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Prior and new knowledge in language comprehension: Referent lifetime status versus biographical accomplishments

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ABSTRACT

Knowledge about the real-world, fictional worlds, and well-known individuals is rapidly available during language processing, eliciting rapid processing costs when contradicted. Less is known about how effects of knowing famous personalities' lifetime status (dead or alive in a year) compare to effects of knowing their factual accomplishments (e.g., having starred in a movie) during language comprehension. Likewise, rapid processing costs ensue when short-term knowledge acquired through one-shot learning is contradicted. We ask whether such effects vary depending on whether knowledge of a famous referent is prior-held, recently learned, or absent. In two eye-tracking during reading experiments we investigated how world knowledge conveyed via photographs of well-known referents influences the processing of temporal (lifetime-year) and (referent-specific) factual knowledge (mis)matches. We distinguished whether people had the world knowledge, were trained on it and learned it new, or did not have it. In both experiments, congruence effects emerged in world-knowledge-present trials. In Experiment 1 (64 participants), lifetime-year and referent-fact congruence effects were elicited across measures, with nested congruence effects in total reading times in world-knowledge present, but not absent, trials. In Experiment 2 (32 participants), lifetime-year (but not referent-fact) congruence effects emerged with no significant differences between prior and newly-learned knowledge trials. These findings confirm that prior-held factual knowledge is rapidly available during processing. In addition, they provide novel evidence that both prior-held and newly-learned temporal (lifetime) knowledge influences comprehension, with implications for models of memory integration and the contribution of prior knowledge in language comprehension.

1. Introduction

A large psycholinguistic literature has revealed that all sorts of long-term world knowledge – such as the colour of New York City taxis among others – can elicit rapid processing cost. In their seminal study, Hagoort et al. (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 similar in latency and distribution to semantic violations, but with a reduced amplitude (e.g., *Dutch trains are* ***yellow/white/sour***[2]; Dutch trains are in fact yellow). Since this study, similar findings have been found for other types of lexico-semantic world knowledge violations in counter-factual conditions (Nieuwland & Martin, 2012), violations of traits of familiar cartoon characters (Filik, 2008; Rapp, 2008), even knowledge specific to the wizarding world of Harry Potter (Troyer & Kutas, 2018, 2020). Recent work has also demonstrated that new knowledge can be rapidly acquired and updated by adult comprehenders, even with minimal exposure to new information (Borovsky et al., 2010) or strong contextual constraint (Nieuwland & van Berkum, 2006). In this paper we extend this literature about knowledge types and explore how bibliographic knowledge affects sentence processing. We take bibliographic knowledge to be part of world knowledge; it includes both factually-related knowledge about individuals, such as important events they are associated with, and knowledge about an individual's lifetime (e.g., are they alive or dead?). Temporal knowledge about the lifetime of an individual has recently been found to affect the processing of tense and aspectual morphosyntax, especially for the English present perfect

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[2] Bold font added for emphasis and not present for presentation of the stimuli.

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which requires an individual to be alive at speech time (Palleschi et al., 2025). As a further extension, we assess to what extent minimal exposure to factual and temporal knowledge, too, can influence adult language processing during reading.

Though a variety of types and sources of long-term knowledge have been found to influence comprehension, much of this research has focused on knowledge conveyed via text. However, other non-linguistic sources, such as visual images, can also convey long-term world knowledge. We explore how this long-term knowledge may be activated by non-linguistic contexts, such as pictures of cultural figures, to influence ensuing language comprehension. The current study presents two eye-tracking during reading studies investigating how photos conveying temporal and factual knowledge relevant to well-known cultural figures can influence processing as a function of whether the relevant knowledge was available in prior-knowledge, newly learned via a training session, or absent altogether. The next section gives an overview of extant literature on prior knowledge effects, followed by a discussion of previous studies that contrasted prior knowledge with absent and recently-learned knowledge.

1.1. Real-world knowledge integration during comprehension

Our specific, knowledge of the real world is rapidly available during communication, from which city the Eiffel Tower is in to the colours of our local trains. Violations of this type knowledge elicit rapid processing costs, with longer eye fixations or larger N400 effects elicited by input incongruent with our prior-held knowledge (e.g., *Paris/*Rome is the capital of France*; Hagoort et al., 2004; Hald et al., 2007; Metzner et al., 2015; Nieuwland & Martin, 2012). Such effects have also been found when incongruent words appear in low-constraint contexts (e.g., *The Beatles were popstars/lawyers/horses in the 60's*; Martin et al., 2014). High-level prior knowledge of a referent is thereby activated when the referent is named sentence-initially. Our expectations can also be reversed by sentential contexts, as in counter-factual statements (Nieuwland & Martin, 2012), or even by preceding discourse contexts foregrounding lesser-known information about a well-known referent (Hald et al., 2007).

In addition, discourse contexts are able to reverse expectations based on high-level knowledge of the world, such as the city of Venice famously having many canals rather than roundabouts. In Hald et al. (2007), discourse contexts described some well-known referent (e.g., the city of Venice) that either corresponded to typical real-world knowledge of the referent (*Venice-gondola tours*) or foregrounded alternative information (*Venice-traffic*). These contexts were followed by a sentence with a critical word that was either congruent or incongruent with real-world knowledge and/or the preceding discourse context (e.g., *The city of Venice has very many canals/roundabouts and beautiful buildings)*. Both world-knowledge congruent (*canals*) and incongruent (*roundabouts*) words elicited an increased N400 amplitude in unsupported (*traffic-canals*, *gondola tours - roundabouts*) versus supported (*gondola tours-canals*, *traffic-roundabouts*) contexts. These findings provide evidence that high-level knowledge of the real world interacts with discourse contexts during language processing, similar to general real-world knowledge, for example that peanuts are inanimate (Nieuwland & van Berkum, 2006) or that vegetarians don't eat cheeseburgers (Cook & O'Brien, 2014).

The influence of long-term knowledge on language processing is not limited to our knowledge of the real world, however. Similar effects have been found when prior knowledge about well-known fictional characters, worlds, or events is violated, such as well-known cartoon characters (Filik, 2008; Filik & Leuthold, 2013; Foy & Gerrig, 2014; Warren et al., 2008) or the wizarding world of Harry Potter (Troyer & Kutas, 2018, 2020; Troyer et al., 2022, 2020). Troyer and Kutas (2018) compared semantic violations of a fictional world (the wizarding world of Harry Potter) with those of the real-world, reporting similar N400 effects in both types of prior knowledge. Furthermore, N400 effects were graded by participants' Harry Potter expertise, with Harry Potter violations eliciting larger N400 effects in participants highly familiar with the wizarding world of Harry Potter. Participants who scored very low in their Harry Potter familiarity showed no N400 effects in the Harry Potter violations, with no differences between participants in real-world semantic violations as a function of their Harry Potter familiarity. This effect was replicated and extended to real-world and Harry Potter texts in Troyer and Kutas (2020). Importantly, individual differences in N400 effects emerged again as a function of Harry Potter familiarity for the Harry Potter-related sentences but not for real-world sentences. Together these findings indicate that domain-specific familiarity relevant to the incoming linguistic signal is utilised during comprehension.

However, our individual knowledge does not only vary in terms of factual knowledge of the world that is commonly shared in a community or culture. We each have our own individual preferences, ethical beliefs, and personal semantics (knowledge about one's own personal preferences). Each of these seems to be able to modulate expectations during comprehension in a similar manner to long-term world knowledge, eliciting longer reading times (Rapp & Gerrig, 2006) and N400 effects (Coronel & Federmeier, 2016; van Berkum et al., 2009). In van Berkum et al. (2009) participants were presented statements that were either congruent or incongruent with their personal moral beliefs about divisive topics (e.g., *I think the increasing emancipation of women is a <u>negative/positive</u> development.*). Likewise, Coronel and Federmeier (2016) presented participants with sentences that either matched or mismatched statements describing their own personal preferences (e.g., *A genre of film you like watching is <u>horror/fantasy</u>.*). In both experiments, increased N400 amplitudes were elicited by critical words that violated the participant's personal beliefs (van Berkum et al., 2009) or personal semantics (Coronel & Federmeier, 2016).

Other studies have demonstrated that world knowledge from non-linguistic sources can also influence the processing of lexico-semantic input. Faces of familiar individuals can activate long-term semantic knowledge about the individual, whether they be real-world cultural figures (Abdel Rahman et al., 2002; Suess et al., 2013) or well-known cartoon characters (Abdel Rahman et al., 2004). Our assumptions about the social identity of an unfamiliar speaker, based on facial or voice characteristics, can play a role during comprehension. For example, in Van Berkum et al. (2008) an N400 effect was elicited when participants heard statements that violated stereotypes of the speaker based on their voice (e.g., a child vs. adult voice: *Every evening I drink some* ***wine*** *before I go to sleep*). Additionally, inferences about speaker nativeness, based on physical features of unknown faces and accompanying native or non-native accented speech, can influence on-line processing of linguistic input, as well as well-formedness judgements (Xu et al., 2019). The rapid effects elicited by visual or auditory (social) attributes of a referent or speaker 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 prior, long-term knowledge of a known individual, or stereotypes based on demographic assumptions, like age.

Prior (world) knowledge seems then to guide expectations and to be rapidly available during comprehension, with inter- and intra-individual knowledge playing a role. A variety of sources of information, from narrative contexts (e.g., Nieuwland & van Berkum, 2006) to long-term knowledge of fictional worlds (Filik & Leuthold, 2013; Troyer & Kutas, 2018, 2020; Troyer et al., 2020) or the real-world (Hagoort et al., 2004; Hald et al., 2007; Martin et al., 2014; Metzner et al., 2015), have been shown to be rapidly available during comprehension. Violations of this knowledge elicit early effects in the electroencephalogram (EEG: so-called 'N400' component) and eye-tracking during reading (first-fixation, first-pass reading time). Processing costs are positively correlated with participants' domain-specific knowledge (Troyer & Kutas, 2018) and the presence of sentence-specific knowledge (Martin et al., 2014; Troyer et al., 2020). Contradictions of participants' own personal morals and preferences elicit similar effects (Coronel & Federmeier, 2016; van Berkum et al., 2009), suggesting that it is not only our shared knowledge of the world that influences language processing, but what the comprehender holds to be true.

1.2. In the absence of prior knowledge

How we define *knowledge* of real-world events is not trivial, as there is likely both inter- and intra-individual variation when it comes to common knowledge. Though most individuals would say they *know* the Earth is round and that Elvis Presley is dead, there are some who would say they *know* the Earth is flat and that Elvis Presley is alive. To explore trial-level effects of prior Harry Potter knowledge, Troyer et al. (2020) presented 'correct' Harry Potter related sentences (i.e., there were no violation conditions) and collected post-trial participant responses indicating familiarity with the information presented (familiar or unfamiliar). When trials were grouped by response, '*unfamiliar*' trials (i.e., information the participant did not already know) elicited increased N400 amplitudes compared to '*familiar*' trials (i.e.,information the participant already knew). Furthermore, N400 effects in '*unfamiliar*' trials were marginally stronger in participants with a low Harry Potter-familiarity score than those with a high score. The authors took this as evidence that "greater knowledge eases otherwise difficult retrieval processes" (Troyer & Kutas, 2020, p. 476).

