultural figures were presented to participants (photographs for modern cultural figures, paintings or drawings for more historical cultural figures), followed by a first-person quotation describing an accomplishment of this person and the year that it occured. We manipulated whether or not the accomplishment (hereafter "fact") was true for the given cultural figure, and whether or not the year was true or fell beyond the bounds of the cultural figure's lifetime (before a living cultural figure was born, or after a dead cultural figure had died). The study thereby has implications for the study of how and which types of high-level information stored in long-term memory influences language comprehension.

Methods and Design

Participants The number of participants (n = 64) was based on power analysis (`powerSim` and `powerCurve` functions in `simr` package) from pilot data (n = 8) filtered to include only trials which received correct world-knowledge prompt responses (i.e., 'filtered' trials, see below). Participants were right-handed 18-31 year olds, native German speakers who grew up monolingual until at least the age of 6, with no reading or learning impairments (e.g., dyslexia). They were paid 22 Euro for their time.

Stimuli Experimental items (n = 40) contained two two-level factors: *year congruence* (match, mismatch) and *fact congruence* (match, mismatch). Each item consisted of 4 cultural figures of the same occupation, two dead and two living. Each cultural figure contributed four stimuli, one for each experimental condition (see Table 1 for example stimuli for a single cultural figure). Both the fact and year were manipulated to either be true, or false. False years additionally did not fall within the lifetime of the cultural figure by either being before a living cultural figure was born, or after a dead cultural figure had died. The mismatching years and facts were rotated throughout the other cultural figures from the same item, where the mismatching *year* came from a cultural figure with a different life status (living vs. dead), and the mismatching *fact* region came from a cultural figure with the same life status. The *year* and *fact* region manipulations result in four conditions: *full match* (no mismatches), *year mismatch* (year mismatches the life of the cultural figure, and also the year of the 'fact' region), *fact mismatch* (the fact is not related to the cultural figure, but matches the year), and *double mismatch* (the year and fact each mismatch the cultural figure, and there is a mismatch between the year and fact). Each item contributed two stimuli of the same condition to each experimental list, resulting in 80 critical trials per participant. Filler items (n = 120) consisted of pictures of cultural figures and sentences describing them in a mixture of first-person quotations, and sentences in the third person.

Procedure

The participant rested their chin in a desk-mounted head mount, and placed their index fingers on the 'Yes' and 'No' buttons on a Cedrus box, and their left thumb on a green button. The placement of the 'Yes' and 'No' buttons (left/right) was counterbalanced. Eye movements were monitored using

Table 1: Example stimuli for a given cultural figure. Each item (n = 40) contains 4 cultural figures of the same occupation, two living and two dead. Mismatching years were swapped between dead and living referents, and mismaching facts swapped between two cultural figures of the same lifetime so that fact mismatches matched referent lifetime (top: region name, middle: German sentence, bottom: English gloss and translation)

pre-year	**year**	year+1	year+2	**fact**	fact+1	fact+2	**name**	final
Im Jahr	**2001 / 1939**	*habe ich*	*in dem Film*	**Harry Potter / *A Beautiful Mind**	*gespielt,*	*behauptete*	**Emma Watson**	*in einem Interview*
in the year	**1939 / *2001**	*have I*	*in the film*	**Harry Potter / *A Beautiful Mind**	*starred,*	*said*	**Emma Watson**	*in an interview*
'In the year **2001/*1939**, I starred in the film **Harry Potter/*A Beautiful Mind**, said **Emma Watson** in an interview.'								

an EyeLink 1000 (SR Research). Button presses and reaction times were also recorded.

Trials began with a drift check in the center of the screen. The participant was then presented with a picture of a cultural figure, and indicated whether they were familiar with the cultural figure by pressing 'yes' or 'no' on the Cedrus box. A fixation box appeared where aligned with the first word of the upcoming sentence. The experimenter manually accepted the fixation. Participants were then presented with a sentence that, in critical trials, contained a fictious direct quote attributed to the cultural figure previously pictured. Fillers contained a mixture of sentences in the third and first person. Participants pressed the 'green' button when they had fully read and understood the sentence. They were then presented with an attention task, which contained a sentence which repeated information from the preceding sentence correctly or incorrectly. These comprehension statements contained either a year-mismatch, fact-mismatch, or both double-mismatch, or no mismatch. Participants were instructed to answer based on what they had just read, not based on what they believed to be true in the real world.

Following experimental trials, participants continued to a post-experimental task in which they indicated again whether they are familiar with the cultural figures from the critical items (presented the same picture: yes/no), whether the cultural figure is currently dead or alive (yes/no), whether they were alive or not in the year from the critical sentence (presented the year: yes/no), whether they are known for the 'fact' from the critical sentence (presented the fact: yes/no), and whether their name is who they believed the picture to be (presented the name: yes/no). The responses to the picture, the year, and the fact were used to exclude the correspond in-experiment trial for those that received incorrect/unrecognised responses.

Hypotheses

Hypotheses pertain to effects of *year congruence*, *fact congruence*, their interaction, and the effect of long-term knowledge presence.

Year congruence effects If tense is rapidly related to knowledge about lifetime status (conveyed by the speaker photo prior to the sentence), then we should observe longer first pass reading time at the *year* region (see Table 1) when it mismatches the lifetime of the cultural figure (i.e., it is after their death (for dead cultual figures) or before their birth (for living cultural figures)). This effect should emerge in early measures (i.e., first pass reading time).

Fact congruence effects If factual (world) knowledge about a speaker is immediately exploited, then we should observe fact mismatch effects at the *fact* region (Table 1: *Harry Potter/A Beautiful Mind*) and in early measures (e.g., first pass reading time). Reading times should be longer for fact mismatches than matches.

Comparing fact and year congruence effects If a referential processing priority (Knoeferle & Crocker, 2007) during language comprehension extends to facts, then factual (in)congruence (e.g., between a speaker photo and facts about that speaker) should be more sizeable than *year congruence* effects (larger difference reflecting more extensive difficulty/processing).

Alternatively, if the variability in possible 'facts' affects the immediacy at which a mismatch is detected compared to the binary nature of being alive or dead in a given year, then we should see stronger effects of *year congruence* compared to *fact congruence*.

Effect of prior knowledge If the presence of prior knowledge of a cultural figure and their lifetime and professional milestones (i.e., "facts") influences the processing of sentences about them, then the effects described above should be present in the trials which received correct world-knowledge prompt responses (and potentially not in the unfiltered data, depending on how many additional trials are included which may wash out the effect). Alternatively, if the effects also emerge in the unfiltered data, then we would expect the effects to be stronger in the filtered data.

Data analysis

Eye-tracking measures Three eye-tracking reading measures were analysed: **first-pass reading time** (sum of fixations within a region before exiting the region), **regression path duration** (sum first-pass reading time plus duration of revisits to earlier regions, before exiting to the right), and **total reading time** (sum of all fixations in a region). First-pass reading time and regression path duration are often referred to as 'early' measures, with longer reading times in these measures taken to reflect disruptions in early processing. Total reading time is considered a 'late' measure reflecting late pro-