Likewise, Martin et al. (2014) presented participants with sentences describing real-world facts (e.g., *The Beatles were popstars/lawyers/horses in the 60's*), with world knowledge violations (*lawyers*) and semantic violations (*horses*) eliciting larger N400 amplitudes than correct words (*popstars*). Similar to Troyer et al. (2020), truth ratings of the items were collected in a surprise post-experimental task where participants indicated whether they believed each sentence was (a) true, (b) false, (c) that they didn't know, or (d) that they couldn't tell because the sentence was nonsensical, with an overall accuracy of 85.6%. The authors used this information to compare P2 and N400 time-windows between trials containing semantic violations, trials that received a '*don't know*' response, and trials that presented correct sentences and received a '*true*' response. In the P2 window, '*don't know*' trials patterned with semantic violations, eliciting a decreased positivity compared to '*true*' trials. In the N400 time-window, semantic violations elicited an increased negativity compared to '*true*' trials, but '*don't know*' trials did not differ from either of the other trial types. This seems to suggest that the P2 was sensitive to semantic violations and the inability to check plausibility when participants did not have relevant prior knowledge. The N400 was sensitive to semantic and world-knowledge violations, but not the inability to check plausibility. Importantly, these results show processing differences between trials where participants '*don't know*' if a sentence is true or even plausible and trials where sentences are known to be true, as indicated by differences in the P2 time-window.

Sometimes even if one does not know a fact, further contextual information may permit acquiring the new fact even short-notice; to the extent that this happens, such newly-learned facts may then be available for real-time language comprehension, too: To what extent do learning effects emerge in on-line sentence processing? Borovsky et al. (2010) reported semantic congruence N400 effects for pseudo-words newly learned in preceding high-constraint (but not low-constraint) conditions, eliciting similar effects to prior known real-words. Importantly, these effects were elicited at a verb which itself was congruent or not with the pseudo-/real-word. These findings demonstrated that verb-argument constraints were rapidly available after one-shot novel word learning, but only when the meaning of the novel word was learned in highly-constrained contexts. Recently learned referent- or speaker-specific information has also been shown to be available during processing. Building on Van Berkum et al. (2008), in which inferences made about speaker-identity based on their voice modulated expectations (a child vs. adult voice: *Every evening I drink some **wine** before I go to sleep*), Borovsky and Creel (2014) investigated how adults and children integrate prior speaker-specific knowledge during speech comprehension. In both children and adults, prior-learned speaker identity elicited inferences regarding an upcoming target noun (e.g., a pirate or a princess saying *I want to hold the…*), reflected in more anticipatory fixations towards a visually depicted target object than a competitor (e.g., a sword or a wand) in the Visual World Paradigm. These findings provide evidence for contextual constraints established through people-as-context (Brown-Schmidt et al., 2015), as well as the influence of newly-learned referent- or speaker-specific information on language processing.

It seems then that prior knowledge of both the real-world and fictional worlds, as well as historical and fictional events, is rapidly available during processing of lexico-semantic input, and that linguistic contexts can interact with this prior knowledge. There is evidence of a processing-facilitation effect when relevant knowledge is present and congruent with the incoming linguistic signal, compared to when it is incongruent or absent.

Less well-understood is just how accessible different types of world knowledge are during language processing. Prior research has investigated whether strictly semantic knowledge differed from real-world experiential knowledge, but found similar effects in terms of time course (Hagoort et al., 2004). 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, tense effects observed in eye-tracking experiments were relatively subtle (Altmann & Kamide, 2007, 2009, Exp. 3). However, early processing costs have been elicited by lifetime-tense violations in eye-tracking during reading following linguistic lifetime contexts, indicating that referent-lifetime knowledge is readily checked against relevant temporal morphology (Palleschi et al., 2025). 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, Exp. 3). Alternatively, factual knowledge (e.g., the books an author has written, the films an actor has starred in) is more probabilistic in its association with language than the arguably more binary life status information associated with a speaker's face. That is, lifetime status might be viewed as linked to the core semantic knowledge of an individual, whereas career-specific accomplishments might be viewed as linked to event-specific knowledge, with many possible events and accomplishments mapping onto an individual. Under this distinction, lifetime status, coupled with more general semantic knowledge about the categories of *dead* and *living* individuals (i.e., that dead individuals do not act in new films), would support strong expectations, whereas accomplishments would generate weaker expectations. Lifetime-year violations should then elicit larger updating costs than accomplishment violations. For example, 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 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 suggest that, in the presence of long-term knowledge about the cultural figures, violations of such prior knowledge should elicit rapid processing costs. Critically, such studies investigated have elicited differences in mean amplitudes of the N400 event-related potential in EEG studies, whereas (temporal) adverb-verb violations have been shown to elicit differences in mean amplitudes of the P600 component. This distinction suggests distinct cognitive mechanisms for the processing of semantic (factual) violations and temporal violations.

Table 1
Example stimuli for a given cultural figure (German with English gloss). 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 mismatching facts swapped between two cultural figures of the same lifetime so that fact mismatches matched referent lifetime.

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	**2001/ *1939**	have I	in the film	**Harry Potter/ *A Beautiful Mind**	starred,	said	Emma Watson	in an interview

1.3. Current study

The present study extends the previous findings of rapid effects for violations of high-level world knowledge to violations of prior knowledge about a given well-known figure and temporal lifetime and factual accomplishment information (activated by their photograph). It consists of two eye-tracking during reading experiments which were identical, differing only in the presence of a pre-experimental training/testing session. We expected to find longer reading times for regions violating biographical (factual) and lifetime (year) knowledge of the cultural figures. Perhaps with a measurement like eye-tracking reading times, one might see distinct time courses of the effects of the two kinds of examined violations. More detailed hypotheses for each experiment are outlined below. In focusing on this topic, we also aimed to extend insights into the effects of a linguistic context to photographic contexts that can activate knowledge about a person, and to specific kinds of world knowledge, namely knowledge about a person's lifetime and accomplishments.

We addressed three research questions. First, is referent-lifetime knowledge rapidly available during comprehension when activated by a picture of a familiar referent? Second, is prior referent-specific knowledge of accomplishments available during incremental processing? Third, is referent-lifetime knowledge comparatively available when held in long-term, prior knowledge versus when it is newly learned knowledge? The first two research questions are addressed by Experiment 1, with Experiment 2 addressing all three. The design and results of Experiment 1 are presented first, followed by Experiment 2 where deviations from Experiment 1 are highlighted. The studies were conducted under a lab-wide ethics approval granted by the German Linguistics Society ethics review board (DGfS, ethics vote number 2020-10-20080).

2. Experiment 1: prior versus no knowledge

We investigated the influence of high-level long-term knowledge about well-known individuals in two eye-tracking during reading studies. Both experiments 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 the elected President of the United States or France). Each experimental trial began with the presentation of a picture of cultural figure (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 occurred. 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 how and which types of such high-level information stored in long-term memory influence language comprehension.

2.1. Methods and design

Participants The number of participants for Experiment 1 (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). Participants were paid 22 Euro for Experiment 1 for two hours of 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 sentence types: those with (i) no mismatches, (ii) a year mismatch (year mismatches the life of the cultural figure, and also the year of the 'fact' region), (iii) a fact mismatch (the fact is not related to the cultural figure, but matches the year), and (iv) both a year and fact mismatch (the year and fact each mismatch the cultural figure, but there is not 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.

2.2. Procedure

Experiment 1 included an eye-tracking reading study followed by a post-experimental task probing for relevant knowledge pertaining to critical manipulations. The presentation of stimuli conditions was counterbalanced across experimental lists and pseudo-randomised to control for order effects. Each phase of the experiment is described below.

Eye-tracking during reading and pre-trial photo familiarity For the eye-tracking during reading experiment, the participant rested their chin on 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 between participants. Eye movements were monitored using an EyeLink 1000 (SR Research). Button presses and reaction times were also recorded.

A 9-point calibration preceded the experiment, with additional recalibrations carried out after breaks (n = 3) or when required. To ensure measurement reliability, each trial began with a drift check in the centre 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 the first word of the upcoming sentence would be presented. The experimenter manually began sentence presentation once the participant was fixated on the fixation box. Participants were then presented with a sentence that, in critical trials, contained a fictitious direct quote attributed to the cultural figure previously pictured. 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, both year- and fact-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.

Post-experimental task The eye-tracking during reading experiment was followed by a post-experimental task probing for knowledge relevant to the critical manipulations in the linguistic stimuli. Participants indicated whether each cultural figure (n = 80) was 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 year and the fact were used as exclusion criteria for the corresponding eye-tracking trial.

2.3. Hypotheses

Hypotheses pertain to effects of YEAR CONGRUENCE, FACT CONGRUENCE, their interaction, and the effect of long-term knowledge presence.

Year congruence effects If the lifetime status conveyed by the speaker photo prior to the sentence 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 times 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), reflecting the rapid availability of prior lifetime knowledge of a referent during the processing of a temporal phrase ('*In the year* [YEAR]'). Effects of year congruence were also expected in total reading times, reflecting late/cumulative processing costs, reflecting a failure to consolidate an incorrect year with prior knowledge about the referent's lifetime, and possibly also the FACT and/or NAME regions which also mismatch the year. In the absence of early effects (e.g., first-pass reading times), total reading times may reflect the integration of prior knowledge related to the name region near sentence-end with the year region, triggering regression into the year region when it mismatches the referent's lifetime.

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/intermediate measures (first pass reading time, regression path duration). We also expected to find effect in total reading time, reflecting failure to quickly consolidate mismatching factual information. In the absence of early effects (e.g., first-pass reading times, regression path duration), total reading times may reflect the integration of prior knowledge related to the NAME region near sentence-end with the fact region, triggering regression into the fact region when it mismatches the referent.

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 larger 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, i.e., the prior-knowledge trials (and potentially not in no-knowledge trials).

2.4. Data analysis

Linear mixed models were fit to eye-tracking during reading measures at the critical YEAR, FACT, and NAME regions with the fixed effects YEAR CONGRUENCE (congruent, incongruent), FACT CONGRUENCE (congruent, incongruent), KNOWLEDGE TYPE (Experiment 1: prior knowledge, no knowledge; Experiment 2: prior knowledge, new knowledge) and their interactions as fixed effects, and centred trial order as co-variate. Factors were sum contrast coded, with CONGRUENT and PRIOR KNOWLEDGE levels coded as −0.5, and INCONGRUENT, NO KNOWLEDGE (Experiment 1) and NEW KNOWLEDGE (Experiment 2) coded as +0.5.