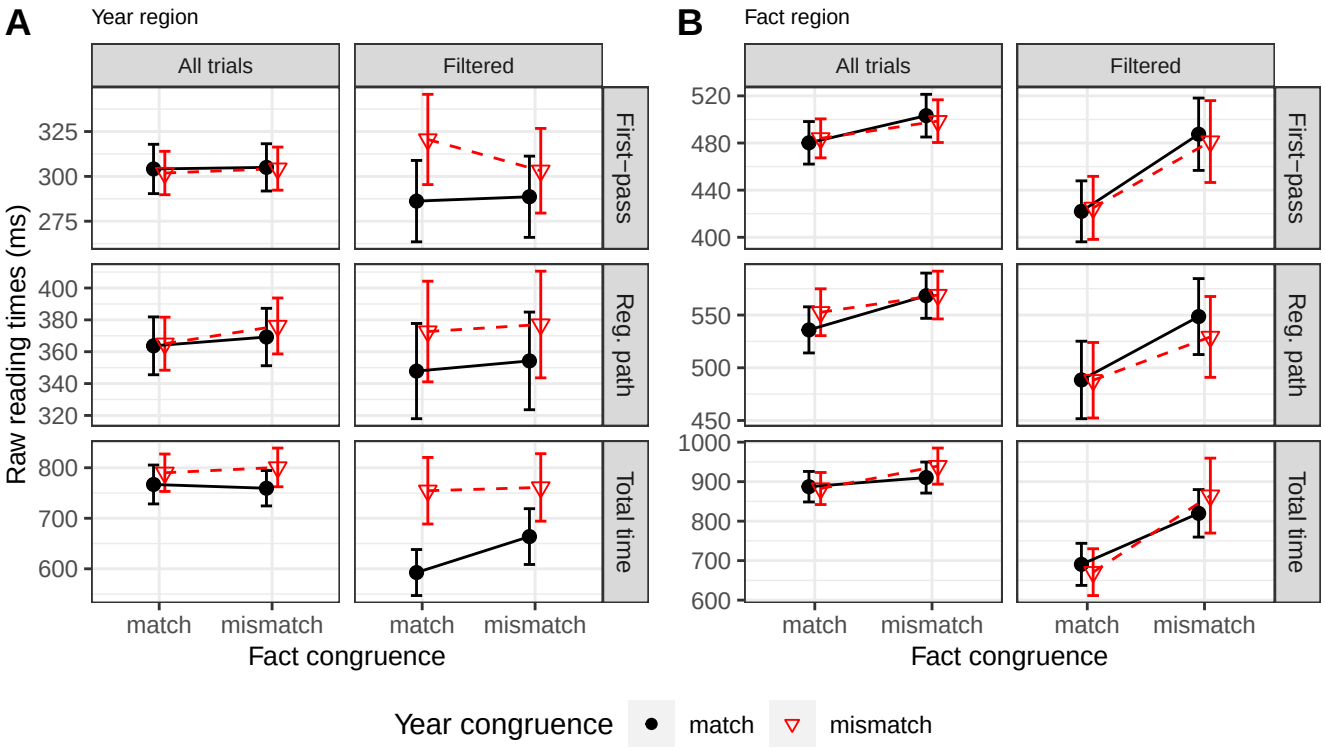

Figure 1: Raw reading times (milliseconds; with 95% confidence intervals) for the 'year' and 'fact' regions for first-pass reading time (top row), regression-path duration (middle row), and total reading times (bottom row) for all trials (left column) and trials with correct world-knowledge responses (right column).

cessing, although it may also include cumulative processing (Vasishth, von der Malsburg, & Engelmann, 2013).

Data cleaning Fixations shorter than 80ms and fixations longer than 800ms were removed prior to analyses. Participants whose average comprehension question response was below 75% were removed prior to analysis (n = 0). Following a BoxCox test (Box & Cox, 1964) `MASS` package), reading times were log transformed.

Models Reading times were fitted to linear mixed effects models with the factors **year congruence** and **fact congruence** and their interaction as fixed effects. Sum coding was used, with the level *match* coded as -0.5 and *mismatch* as +0.5. Model selection was carried out prior to inspection of fixed-effect estimates, and began with the maximal random effect structure justified by the design: by-item and -participant random intercepts with the fixed effects and their interaction as random slopes. Random effects principal component analyses were run (`lme4::rePCA()`) and variance-covariance matrices examined in order to determine whether/how to reduce the random effects structure (`lme4::VarCorr()`) until the model converged was not overfit [as indicated by `rePCA()`; Bates, Kliegl, Vasishth, & Baayen (2015)]. Only once the most parsimonious (and final) model was selected were the fixed-effect estimates inspected (`summary()` function).

A priori analyses were planned to be run on all three reading measures (**first-pass reading time**, **regression path duration**, total reading time) at four regions: *year*, *fact*, *fact+1*, and *name* (see Table 1). The *fact+1* region was included as this region contains a clause end and so maybe contain wrap-up effects. The *name* region was included as this is region may trigger additional world-knowledge information, both in trials in which the participant recognised the picture and in trials when they did not (e.g., more participants might know the name *Humphrey Bogart* than would recognise his picture). Planned analyses were run on all trials (hereafter 'unfiltered' data), and on data filtered to exclude trials that received any response indicated absent or incorrect long-term knowledge (i.e., 'no' trial-initial recognition response, incorrect post-experimental speaker-year and/or -fact congruence response; hereafter 'filtered' data).

Results

All reported *p*-values were generated in R using `lmerTest::lmer()` and have been Bonferroni corrected to reduce Type I error (*p*-values multiplied by 12: 3 measures x 4 regions) (von der Malsburg & Angele, 2017).

Response measures No participants scored below the attention check threshold (75% accuracy in post-trial comprehension statement response), and so no participants were excluded from analyses. Critical trials that received an incorrect comprehension task response (5%) were removed prior to analyses. Of the remaining trials, 57% received a 'no' recognition response, 23% received an incorrect response to the

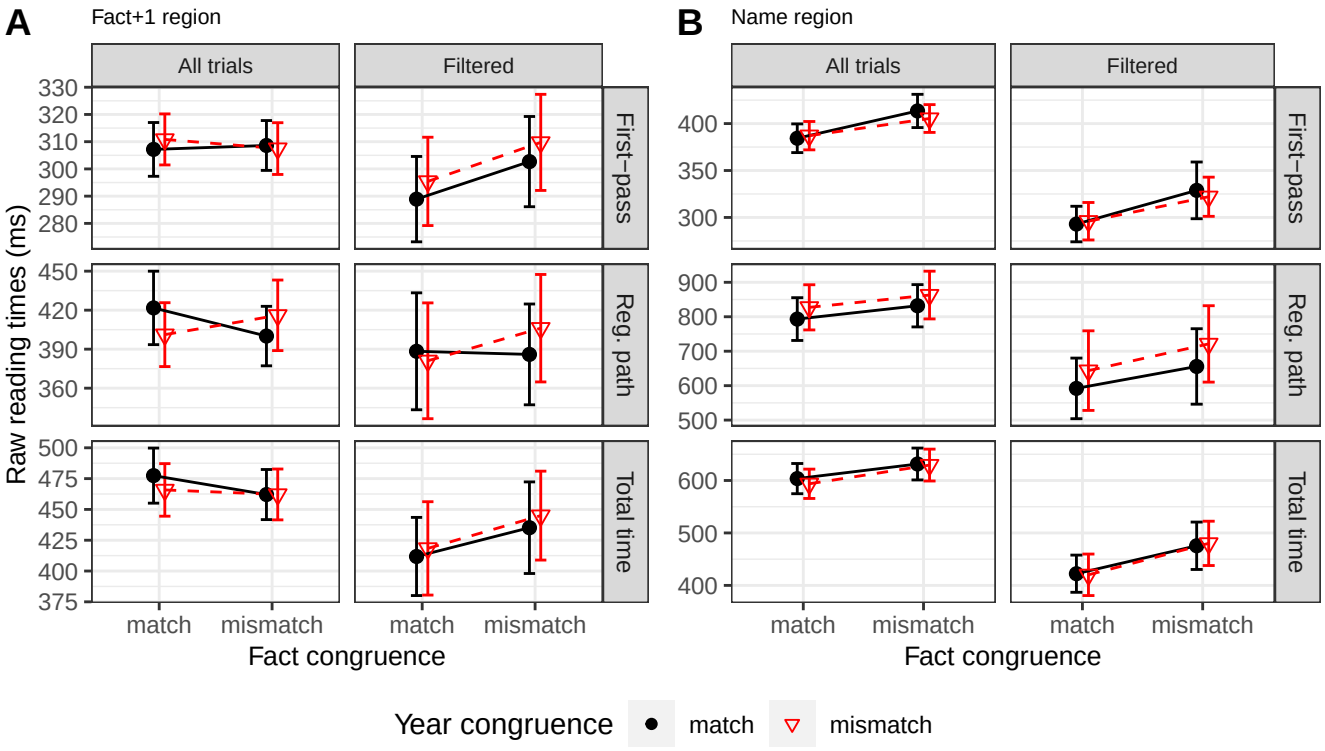

Figure 2: Raw reading times (milliseconds; with 95% confidence intervals) 'fact+1' and 'same' regions for first-pass reading time (top row), regression-path duration (middle row), and total reading times (bottom row) for all trials (left column) and trials with correct world-knowledge responses (right column).