Knowledge-type categorisation Critical manipulations required participants to have the relevant knowledge pertaining to each trial's referent. Without this knowledge, violations could not be detected. For example, '*Rick Mercer starred in 'Strange Brew' in 1983*' cannot be judged as true or false without relevant factual and temporal knowledge about Rick Mercer and the film 'Strange Brew'. Referent-knowledge responses in the pre-trial familiarity probes and post-experimental year- and fact-congruence probes were therefore necessary to infer whether participants had prior referent-specific knowledge relevant to the critical year and fact manipulations in each trial. The three probe responses were therefore used to categorise trials as PRIOR-KNOWLEDGE or NO-KNOWLEDGE trials. To be categorised as a PRIOR-KNOWLEDGE trial all three responses needed to be affirmative/correct: a 'yes' pre-trial familiarity response and correct post-experimental (referent) year- and fact-congruence responses were all required. All trials that received a 'no' pre-trial familiarity response were categorised as NO-KNOWLEDGE trials, regardless of the post-experimental year- and fact-congruence responses. All trials that received a 'yes' familiarity response, but an incorrect post-experimental year- and/or fact-congruence response were removed prior to analyses.

Eye-tracking measures Three eye-tracking reading measures were analysed: **first-pass reading time** (sum of fixations within a region after first entering it and before exiting it), **regression path duration** (summed first-pass reading time plus duration of re-visits to earlier regions, before exiting to the right), and **total reading time** (sum of the duration of all fixations in a region). First-pass reading time and regression path duration are often referred to as early and intermediate measures respectively (e.g., Conklin et al., 2018), with longer reading times in these measures taken to reflect disruptions in early processing (Rayner, 1998). Total reading time is considered a 'late' measure reflecting late processing (Rayner, 1998), although it may also include cumulative processing costs (Vasishth et al., 2013). Data was pre-processed in Data Viewer (SR Research Ltd). Fixations shorter than 80 s or longer than 800 ms were merged with sequential fixations (<80 ms) or removed (>800 ms) in pre-processing. Participants whose average comprehension question response was below 75% were removed prior to analysis. Following a BoxCox test (Box & Cox, 1964; MASS package), reading times were log-transformed.

Linear mixed effects models were fit to log-transformed eye-tracking reading times with the factors YEAR CONGRUENCE (MATCH, MISMATCH), FACT CONGRUENCE (MATCH, MISMATCH), KNOWLEDGE TYPE (PRIOR-KNOWLEDGE, NO-KNOWLEDGE), and their interaction as fixed effects with centred trial order as a covariate. Factors were sum contrast coded (+/−0.5), with the levels MATCH and PRIOR-KNOWLEDGE coded as −0.5 and MISMATCH and NO-KNOWLEDGE as +0.5. Model selection was carried out prior to inspection of fixed-effect estimates, and began with the maximal random

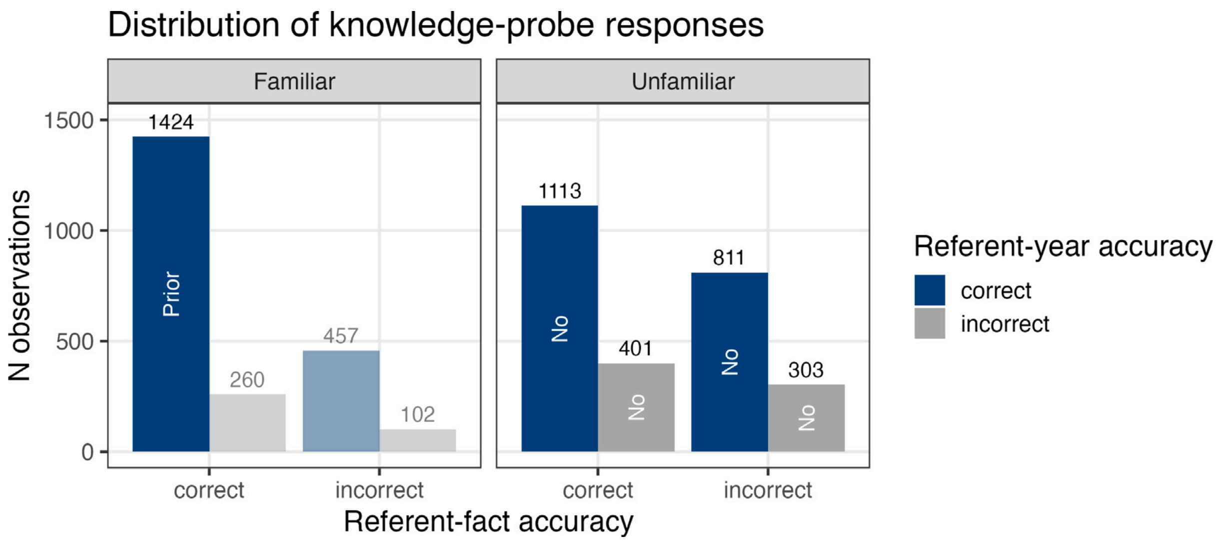

Fig. 1. Distribution of Experiment 1 responses across prior-knowledge prompts: trial-initial referent-familiarity responses (facets), post-experiment referent-fact accuracy (x-axis), and post-experiment referent-year accuracy (bar fill). Bar labels indicate which combination of responses were categorised as PRIOR KNOWLEDGE and NO KNOWLEDGE trials. Opaque bars with no labels indicate trials that were removed prior to analysis.

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 were examined in order to determine whether/how to reduce the random effects structure (`lme4::VarCorr()`) until the model converged and was not overfit (as indicated by `rePCA()`; Bates et al., 2015). Only once the most parsimonious (and final) model was selected were the fixed-effect estimates inspected (`summary()` function).

Analyses were 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) in Experiment 1. The FACT+1 region was included as this region contains a clause end and may 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). Bonferroni corrections were performed to correct for multiple comparisons by dividing the alpha-level (.05) by the number of analyses per experiment (von der Malsburg & Angele, 2017). For Experiment 1, analysis of the FACT+1 region was also planned *a priori* to catch any wrap-up effects at the end of the direct quotation, but is not reported as it did not yield any significant effects of the manipulated factors. Bonferroni corrections for Experiment 1 take the inclusion of the FACT+1 region into account (alpha-level divided by 12 (4 regions × 3 eye-tracking measures) = `.05/12` = .0042). Data and analysis scripts can be found on the OSF: https://osf.io/fe6kp, including for the FACT+1 region.

2.5. Results

All participants scored above 75% in overall post-trial comprehension accuracies from the eye-tracking experiment. Therefore no participants were removed prior to analyses. A total of 4.9% of critical trials received an incorrect comprehension response, and were removed prior to analyses. The remaining 95.1% of trials (n = 4871) were further filtered based on the prior-knowledge probe responses, as described below. Of these trials, 7% (N = 343) of observations were not included in the eye-tracking analyses due to absent fixations in the region(s) of interest or fixation durations falling outside our pre-determined thresholds (< 80 ms or > 800 ms).

2.5.1. Off-line measures

The distribution of referent-familiarity rates and post-experimental referent-fact and -year accuracies is visualised in Fig. 1. The eye-tracking trial-initial familiarity rate for Experiment 1 was 48% of trials (n = 2344 of 4871 trials; 'Familiar' facet in Fig. 1). The remaining trials (n = 2628) received a 'no' familiarity response and were categorised as NO KNOWLEDGE trials prior to analysis ('Unfamiliar' facet in Fig. 1).

For a trial to be categorised as PRIOR KNOWLEDGE, a positive trial-initial familiarity response, accurate post-experimental referent-year, and -fact responses were required. Of the 2344 trials that received a 'yes' familiarity response, 63% received accurate referent-year and referent-fact responses (n = 1424), and were categorised as PRIOR KNOWLEDGE. The remaining 17% of trials that received a 'yes' familiarity response but an incorrect referent-year and/or referent-fact response were excluded from analyses (n = 819). The remaining trials (n = 4052) were included in the analyses.

2.5.2. Eye-tracking during reading and pre-trial photo familiarity

The observed mean eye-tracking reading times per condition and knowledge-type for Experiment 1 are visualised in Fig. 2 for the sentence regions YEAR (A), FACT (B), and NAME (C). Model summaries for each reading measure per sentence region are provided in Tables 2–4. As described in Section 2.4, the threshold for statistical significance for Experiment 1 was set to α = .0042 to control for multiple comparisons.

In the YEAR region (Fig. 2A), an effect of TRIAL ORDER emerged with overall first-pass reading times increasing as the experiment progressed ($\hat{\beta}$ = 0.163 ms [0.091, 0.234], t = 4.5, p < .001). A main effect of PRIOR KNOWLEDGE was found in total reading times, with trials with no knowledge had longer reading times than those without ($\hat{\beta}$ = 62 ms [37, 87], t = 4.9, p < .001). An interaction of YEAR CONGRUENCE and PRIOR KNOWLEDGE was found in first-pass reading time ($\hat{\beta}$ = −33 ms [−50, −15], t = −3.6, p < .001) and total reading time ($\hat{\beta}$ = −137 ms [−184, −91], t = −5.8, p < .001). No effects emerged in regression path duration at the YEAR region.

Nested-contrast models investigating the interaction of YEAR CONGRUENCE and PRIOR KNOWLEDGE at the YEAR region showed that in PRIOR KNOWLEDGE trials, incongruent years elicited longer reading times than congruent years in both first-pass reading time ($\hat{\beta}$ = 22 ms [7, 36], t = 3, p = .003) and total reading times ($\hat{\beta}$ = 104 ms [66, 143], t = 5.4, p < .001). Nested YEAR CONGRUENCE effects in NO-KNOWLEDGE trials were in the opposite direction: Incongruent years elicited *shorter* reading times than congruent years in both first-pass reading times ($\hat{\beta}$ = −11 ms [−21,

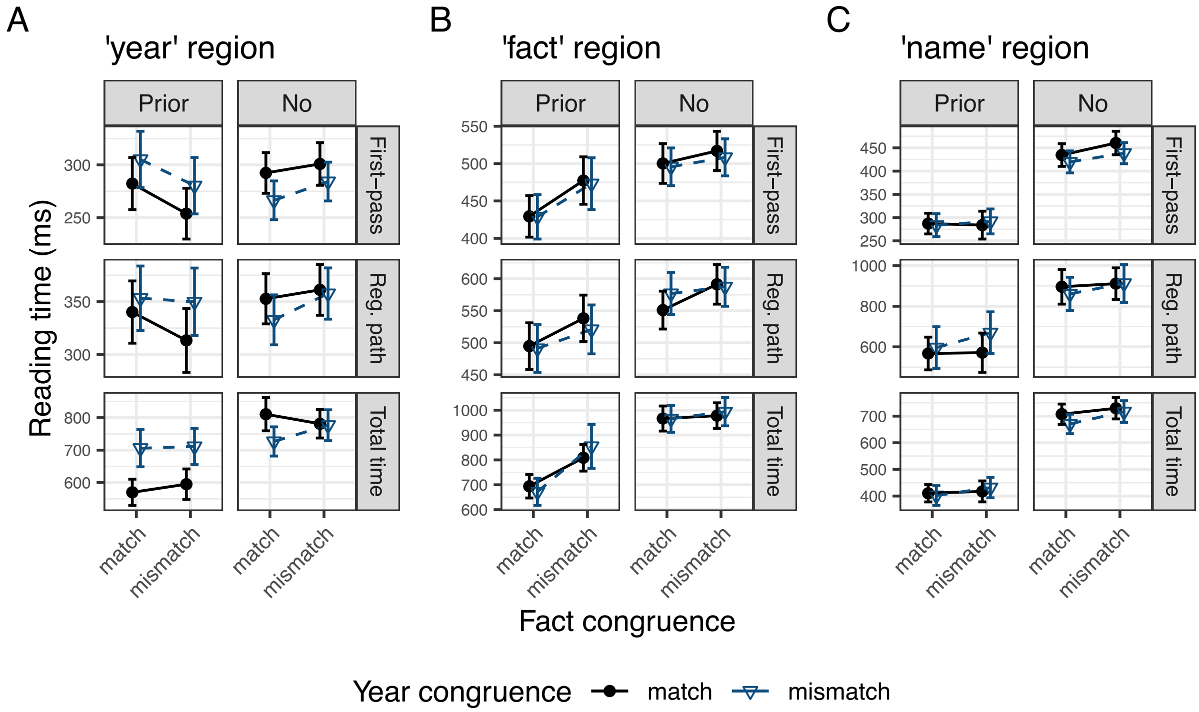

Fig. 2. Mean eye-tracking during reading times across measures (with 95% confidence intervals) from Experiment 1 per critical sentence region and KNOWLEDGE SOURCE type (prior vs. no knowledge).