post-experimental speaker-year prompt, and 36% received an incorrect speaker-fact response. Overall, 31% trials met the inclusion criteria for the 'filtered' analyses, as they received a 'yes' recognition response and correct post-experimental year- and fact-responses. This results in 1487 trials for filtered analyses, and 4871 trials for unfiltered analyses.

Reading time measures

Year congruence effects When all trials were included in analyses (i.e., unfiltered data), a main effect of **year congruence** emerged at the *year* region (Figure 1A) in **total reading times**, but did not maintain significance after Bonferroni correction ($t = 2.86$).

When trials were filtered to exclude incorrect world-knowledge prompt responses, a main effect of **year congruence** emerged at the *year* region in all three reading measures (Figure 1A). After Bonferroni corrections, only the effect in **total reading times** maintained significance ($t = 3.73$, $p < .05$; **first-pass**: $t = 2.61$; **regression path duration**: $t = 2.57$).

Fact congruence effects When all trials were included in analyses (unfiltered data), a main effect of **fact congruence** emerged at the *name* region (Figure 2B) in **first-pass reading time** ($t = 3.5$, $p < .05$), and **total reading times** ($t = 3.33$, $p < .05$). At the *fact* region, effects emerged in all three measures but did not maintain significance after Bonferroni corrections (**first-pass**: $t = 2.27$; **regression path**: $t = 2.68$; **total reading time**: $t = 2.31$).

A main effect of **fact congruence** emerged in **regression path durating** and **total reading time** at the *fact* region (**regression path**: $t = 2.89$, $p < .05$); **total reading time**: $t = 4.21$, $p < .01$; Figure 1B) and *name* region (**regression path**: $t = 3.04$, $p < .05$; ; **total reading time**: $t = 3.44$, $p < .01$; Figure 2B). Effects of *fact congruence* also emerged at these regions in **first-pass reading time** (*fact region*: $t = 2.83$; *name region*: $t = 2.14$), and **total reading times** (*fact region*: $t = 4.21$; *name region*: $t = 3.44$), but were no longer statistically significant after Bonferroni correction.

Main effects of *fact congruence* were found at the *fact+1* region in filtered data, but did not did not maintain significance after Bonferroni corrections (**first-pass reading time**: $t = 2.49$, **total reading times**: $t = 2.23$).

No interaction effects of the two fixed effects were observed.

Discussion

We presented participants with pictures of well-known cultural figures, followed by sentences in which the cultural figure describes an accomplishment ("fact") of theirs, as well as the year it happened. We manipulated whether the fact and year were true for the cultural figure or not. We expected to find early effects (first-pass duration and/or regression path duration) of *year* and *fact* congruence at the respective regions reflecting the influence of long-term knowledge prompted by the trial-initial picture, and later/cumulative ef-

fects (total reading times) at these regions reflecting the influence of the later *name* region. Differences in the temporal emergence (i.e., 'early' versus 'late' measures) and size of *year congruence* and *fact congruence* effects were also of interest, with implications for processing preferences for temporal (*year*) versus *fact* processes. Lastly, effects were expected to be present in the data filtered for accurate long-term knowledge, and to be absent or smaller in the unfiltered data, reflecting the effect of long-term knowledge present in the filtered data.