0], $t = -2$, $p = .044$) and total reading times ($\hat{\beta} = -33$ ms [−62, −5], $t = -2.3$, $p = .024$), but neither effect was significant after Bonferroni correcting the *alpha*-level ($\alpha = .0056$).

In the FACT region (Fig. 2B), an effect of TRIAL ORDER was found in regression path duration ($\hat{\beta} = -0.234$ ms [−0.361, −0.107], $t = -3.6$, $p < .001$) and total reading time ($\hat{\beta} = -0.944$ ms [−1.136, −0.751], $t = -9.6$, $p < .001$), with shorter reading times for later trials in both measures. An effect of KNOWLEDGE-TYPE was found in first-pass reading times, ($\hat{\beta} = 28$ ms [14, 42], $t = 3.8$, $p < .001$), regression path duration ($\hat{\beta} = 37$ ms [20, 54], $t = 4.2$, $p < .001$), and total reading time ($\hat{\beta} = 138$ ms [111, 164], $t = 10.3$, $p < .001$), with longer reading times for NO-KNOWLEDGE versus PRIOR-KNOWLEDGE trials across measures. A main effect of FACT CONGRUENCE was found in first-pass reading time ($\hat{\beta} = 26$ ms [13, 39], $t = 3.9$, $p < .001$), regression path duration ($\hat{\beta} = 30$ ms [14, 46], $t = 3.7$, $p < .001$), and total reading time ($\hat{\beta} = 56$ ms [24, 89], $t = 3.5$, $p < .001$), with longer reading times for INCONGRUENT versus CONGRUENT facts across measures. An interaction of FACT CONGRUENCE and PRIOR KNOWLEDGE was also found in total reading time ($\hat{\beta} = -86$ ms [−135, −37], $t = -3.5$, $p < .001$). An interaction effect was also found in first-pass reading times, but was not significant after correcting for multiple comparisons ($\hat{\beta} = -33$ ms [−59, −7], $t = -2.5$, $p = .012$).

A nested-effects model investigating the interaction between FACT CONGRUENCE and PRIOR KNOWLEDGE in total reading times at the FACT region showed that incongruent facts elicited longer total reading times than congruent facts in PRIOR-KNOWLEDGE trials ($\hat{\beta} = 98$ ms [54, 142], $t = 4.4$, $p < .001$). No nested effect of FACT CONGRUENCE was present in NO-KNOWLEDGE trials ($\hat{\beta} = 13$ ms [−22, 49], $t = 0.7$, $p = .457$).

In the NAME region (Fig. 2C), an effect of TRIAL ORDER was found in total reading times with later trials eliciting shorter reading times than earlier trials ($\hat{\beta} = -0.45$ ms [−0.58, −0.32], $t = -6.7$, $p < .001$). An effect of PRIOR KNOWLEDGE was found in first-pass reading time ($\hat{\beta} = 100$ ms [88, 112], $t = 16.3$, $p < .001$), regression path duration ($\hat{\beta} = 198$ ms [170, 226], $t = 14$, $p < .001$), and total reading time ($\hat{\beta} = 205$ ms [187, 223], $t = 22.3$, $p < .001$). In all three measures, longer reading times were elicited by trials with no prior knowledge (versus with prior knowledge). An effect of FACT CONGRUENCE was also found in total reading times ($\hat{\beta} = 27$ ms [9, 45], $t = 3.1$, $p = .003$), with longer reading times for referent-fact mismatches versus matches.

2.6. Interim discussion

Experiment 1 investigated the role of referent-specific knowledge in the processing of biographical facts such as lifetime-year relations and professional bodies of work. Off-line measures (familiarity responses, referent-year and -fact congruence responses) were used to categorise trials into PRIOR KNOWLEDGE trials (29% of trials) and NO-KNOWLEDGE trials (54% of trials). Overall differences in reading times were found between the two types of trials, with overall longer reading times elicited by unfamiliar (NO-KNOWLEDGE) names versus familiar (PRIOR-KNOWLEDGE) names in all measures at the NAME region, and by facts in unfamiliar (NO-KNOWLEDGE) versus familiar (PRIOR-KNOWLEDGE) trials in the early and intermediate measures.

Further differences emerged between knowledge types in the emergence of referent-year and -fact congruence effects. Year congruence effects were found at the YEAR region in measures of early and late/cumulative processing in the prior-knowledge, but not no-knowledge trials. This suggests that referent lifetime knowledge is rapidly available during processing of lifetime-year relations, but only when relevant prior knowledge is available. Violations of this knowledge elicit processing difficulties as early as the first-pass of a year and these difficulties are not rapidly consolidated, eliciting longer total reading times.

In processing of referent-fact congruence, main effects were present in both the FACT and NAME regions, with nested effects present only in prior-knowledge trials in the late measure in the FACT region. This suggests that prior knowledge of a cultural figure's accomplishments and their bodies of work is available during processing and that violations of this knowledge elicit processing costs, but that the absence of this prior knowledge led to earlier consolidation in incongruent conditions compared to when prior knowledge was present.

The discrepancies between the two levels of KNOWLEDGE-TYPE across regions, namely that absence of relevant knowledge leads to absence of congruence effects, is reminiscent of the findings from Troyer et al. (2020) and Martin et al. (2014) in which '*don't know*' trials elicited processing costs overall, regardless of the truth-value of the linguistic

Table 2
Model summaries for reading time at the YEAR region in Experiment 1.

Term	$\hat{\beta}$	SE	t	df	p[a]	Bonf.sig.[b]
First-pass reading time						
Intercept	5.53	0.03	184.7	73.7	<.001	***
Year congr	0.02	0.02	1.2	48.2	.236	n.s.
Fact congr	0.00	0.02	0.2	77.3	.856	n.s.
Knowledge	0.00	0.02	0.0	2476.6	.982	n.s.
Year congr:Fact congr	−0.02	0.04	−0.6	3686.4	.545	n.s.
Year congr:Knowledge	−0.13	0.04	−3.6	1212.2	<.001	**
Fact congr:Knowledge	0.06	0.04	1.6	3328.4	.108	n.s.
Year congr:Fact congr:Knowledge	0.05	0.07	0.7	3708.2	.494	n.s.
Regression path duration						
Intercept	5.67	0.03	166.0	70.7	<.001	***
Year congr	0.03	0.02	1.5	45.0	.145	n.s.
Fact congr	0.02	0.02	1.0	32.5	.306	n.s.
Knowledge	0.01	0.02	0.3	2008.0	.797	n.s.
Year congr:Fact congr	0.00	0.04	−0.1	3683.4	.938	n.s.
Year congr:Knowledge	−0.09	0.04	−2.3	1195.1	.021	n.s.
Fact congr:Knowledge	0.02	0.04	0.5	1334.1	.601	n.s.
Year congr:Fact congr:Knowledge	−0.01	0.08	−0.1	3703.5	.95	n.s.
Total reading time						
Intercept	6.32	0.06	104.7	72.3	<.001	***
Year congr	0.06	0.02	2.9	42.5	.006	n.s.
Fact congr	0.00	0.02	0.1	45.3	.887	n.s.
Knowledge	0.11	0.02	4.9	3217.0	<.001	***
Year congr:Fact congr	0.01	0.04	0.2	3681.1	.871	n.s.
Year congr:Knowledge	−0.25	0.04	−5.8	1250.4	<.001	***
Fact congr:Knowledge	0.03	0.04	0.6	1395.5	.553	n.s.
Year congr:Fact congr:Knowledge	0.16	0.08	1.9	3692.4	.062	n.s.
First-pass reading time: nested comparisons						
No knowledge/Year congr	−0.04	0.02	−2.0	69.6	.044	n.s.
Prior knowledge/Year congr	0.09	0.03	3.0	218.2	.003	*
Total reading time: nested comparisons						
No knowledge/Year congr	−0.06	0.03	−2.3	61.5	.024	n.s.
Prior knowledge/Year congr	0.19	0.03	5.4	187.2	<.001	***

[a] Pre-Bonferroni corrected p-values.
[b] Post-Bonferonni corrections: * <.0042; ** <.0008; *** <.00008.

input. In a further experiment, we employed a pre-experimental training/testing phase to explore whether newly learned referent-specific knowledge is rapidly available during processing, similar to prior-held referent specific knowledge.

3. Experiment 2: prior versus new knowledge

Experiment 2 was a replication of Experiment 1 with the addition of a pre-experimental training/testing phase in which participants were presented the picture, name, and lifetime information of each cultural figure. The inclusion of the training/testing session allowed for the investigation of the role of prior-held versus newly-learned knowledge. The materials and design for the eye-tracking during reading experiment and post-experiment knowledge-probe task were identical to Experiment 1.

3.1. Methods and design

The materials and design were identical to Experiment 1. Trial categorisation was based on the pre-training familiarity response. Trials were removed prior to analyses if they received at least one response indicating insufficient referent-specific knowledge: (i) a 'no' familiarity response in the eye-tracking experiment trial-initial picture prompt, (ii) an incorrect post-experimental referent-year congruence response, or (iii) an incorrect post-experimental referent-fact congruence response. Remaining trials were considered to have sufficient knowledge to be sensitive to the critical sentence manipulations. New to Experiment 2, these trials were then categorised into two categories based on the pre-training referent-familiarity response: Trials that received a 'yes' familiarity response were categorised as PRIOR KNOWLEDGE, whereas those that received a 'no' familiarity response were categorised as NEW KNOWLEDGE. In other words, only trials meeting the PRIOR KNOWLEDGE criteria from Experiment 1 were included in Experiment 2 analyses, and were further categorised based on pre-training familiarity responses into PRIOR KNOWLEDGE and NEW KNOWLEDGE trials.

Participants For Experiment 2, the number of participants was halved (n = 32) with the expectation that the training session would increase the number of trials included in analyses and therefore increase statistical power. As in Experiment 1, 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). Participants were paid 33 Euro for three hours of their time.

3.2. Procedure

Experiment 2 included a pre-experimental training/testing session prior to the eye-tracking reading study that was not present in Experiment 1. Experiment 2 included the same eye-tracking reading study followed by a post-experimental task probing for relevant knowledge pertaining to critical manipulations.

Pre-experimental training/testing session Experiment 2 additionally included a pre-experimental training/testing task. The training session presented 100 cultural figures, 80 of which later appeared in critical items in the eye-tracking experiment, and 20 in filler items. The training and testing of cultural figures was divided into four blocks (25 culture figures per block). Each block began with the training of 25 cultural figures, followed by a testing of their lifetime relative to a given year, and re-testing of the cultural figures that received an incorrect response. This was followed by the next block of 25 cultural figures. During the training, a cultural figure's picture was presented and participants indicated by button press whether they were already

Table 3
Model summaries for eye-tracking reading measures at the FACT region in Experiment 1.

Term	$\hat{\beta}$	SE	*t*	df	*p*[a]	Bonf.sig.[b]
First-pass reading time						
Intercept	6.03	0.05	129.2	68.5	<.001	***
Year congr	0.00	0.02	0.2	40.6	.838	n.s.
Fact congr	0.06	0.02	3.9	74.6	<.001	**
Knowledge	0.07	0.02	3.8	3980.9	<.001	**
Year congr:Fact congr	−0.03	0.03	−1.0	3892.5	.321	n.s.
Year congr:Knowledge	−0.02	0.03	−0.6	1156.3	.555	n.s.
Fact congr:Knowledge	−0.08	0.03	−2.5	3379.3	.012	n.s.
Year congr:Fact congr:Knowledge	0.02	0.06	0.3	3910.9	.764	n.s.
Regression path duration						
Intercept	6.14	0.04	144.2	72.4	<.001	***
Year congr	0.00	0.02	0.2	3886.4	.824	n.s.
Fact congr	0.06	0.02	3.7	73.8	<.001	**
Knowledge	0.08	0.02	4.2	3987.1	<.001	***
Year congr:Fact congr	−0.06	0.03	−1.6	3895.2	.1	n.s.
Year congr:Knowledge	0.02	0.03	0.5	3915.2	.638	n.s.
Fact congr:Knowledge	−0.05	0.03	−1.4	3385.1	.151	n.s.
Year congr:Fact congr:Knowledge	0.01	0.07	0.2	3913.4	.87	n.s.
Total reading time						
Intercept	6.53	0.06	103.7	98.5	<.001	***
Year congr	−0.01	0.02	−0.4	3854.2	.702	n.s.
Fact congr	0.08	0.02	3.5	43.6	<.001	*
Knowledge	0.20	0.02	10.3	3947.5	<.001	***
Year congr:Fact congr	0.02	0.03	0.5	3877.0	.629	n.s.
Year congr:Knowledge	0.02	0.04	0.5	3882.8	.633	n.s.
Fact congr:Knowledge	−0.13	0.04	−3.5	1779.3	<.001	**
Year congr:Fact congr:Knowledge	−0.04	0.07	−0.6	3902.1	.581	n.s.
Total reading time: nested comparisons						
No knowledge/Fact congr	0.02	0.03	0.7	60.8	.457	n.s.
Prior knowledge/Fact congr	0.14	0.03	4.4	139.1	<.001	***

[a] Pre-Bonferroni corrected p-values.
[b] Post-Bonferonni corrections: * <.0042; ** <.0008; *** <.00008.

Table 4
Model summaries for eye-tracking reading measures at the NAME region in Experiment 1.

Term	$\hat{\beta}$	SE	*t*	df	*p*[a]	Bonf.sig.[b]
First-pass reading time						
Intercept	5.74	0.04	146.7	85.6	<.001	***
Year congr	0.00	0.02	0.1	3752.6	.91	n.s.
Fact congr	0.06	0.02	2.9	40.5	.006	n.s.
Knowledge	0.32	0.02	16.3	3865.9	<.001	***
Year congr:Fact congr	−0.01	0.04	−0.4	3782.2	.674	n.s.
Year congr:Knowledge	−0.06	0.04	−1.7	3794.1	.081	n.s.
Fact congr:Knowledge	−0.02	0.04	−0.6	1581.1	.516	n.s.
Year congr:Fact congr:Knowledge	−0.06	0.07	−0.8	3809.5	.418	n.s.
Regression path duration						
Intercept	6.14	0.05	122.0	89.4	<.001	***
Year congr	0.02	0.03	0.6	3760.7	.552	n.s.
Fact congr	0.07	0.03	2.0	40.4	.052	n.s.
Knowledge	0.42	0.03	14.0	3786.0	<.001	***
Year congr:Fact congr	0.03	0.05	0.6	3786.3	.538	n.s.
Year congr:Knowledge	−0.14	0.05	−2.6	3802.9	.01	n.s.
Fact congr:Knowledge	0.00	0.06	0.0	1547.8	.994	n.s.
Year congr:Fact congr:Knowledge	−0.10	0.11	−0.9	3814.2	.368	n.s.
Total reading time						
Intercept	6.11	0.05	120.0	96.5	<.001	***
Year congr	−0.01	0.02	−0.6	3776.6	.579	n.s.
Fact congr	0.06	0.02	3.1	75.2	.003	*
Knowledge	0.45	0.02	22.3	3860.4	<.001	***
Year congr:Fact congr	0.03	0.04	0.8	3788.0	.419	n.s.
Year congr:Knowledge	−0.07	0.04	−2.0	3804.0	.044	n.s.
Fact congr:Knowledge	−0.02	0.04	−0.5	3449.9	.642	n.s.
Year congr:Fact congr:Knowledge	0.00	0.07	0.0	3806.7	.993	n.s.

[a] Pre-Bonferroni corrected p-values.
[b] Post-Bonferonni corrections: * <.0042; ** <.0008; *** <.00008.

familiar with the cultural figure (yes/no). This response was taken to reflect the presence of prior knowledge. This was followed by a two-sentence biography of the cultural figure, containing their nationality, occupation, year of birth (if still living) or death (if dead), as well as a fact about them found on their Wikipedia page (e.g., German: *Beyoncé ist eine amerikanische Musikerin und Schauspielerin, die 1981 geboren wurde. Sie sieht sich selbst als moderne Feministin.*, English translation: '*Beyoncé is an American musician and actress who was born in 1981.*

She considers herself a modern feminist.'). Participants indicated whether they already knew all of this information (yes/no). Another cultural figure would then be presented, until all 25 cultural figures had been trained. This was followed by the testing phase for these 25 cultural figures, which presented the picture of each cultural figure, again asked if the participant is currently familiar with this person, and if the cultural figure was alive in a given year ('test-year'). Importantly, the test-year fell half-way between the training-year (year of birth or death) and the year that would later appear in the eye-tracking during reading experiment (e.g., *Was she alive in the year 1992/1974?* for a year-match/mismatch in the eye-tracking experiment). This resulted in the lifetime-year (in)congruence to the test-year logically entailing the lifetime-year (in)congruence for the eye-tracking experiment. Feedback was provided which repeated the training-year regardless of the accuracy (i.e., *Correct/Incorrect! She was born in 1981.*). Cultural figures who received an incorrect response to the testing lifetime-year congruence prompt were re-tested after the testing phase within a block. The training took between 40–60 min and took place immediately before the eye-tracking experiment in a different room of the same building. Participant lists were newly pseudo-randomised for Experiment 2.

3.3. Data analysis

Data analysis and model selection were identical to Experiment 1. Importantly, trials that received the necessary responses for inclusion in analyses (i.e., 'yes' trial-initial familiarity response in eye-tracking during reading and correct year- and fact-referent congruence responses in post-experimental task) were further categorised into PRIOR-KNOWLEDGE and NEW-KNOWLEDGE trials based on the pre-training familiarity responses provided in the pre-experimental training/testing session.

As in Experiment 1, linear-mixed models were fit to log-transformed reading times with the fixed effects LIFE-YEAR CONGRUENCE, FACT CONGRUENCE, and KNOWLEDGE TYPE, and the co-variate TRIAL ORDER. In Experiment 2 the factor KNOWLEDGE-TYPE contained the levels prior-knowledge and NEW-KNOWLEDGE (instead of no-knowledge in Experiment 1) based on the pre-training familiarity responses. Again, all factors were which were sum contrast coded as −0.5 and +0.5, respectively. The co-variate TRIAL ORDER was centred (median trial order number subtracted from each value).

3.4. Hypotheses

We expected to replicate the effects observed in the PRIOR-KNOWLEDGE trials Experiment 1, namely effects of lifetime-year congruence in the YEAR region, and referent-fact congruence in the FACT region and NAME region, as well as the interactions of KNOWLEDGE TYPE with YEAR CONGRUENCE and FACT CONGRUENCE at the relevant regions. Due to the addition of a learning phase that trained and tested participants for referent-lifetime knowledge (but not referent-fact knowledge), the effects for year congruence were expected to be larger than those observed in Experiment 1. An additional hypothesis was established for Experiment 2 pertaining to the role of prior versus newly learned (i.e., successfully trained) referent knowledge, outlined below.

3.4.0.1. Knowledge-type effects. If the presence of prior knowledge of a cultural figure and their lifetime and professional milestones influences the processing of sentences about them differently than newly learned/refreshed knowledge about them, then the effects described above should differ between trials in which participants had prior knowledge, versus those where they did not. Namely, if long-term prior knowledge is more readily available than, and/or has an additive effect to, newly learned knowledge then we should see stronger congruence effects for trials with present long-term knowledge (PRIOR-KNOWLEDGE) than those without long-term knowledge (NEW-KNOWLEDGE).

3.5. Results

No participants scored below 75% in overall post-trial comprehension response from the eye-tracking experiment, and so all participants were included in analyses. A total of 6.7% of critical trials received an incorrect comprehension response, and were removed prior to analyses. A total of 14% (N = 328) of observations were not included in the eye-tracking analyses due to fixations that were missing or fell outside our thresholds, following the same procedure as described for Experiment 1.

3.5.1. Off-line measures

Familiarity responses Mean referent-familiarity rates across prompts are visualised in Fig. 3A. In the training phase, 46% of trials (n = 1181 of 2558 trials) received an initial 'yes' familiarity response prior to presentation of any further identifying information. The remaining 54% trials received a 'no' familiarity response (n = 1377). After the initial training phase, the rate of 'yes' familiarity responses in the testing phase increased to 80% of trials (n = 2050). In the eye-tracking experiment, the trial-initial familiarity response then received 74% of trials (n = 1888).

Referent-year accuracy Mean referent-year accuracy rates across prompts are visualised in Fig. 3B. In the test phase, 50% of trials (n = 1280) received an initial 'yes' familiarity response prior to presentation of any further identifying information. Following a re-test phase, the total referent-year accuracy was 96% of trials (n = 2451. In the post-experimental referent-year probe, the accuracy rate was 84% of trials (n = 2159). For the referent-fact probe, which was not trained, the accuracy rate was 67% of trials (n = 1708.