When trials with incorrect world-knowledge prompt responses were excluded from analyses ('filtered' trials), effects of **year** and **fact congruence** emerged in their respective regions in all three measures. However, after correcting for multiple comparisons, not all measures maintained statistical significance: After Bonferroni corrections, main effects of both **year** and **fact congruence** maintained statisical significance in **total reading times** at their relative regions in filtered analyses, as well as an effect of **fact congruence** in **first-pass reading time** at the *fact* region. This suggests each type of information was rapidly available after presentation of a picture of a well-known speaker (first-pass reading time), but effects of **fact congruence** were more robust, and that violations were not quickly resolved (total reading time). However, effects of **fact congruence** at the *name* region were present in unfiltered data, with no effects of **year congruence**. This suggests asymmetries in the processing of the two types of information when prior world knowledge is more variable. The observed effect differences could be attributed to a preference for attending to factual relations (*fact* region), compared to temporal relations (*year* region) when encountering contrasting information, such as long-term information activated by the *name* region in unfiltered trials. While a given year requires some temporal relations be computed for a cultural figure's lifetime, preferential attention may have been given to *fact-name* relations at name presentation when the picture was not recognised, leading to the *fact congruence* effects at the *name* region (e.g., *2018...the song **I Shot the Sheriff**...John Lennon*).

This leads to the last research question, in which we were interested in investigating the role of long-term knowledge in the processing of temporal and factual relations to a given cultural figure **when prompted by their face**. Troyer & Kutas (2018) reported individual-level differences in the processing of sentences about the Wizarding World of Harry Potter, finding graded N400 effects positively correlated with a participant's score on a Harry Potter familiarity questionnaire. Given these findings, we expected to find differences in effects when trials were filtered to exclude those that received incorrect world-knowledge prompt responses (i.e., trial-initial picture recognition, post-experimental speaker-year and -fact congruence responses). Indeed, we observed differences between the unfiltered and filtered data, suggesting that the presence of long-term knowledge when prompted prior to sentence presentation by a picture did play a role in processing. Where effects were present in both filtered and unfiltered trials at the *year* and *fact* regions, effects were larger in the filtered data. As the filtered data consisted of fewer observations than the unfiltered data, the emergence of stronger effects in the former indicates a more robust effect compared to the larger unfiltered dataset which had smaller effects. This could indicate that the filtered data points were driving the effect in the unfiltered data, in which they were also included. Only in the *name* region were effects present in the unfiltered data but not the filtered data, but only for *fact congruence*. This could be attributed to the new information provided by the name when the speaker was not recognised by their picture. In the presence of more variable knowledge of a given cultural figure, it seems knowledge of their accomplishments is more reliable than knowledge of when they were born or died.

Given the high number of trials in which relevant prior knowledge was not present, a follow-up experiment is currently underway in which we precede the experiment with biographical training and testing sessions. This follows Suess et al. (2013), in which no differences were found in perceived facial expression (positive or negative) between faces of prior-known and newly-learned individuals following training sessions presenting factual or fictitious biographies, respectively. In our follow-up study, the training session is designed to (i) increase the number of trials for 'filtered' analyses, and (ii) provide further opportunity to compare trials with prior long-term knowledge to those with newly-learned information.

In conclusion, the findings from the presented study suggest that prior high-level knowledge about well-known individuals is activated by their picture and available during comprehension. This was true for both years which did not fall within the bounds of the speaker's lifetime (e.g., *Angela Merkel - 1930*), and for 'facts' that were not true (e.g., *Angela Merkel - China*). These effects were stronger at their relative critical regions (*year* and *fact*) when data were filtered to exclude trials containing false world-knowledge responses, indicating an effect of trial-specific long-term knowledge, mirroring individual-level graded effects in Troyer & Kutas (2018). Conversely, effects of *fact congruence* at the *name* region were more robust for unfiltered data (versus filtered) at the *name* region, indicating that the additional speaker information provided by the name may have been more beneficial in trials in which participants had partial long-term knowledge of the speaker, or did not recognise their picture. The absence of *year congruence* effects at the *name* region, but presence of *fact congruence* effects in the unfiltered data at the same region, suggest *fact-name* processes may outweigh temporal relations (*year-name*) relations when long-term knowledge is more variable. These findings suggest these types of relations are rapidly available during language processing, but differ in their processing in the presence of variable prior knowledge.

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