Referent-fact accuracy In Experiment 2, 64% of trials (726) met the criteria for PRIOR KNOWLEDGE, and a total of 36% of trials (404) met the criteria for NEW KNOWLEDGE.

3.5.2. Eye-tracking during reading

The observed mean eye-tracking reading times per condition and knowledge-type for Experiment 2 are visualised in Fig. 4 for the sentence regions YEAR (A), FACT (B), and NAME (C). Model summaries for each reading measure per sentence region are provided in Tables 5–7. As described in Section 2.4, the threshold for statistical significance for Experiment 2 was set to α = .0056 to control for multiple comparisons. Two participants were removed prior to analyses: one due to poor performance in the responses leading to only three observations meeting the inclusion criteria, and the other for having much larger reading time values compared to other participants which affected model fit (as indicated by diagnostic plots).

In the YEAR region (Fig. 4A), a main effect of YEAR CONGRUENCE emerged in total reading time ($\hat{\beta}$ = 48 ms [19, 77], t = 3.2, p = .001) but not in first-pass reading time ($\hat{\beta}$ = 6 ms [−6, 19], t = 1, p = .332) or regression path duration ($\hat{\beta}$ = 10 ms [−5, 25], t = 1.3, p = .187). No effects of FACT CONGRUENCE or KNOWLEDGE SOURCE emerged, nor any interaction effects. No effects emerged in the FACT region (Fig. 4B).

In the NAME region (Fig. 4C), a main effect of KNOWLEDGE SOURCE was found in first-pass reading time ($\hat{\beta}$ = 31 ms [15, 48], t = 3.7, p < .001), regression path duration ($\hat{\beta}$ = 109 ms [78, 140], t = 6.9, p < .001), and total reading time ($\hat{\beta}$ = 59 ms [34, 83], t = 4.7, p < .001). In all three measures longer reading times were elicited by names of newly-learned versus prior-known referents.

3.5.3. Post-hoc analyses: nested effects

Experiment 2 yielded no significant interaction effects with KNOWLEDGE TYPE, indicating that observed effects did not differ significantly between PRIOR-KNOWLEDGE versus NEW-KNOWLEDGE trials. Post-hoc models were run to explore nested comparisons between the types of KNOWLEDGE TYPE, however, as visual inspection of Fig. 4 suggested, effects of YEAR CONGRUENCE in the YEAR region may have been driven by the PRIOR KNOWLEDGE trials in total reading times, and YEAR CONGRUENCE effects

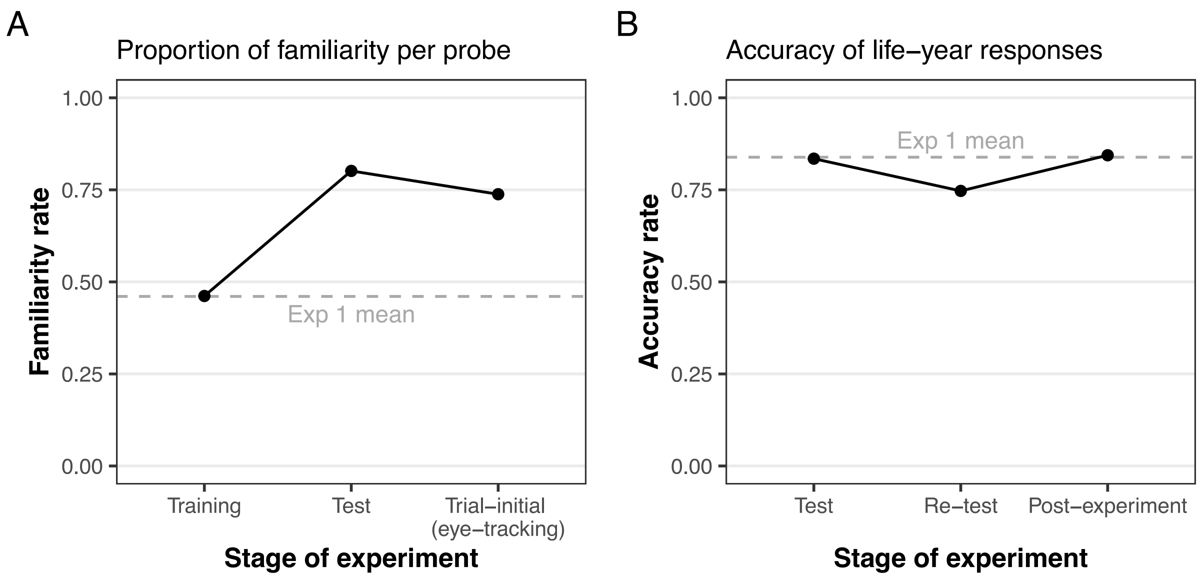

Fig. 3. Mean response rates for Experiment 2 across familiarity prompts (A) and referent-year prompts (B). Grey dashed line indicates overall mean eye-tracking trial-initial familiarity rate from Experiment 1 (A) and overall post-experimental referent-year accuracy for prior-knowledge trials in Experiment 1 (B).

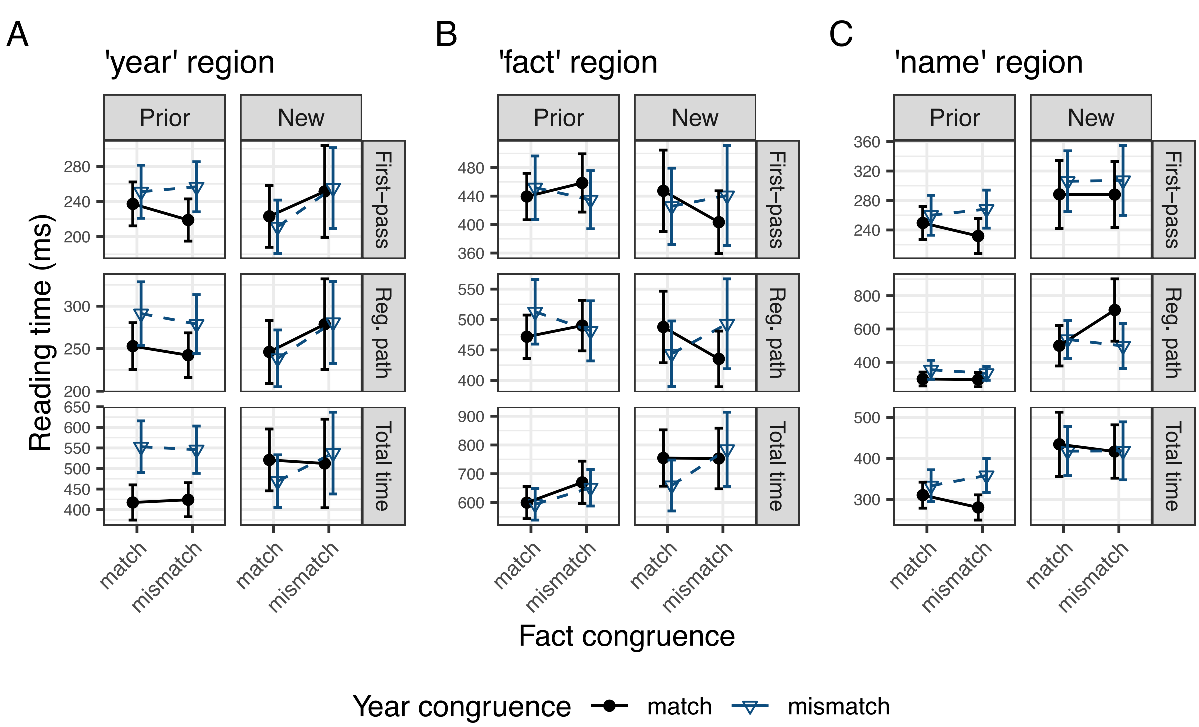

Fig. 4. Mean eye-tracking during reading measures (with 95% confidence intervals) from Experiment 2 per critical sentence region and KNOWLEDGE SOURCE type (prior vs. new knowledge).

may be present in PRIOR-KNOWLEDGE trials, but not NEW-KNOWLEDGE trials, in first-pass reading time and regression path duration in this region. To correct for these additional comparisons (three additional models), these exploratory analyses will be considered significant if p-values are smaller than 0.0042. The models investigated nested effects of YEAR CONGRUENCE within either level of KNOWLEDGE TYPE at the YEAR region, and thus did not include FACT CONGRUENCE as a fixed effect. For the sake of consistency, the post-experimental response to the fact congruence probe was still used for trial-exclusion, however. Model summaries are provided on the OSF.

In the YEAR region (Fig. 4A), a nested effect of YEAR CONGRUENCE emerged in total reading time in the PRIOR-KNOWLEDGE trials reflecting longer reading times for life-year mismatches versus matches ($\hat{\beta}$ = 77 ms [41, 113], t = 4.2, p < .001). This effect was absent in NEW-KNOWLEDGE trials ($\hat{\beta}$ = 21 ms [−26, 69], t = 0.9, p = .382). No effects of YEAR CONGRUENCE were found nested within either level of KNOWLEDGE-TYPE in first-pass reading times (PRIOR-KNOWLEDGE: $\hat{\beta}$ = 13 ms [−2, 29], t = 1.7, p = .094; NEW-KNOWLEDGE: $\hat{\beta}$ = −4 ms [−25, 17], t = −0.4, p = .705) nor regression path duration (PRIOR-KNOWLEDGE: $\hat{\beta}$ = 15 ms [−2, 33], t = 1.7, p = .086; NEW-KNOWLEDGE: $\hat{\beta}$ = 4 ms [−20, 27], t = 0.3, p = .75).

Table 5
Model summaries for eye-tracking reading measures at the YEAR region in Experiment 2.

Term	$\hat{\beta}$	SE	*t*	df	*p*[a]	Bonf.sig.[b]
First-pass reading time						
Intercept	5.39	0.03	168.3	29.3	<.001	***
Year congr	0.03	0.03	1.0	918.5	.332	n.s.
Fact congr	0.03	0.04	0.7	29.2	.466	n.s.
Knowledge	0.03	0.03	1.1	939.0	.293	n.s.
Year congr:Fact congr	0.04	0.06	0.7	919.9	.493	n.s.
Year congr:Knowledge	−0.10	0.06	−1.7	918.8	.098	n.s.
Fact congr:Knowledge	0.13	0.06	2.2	903.7	.028	n.s.
Year congr:Fact congr:Knowledge	−0.10	0.12	−0.9	919.8	.375	n.s.
Regression path duration						
Intercept	5.46	0.03	162.9	29.1	<.001	***
Year congr	0.04	0.03	1.3	922.6	.187	n.s.
Fact congr	0.02	0.04	0.5	28.7	.59	n.s.
Knowledge	0.04	0.03	1.1	935.6	.257	n.s.
Year congr:Fact congr	0.02	0.06	0.2	923.8	.804	n.s.
Year congr:Knowledge	−0.05	0.06	−0.9	923.1	.392	n.s.
Fact congr:Knowledge	0.10	0.06	1.5	869.2	.123	n.s.
Year congr:Fact congr:Knowledge	−0.01	0.13	−0.1	923.6	.94	n.s.
Total reading time						
Intercept	5.95	0.08	79.3	30.3	<.001	***
Year congr	0.12	0.04	3.2	950.4	.001	*
Fact congr	−0.03	0.04	−0.7	960.5	.486	n.s.
Knowledge	0.02	0.04	0.4	841.6	.679	n.s.
Year congr:Fact congr	0.00	0.08	0.0	948.1	.988	n.s.
Year congr:Knowledge	−0.14	0.08	−1.8	960.0	.07	n.s.
Fact congr:Knowledge	−0.10	0.08	−1.3	962.2	.181	n.s.
Year congr:Fact congr:Knowledge	0.04	0.15	0.2	956.4	.813	n.s.

[a] Pre-Bonferroni corrected p-values.
[b] Post-Bonferonni corrections: * <.0056; ** <.001; *** <.0001.

Table 6
Model summaries for eye-tracking reading measures at the FACT region in Experiment 2.

Term	$\hat{\beta}$	SE	*t*	df	*p*[a]	Bonf.sig.[b]
First-pass reading time						
Intercept	5.97	0.06	99.9	59.6	<.001	***
Year congr	0.00	0.03	−0.1	968.1	.928	n.s.
Fact congr	0.01	0.03	0.4	41.0	.711	n.s.
Knowledge	−0.01	0.03	−0.2	996.6	.833	n.s.
Year congr:Fact congr	0.04	0.06	0.7	967.8	.494	n.s.
Year congr:Knowledge	0.00	0.06	0.0	974.3	.986	n.s.
Fact congr:Knowledge	0.01	0.06	0.2	715.8	.85	n.s.
Year congr:Fact congr:Knowledge	0.11	0.12	0.9	976.8	.385	n.s.
Regression path duration						
Intercept	6.03	0.06	105.7	53.5	<.001	***
Year congr	0.01	0.03	0.3	972.2	.773	n.s.
Fact congr	0.01	0.03	0.3	45.9	.79	n.s.
Knowledge	−0.03	0.04	−0.8	994.1	.425	n.s.
Year congr:Fact congr	0.04	0.06	0.6	971.4	.518	n.s.
Year congr:Knowledge	−0.02	0.07	−0.3	978.7	.785	n.s.
Fact congr:Knowledge	−0.02	0.07	−0.3	720.6	.748	n.s.
Year congr:Fact congr:Knowledge	0.23	0.13	1.8	978.7	.077	n.s.
Total reading time						
Intercept	6.33	0.07	86.5	48.6	<.001	***
Year congr	0.00	0.03	−0.1	1022.1	.944	n.s.
Fact congr	0.07	0.04	1.9	1027.4	.053	n.s.
Knowledge	0.09	0.04	2.3	1057.8	.021	n.s.
Year congr:Fact congr	0.03	0.07	0.5	1019.3	.614	n.s.
Year congr:Knowledge	−0.01	0.07	−0.2	1025.6	.834	n.s.
Fact congr:Knowledge	−0.07	0.07	−1.0	1033.9	.34	n.s.
Year congr:Fact congr:Knowledge	0.09	0.14	0.7	1021.4	.494	n.s.

[a] Pre-Bonferroni corrected p-values.
[b] Post-Bonferonni corrections: * <.0056; ** <.001; *** <.0001.

3.6. Interim discussion

Experiments 1 and 2 investigated the role of referent-specific knowledge in the processing of biographical facts such as lifetime-year relations and factual accomplishments. The off-line measures (familiarity responses, referent-year and -fact congruence responses) indicated that participants were initially familiar with approximately 46% of pictured cultural figures in each experiment (Experiment 1 trial-initial familiarity response and Experiment 2 pre-training familiarity response). The training and testing phases in Experiment 2 boosted this number to 74% of trials.

In the pre-trial familiarity responses collected during the eye-tracking during reading experiment (i.e., familiarity with a pictured cultural figure), 45.7% (Experiment 1) and 74% (Experiment 2) of trials received

Table 7
Model summaries for eye-tracking reading measures at the NAME region in Experiment 2.

Term	$\hat{\beta}$	SE	t	df	p[a]	Bonf.sig.[b]
First-pass reading time						
Intercept	5.57	0.04	130.1	48.3	<.001	***
Year congr	0.03	0.03	0.9	942.9	.382	n.s.
Fact congr	0.02	0.03	0.7	27.5	.503	n.s.
Knowledge	0.12	0.03	3.7	977.3	<.001	**
Year congr:Fact congr	−0.03	0.06	−0.5	942.6	.615	n.s.
Year congr:Knowledge	−0.11	0.06	−1.8	950.1	.073	n.s.
Fact congr:Knowledge	0.01	0.06	0.2	899.3	.825	n.s.
Year congr:Fact congr:Knowledge	−0.16	0.12	−1.3	946.6	.185	n.s.
Regression path duration						
Intercept	5.84	0.05	129.6	42.5	<.001	***
Year congr	0.01	0.04	0.3	960.3	.751	n.s.
Fact congr	0.05	0.04	1.2	974.9	.242	n.s.
Knowledge	0.31	0.05	6.9	934.0	<.001	***
Year congr:Fact congr	−0.16	0.09	−1.9	956.4	.056	n.s.
Year congr:Knowledge	−0.22	0.09	−2.6	964.8	.009	n.s.
Fact congr:Knowledge	0.02	0.09	0.2	980.4	.854	n.s.
Year congr:Fact congr:Knowledge	−0.29	0.17	−1.7	962.4	.085	n.s.
Total reading time						
Intercept	5.80	0.05	110.7	49.7	<.001	***
Year congr	0.03	0.04	1.0	945.0	.33	n.s.
Fact congr	0.01	0.04	0.2	956.8	.819	n.s.
Knowledge	0.18	0.04	4.7	980.2	<.001	***
Year congr:Fact congr	−0.02	0.07	−0.2	941.9	.822	n.s.
Year congr:Knowledge	−0.15	0.07	−2.1	948.4	.034	n.s.
Fact congr:Knowledge	−0.04	0.07	−0.5	963.1	.607	n.s.
Year congr:Fact congr:Knowledge	−0.26	0.14	−1.9	946.1	.063	n.s.

[a] Pre-Bonferroni corrected p-values.
[b] Post-Bonferroni corrections: * <.0056; ** <.001; *** <.0001.

a positive response in Experiment 2. This discrepancy is attributed to the pre-experimental training/testing session in Experiment 2. In Experiment 1, analyses were also planned to be run on all trials that received a 'no' pre-trial familiarity response in order to explore congruence effects when prior knowledge is absent or more variable (i.e., the remaining 54.3% of trials).

In terms of the processing of referent-year congruence, the emergence of effects varied between knowledge source and between experiments. In Experiment 1, year congruence effects were found at the YEAR region in measures of early and late/cumulative processing in the prior-knowledge, but not no-knowledge trials. This suggests that referent lifetime knowledge is rapidly available during processing of lifetime-year relations, but only when relevant prior knowledge is available. Violations of this knowledge elicit processing difficulties as early as the first-pass and these difficulties are not rapidly consolidated, eliciting longer total reading times, too. In Experiment 2, a main effect of year congruence was found at the YEAR region in total reading time, with no interaction with knowledge-type (prior versus new). This suggests that trials with prior-held referent-lifetime knowledge and those with newly acquired referent-lifetime did not differ significantly in their respective year-congruence effects. Descriptively, these two knowledge-types did seem to differ in that mismatching years seemed to have longer reading times across measures in prior-knowledge trials, but not in new-knowledge trials, as visualised in Fig. 4. In processing of referent-fact congruence, effects were present in Experiment 1, but not Experiment 2. This difference is presumably due to the training of referent-lifetime, but not -fact, information in the pre-experimental training session in Experiment 2.

4. General discussion

The two eye-tracking during reading studies presented explored the role of high-level, prior knowledge relevant to a person's lifetime (whether they were alive or not in a given year) and their accomplishments (e.g., whether they starred in a particular film or not) on sentence processing. This allowed us to assess the effects of two distinct types of knowledge, temporal and factual, and to what extent these types of knowledge could be rapidly learned to affect language comprehension.

In Experiment 1, we presented participants with an image of a referent (a cultural figure) prior to having them read a sentence about the referent. We determined whether participants had the relevant bibliographic knowledge during the eye-tracking experiment via a pre-trial cultural figure familiarity test and post-experiment lifetime-year and referent-fact congruence tests. Experiment 2 was identical to Experiment 1 with the addition of a pre-trial training phase in which participants gave an initial cultural figure familiarity response, read a short biography of the cultural figure including their year of birth or year of death, and were tested on this knowledge. The same prompts were used as in Experiment 1 to determine whether participants had the relevant knowledge during the eye-tracking experiment. The trials were then divided into prior-knowledge and new-knowledge trials, based on whether the participant had indicated initial familiarity with the cultural figure in the pre-experimental training phase or not (yes: prior-knowledge, no: no-knowledge). We measured effects of such knowledge at several sentence regions where the relevant knowledge could, in principle, influence processing (e.g., the YEAR, FACT, and NAME, see Table 1).

Turning to the results, in Experiment 1, trials where the relevant referent-specific information was available elicited a facilitation effect (shorter reading times) compared to no-knowledge trials in almost all measures analysed, as well as effects of YEAR CONGRUENCE and FACT CONGRUENCE effects at the YEAR and FACT regions, respectively, with incongruent conditions eliciting longer reading times than congruent conditions. Importantly, these effects were absent when the relevant knowledge was absent (i.e., participants stated they were not familiar with the cultural figure). The time course of these effects differed, however. Effects of life-year congruence emerged at the year region in prior-knowledge trials (but not no-knowledge trials) in the earliest measure analysed (first-pass reading times) and were still present in the latest measure analysed (total reading times). Effects of referent-fact congruence emerged overall in the fact region in all three measures analysed (first-pass reading time, regression path duration, and total reading time), with differences in fact-congruence effects emerging between prior- and no-knowledge trials in the late measure only. In addition, fact-congruence (but not year-congruence) effects were also present in the name-region in the late measure, with longer reading times for names with a referent-fact mismatch regardless of whether participants indicated familiarity with the referent or not.

In Experiment 2, YEAR CONGRUENCE effects emerged at the YEAR region in total reading times, with incongruent years eliciting longer reading times than congruent years. An effect of KNOWLEDGE-TYPE emerged at the NAME region in first-pass reading time, regression path duration, and total reading time. In all three measures, names of newly-learned cultural figures elicited longer reading times than names of previously-familiar cultural figures. Interestingly, there were no significant differences in congruence effects elicited by newly-learned versus previously-familiar cultural figures indicating that lifetime-year incongruence elicited comparable processing costs when a referent's lifetime information was available prior to training and when it was newly learned. Post-hoc analyses revealed nested congruence effects in prior-knowledge, but not new-knowledge, trials in the year region in total reading times. The absence of effects of referent-fact congruence in Experiment 2 suggests the task demands from the (referent-year) pre-experiment training session affected the processing of referent-fact relations, which were not trained. This suggests an allocation of attention to the information encoded in the *year* region at the cost of that in the *fact* region, leading to a potential blindness to the referent-fact congruence in favour of checking the referent-year congruence against the trained information (e.g., Batterink et al., 2010; Hutchinson et al., 2024).

4.1. Knowledge-type effects

The present study builds on previous findings of processing costs elicited by violations of prior, long-term knowledge about the world in sentences like *Rome is the capital of France*. Experiments 1 and 2 provided clear support for the availability of referent-lifetime information stored in long-term knowledge during comprehension. In Experiment 1, lifetime information was not explicitly mentioned, but could only be gleaned from long-term prior knowledge of a famous referent prompted by a trial-initial picture and/or their name near sentence-end. Therefore, the lifetime-year congruence effects observed in prior-knowledge trials could only be due to long-term knowledge of the referent, or potentially to lifetime information inferred by the perceived era the photograph was taken (e.g., a black-and-white picture of an older person such as Humphrey Bogart might lead to the inference this person was dead in 2002). Effects of lifetime-year congruence were found at the critical YEAR region in all three reading measures. In addition, nested effects of fact congruence emerged at the critical FACT region in prior-knowledge trials, but not no-knowledge trials, in first-pass reading time and total reading time, suggesting that this information was just as rapidly available during incremental processing. Importantly, the absence of such effects in the no-knowledge trials indicates that it was indeed individuals' prior-held knowledge of a referent that triggered processing costs when this knowledge was contradicted, and not some inferred meaning from the pre-trial picture of the referent. It also indicates that our familiarity and year/fact congruence prompts, which were used to categorise trials as prior-knowledge or no-knowledge, were sufficient to meaningfully capture the distinction between the intended trial categories.

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 and 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). But this did not seem to be the case based on the clear main effects of fact congruence in all measures in Experiment 1 (with nested knowledge-type effects in the total reading time measure only, which yielded effects in prior-knowledge, but not no-knowledge, trials), life-year congruence effects emerging only in prior-knowledge trials in first-pass reading time and total reading time. Training of lifetime status knowledge (in Experiment 2) was however able to substantially change the reading time pattern, eliminating the significant fact congruence effects observed in Experiment 1.

It should be noted that effects available in total reading times may be driven, at least in part, by prior knowledge activated by the NAME region at sentence-end, and not solely by prior knowledge activated by the trial-initial picture. Even if effects of lifetime-year congruence nested within the prior-knowledge trials were driven by the NAME region, any lifetime information would still need to be accessed via long-term memory as no lifetime information was provided. Importantly, lifetime-year congruence effects were only found in trials where prior knowledge was available, as indicated by post-experimental prior knowledge probes, whereas fact congruence effects were only differentially present in prior-knowledge (versus no-knowledge) trials in the late reading measure. Experiment 1 therefore provides evidence that lifetime information is available via long-term knowledge, during comprehension, and that lifetime-tense congruence effects can be generalised to lifetime-year congruence. The emergence of reliable main effects of fact-congruence is evidence that referent-specific (factual) biographical information is likewise rapidly available during comprehension, even in cases where participants indicated they are not familiar with the referent.

The presence of effects in trials with prior knowledge, but not in those without, mirrors trial-specific knowledge effects reported in Troyer et al. (2020) and Martin et al. (2014). In Troyer et al. (2020), participants read Harry Potter-related sentences that ended with contextually supported word (i.e., the sentences were always 'true' based on the Harry Potter books). After each trial, participants indicated whether they already knew what was presented in the sentence. This self-reported trial-level knowledge was shown to be a strong predictor of the N400, with an increased amplitude for trials with a "no" prior-knowledge response than those with a "yes" response. Martin et al. (2014) reported an increased positivity 150–200 ms post critical-word onset when participants previously knew whether statement of the real-world was true compared to when they did not (e.g., "*The football player Maradona was a forward in the Argentinean team…*"). This was taken to reflect the P2 component which has previously been reported to be larger for correct versus incorrect words in context (e.g., Federmeier & Kutas, 1999; Pinheiro et al., 2010). The emergence of early processing differences between "known" and "unknown" factual statements (i.e., true statements) in Martin et al. (2014) and in Troyer et al. (2020) mirrors the main effect of *prior knowledge* (present or absent) in Experiment 1 at the YEAR, FACT, and NAME regions, with longer reading times for trials for which relevant prior knowledge was absent versus present.

Experiment 2 contributed to extant literature investigating the role of prior-held and newly-learned referent- or speaker-specific knowledge in language processing. In the present study, we built on prior research that has examined a range of types of world knowledge by contrasting how effects related to knowing famous personalities' lifetime status (dead or alive in a given year) compared to effects of knowing their biographical accomplishments (e.g., having starred in a particular movie). In particular, Experiment 2 examined whether/when newly learned referent-*lifetime* information, such as a year of birth or death, influences processing of ensuing temporal reference, as well as high-level knowledge of familiar referents' accomplishments. Post-hoc analyses indicated that this information was in fact rapidly available during processing for previously-familiar referents, but not for newly-learned referents, although a priori analyses indicated that differences between these effects was not statistically significant. Furthermore, overall effects of lifetime-year congruence were less robust in Experiment 2, potentially due to the lower number of observations that met the inclusion criteria. However, the presence of effects in the YEAR region support the findings from Experiment 1 that referent-lifetime knowledge is available during processing and is sensitive to lifetime-year constraints. These effects were present in PRIOR-KNOWLEDGE trials, but not NEW-KNOWLEDGE trials, in post-hoc analyses although a prior analyses indicated that these nested lifetime-year effects were not significantly different from each other. In sum, referent-lifetime knowledge was found to elicit processing costs in both experiments. It seems that both previously known and newly learned information are sufficiently available during comprehension, and that the pre-experiment referent-lifetime training may have foregrounded life-year congruence during comprehension, at the expense of referent-year congruence.

The findings from Experiments 1 and 2 could be viewed as having implications for theories of predictive coding and models of memory integration. Firstly, long-term knowledge relevant to the lifetime and professional accomplishments of famous cultural referents elicited processing costs as early as the first-pass of a relevant year nested in prior-knowledge (but not no-knowledge) trials, but with main effects for fact violations and nested fact-congruence effects in prior-knowledge trials in total reading time only (in Experiment 1). This discrepancy between processing costs elicited by the two types of long-term knowledge could be explained by differences in the strength of the inconsistency, similar to the findings in Cook and O'Brien (2014) where weaker inconsistencies (e.g., a vegetarian eating a tuna salad) elicited later processing costs than stronger inconsistencies (e.g., a vegetarian eating a hamburger). One might assume that the prediction for a given fact would be stronger following the presentation of a picture of a referent and a given year (e.g., *Emma Watson...2001* could pre-activate Harry Potter and the Philosopher's Stone), which could explain the elicitation of main effects of fact congruence in the (later) fact region, signalling potentially stronger inconsistency compared to a violation of lifetime-year even in no-knowledge trials.

Though both lifetime information and professional accomplishments are types of knowledge we may hold for a given individual, the former constitutes a global constraint on the individual and their active participation in events (like writing a book), whereas the latter is a more localised proposition. As such, encountering information that violates our prior knowledge about a referent's lifetime status versus accomplishments could elicit differing processing costs. From a situation-model perspective, lifetime status constitutes a high-level, global stable property with a binary value (dead or alive) which constrains participation in events, whereas specific professional accomplishments represent event-level information with many accomplishments mapping onto a single individual (e.g., Radvansky & Zacks, 2017; Zwaan & Radvansky, 1998). In addition, as discussed in Section 1.2, the relation of a person's lifetime to a given year is binary and requires little specific knowledge about their achievements, whereas they will have appeared in many films or written multiple novels. In this sense, the lifetime-year relation may access a broader referent-specific knowledge based in long-term memory, whereas which specific films or novels a cultural figure is associated with requires knowledge specific to them, with possible implication for knowledge revision and memory integration. The updating of entrenched knowledge, such as a referent's lifetime at a given point, should require greater revision costs than integrating more peripheral facts, such as accomplishments (Rapp & Gerrig, 2006; Schlichting & Preston, 2015). In other words, the discrepancy in observed effects for the referent-year and referent-fact effects in Experiment 1 (main effects of fact congruence but nested effects of year congruence in prior-trials only) and Experiment 2 (effects only for referent-year, not referent-fact) could be accounted for by how the types of knowledge differ in terms of their stability and representational scope.

5. Conclusions: Reassessing the accounts

Given all the pressures comprehenders face during language processing, one might plausibly expect that certain types of world-knowledge would be available before others, or that their effects on real-time processing might be stronger. As discussed, associations between seeing a speaker and facts about that speaker could have been 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 varied in its association with language than the arguably more binary life status information. 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 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). We had argued that if the uniqueness of a fact matters, then accessing it should be easier for binary (dead vs alive) facts than facts that are part of a larger category of information (e.g., all the films someone has starred in). In addition, long-term factual knowledge might have the most impact on processing as it could ease lexico-semantic processing. Recently-acquired factual knowledge, or temporal knowledge that seems more limited in its usefulness might be considered to be of less relevance or at least less easily accessible, and thus might only affect relatively late processes.

However, the results from the present two experiments suggest no clear differentiation of the effects of the two knowledge types (the interactions of year with fact congruence were not significant in either experiment). The presented eye-tracking experiments provide strong evidence of the rapid availability of the two types of real-world knowledge during processing: that of (referent) lifetime-year congruence, and high-level biographical knowledge of well-known referents. Importantly, processing costs were found for violations of both types of knowledge, with year congruence (but not fact congruence) effects only nested within trials for which participants held the relevant information in long-term memory. When this knowledge had just been learned immediately preceding the experiment, congruence effects did not significantly differ compared to when this knowledge was already known. Future studies could utilise EEG to investigate whether processing of violations of these two types of prior knowledge elicit distinct event-related potentials, following previous findings of an N400 effect for semantic violations and a P600 effect for (temporal) morphosyntactic violations. Furthermore, such a study could investigate whether the magnitude of observed ERP effects differs as a function of whether knowledge was held in prior or newly learned knowledge. The present study contributes novel findings of cross-modal (picture-elicited) effects of prior knowledge on language comprehension to the existing literature that world knowledge effects during language processing are pervasive and that accounts need not – at least for the examined types of knowledge – make finer differentiations into sub-types of biographical knowledge.

CRediT authorship contribution statement

Daniela Palleschi: Writing – original draft, Writing – review & editing, Methodology, Analysis, Conceptualization. **E. Matthew Husband:** Writing – review & editing, Conceptualization. **Pia Knoeferle:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization.

Ethics and consent

This study fell under a laboratory-wide approval from the ethics review board of the German Linguistics Society (DGfS, ethics vote number 2020-10-200807).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

The experimental items (critical, fillers, practice, and training), data, and analysis code for both experiments are available on the OSF: https://osf.io/fe6kp.

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