

Comprehending Counterfactuals

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Submitted for the Degree of Ph.D. to the Higher Degree Committee
of the Faculty of Information and Mathematical Sciences, University of Glasgow.

August 2007

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Abstract

Counterfactual reasoning, an understanding of events that are counter to reality, or false, is an essential ingredient of our everyday cognition. Counterfactual situations are frequently depicted through language, yet surprisingly little is known of how they are processed during reading or listening. This is remarkable given the social importance of understanding counterfactuals and the wealth of psychological research that has focused on the production of counterfactual statements. In this thesis, I present eight experiments that investigate how a counterfactual discourse can disrupt or facilitate processing of some subsequent linguistic input and address related comprehension issues involving negation and theory of mind. The main findings suggest that a counterfactual scenario (e.g. 'If cats were vegetarians') leads the comprehender to rapidly update their processing model to incorporate a counterfactual continuation. However, a secondary process briefly interferes at the point of ambiguity resolution in cases where world knowledge has been violated (e.g. 'Families could feed their cat a bowl of fish/ carrots'). The effects are compared across the different experimental paradigms used, including eye-tracking, event-related brain potentials and the visual-world paradigm, which reveal distinct integration, neural and anticipatory processes. Finally, these findings are discussed in relation to existing research on counterfactuals and the processing relationships between counterfactuals, negation and theory of mind reasoning.

Acknowledgements

I would like to thank my supervisor, Professor Tony Sanford, for his support and superb supervision during my PhD. It has been a great pleasure working together on this exciting series of experiments and I am hugely thankful for all the opportunities Tony has given me. I would also like to thank my second supervisor, Hartmut Leuthold, for his invaluable expertise in EEG techniques and Christoph Scheepers for his help with the visual- world paradigm. Various other members of the Glasgow University Language group have supported me with interesting discussions on this work and I would particularly like to thank Ruth Filik, Simon Garrod, Sara Sereno, Peter Ward and Chris Hand. This research was supported by an ESRC Postgraduate Training Award, PTA-030-2003-01586.

Special thanks are due to my lovely Mum and Dad for their constant encouragement and positive outlook (and occasional financial support!). Also to my sisters, Victoria and Elaine, who have listened to every inch of my PhD experience and are my benchmark for success. Finally, Markus- I couldn't have done it without you!

Declaration

I declare that this thesis is my own work carried out under the normal terms of supervision.

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Publications

Within this thesis, Chapter 2 has been accepted and Chapter 5 is under review for publication.

Chapter 2

Ferguson, H.J & Sanford, A.J. (in press). Anomalies in Real and Counterfactual Worlds: An eye- movement investigation. *Journal of Memory and Language*.

Chapter 5

Ferguson, H.J, Scheepers, C. & Sanford, A.J. (under review). Expectations in Counterfactual and Theory of Mind Reasoning. *Cognition*.

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Chapter 1

General Introduction: Comprehending Counterfactuals

A statement such as *we could feed our cat a bowl of carrots* clearly causes disruption at the word *carrots*, as our knowledge of the world tells us that cats do not generally eat carrots. However, if such a sentence is preceded by a counterfactual context, such as *If cats were vegetarians*, is an anomaly still detected? Furthermore, if it is no longer detected under these circumstances, what processes have led the comprehender to mentally ‘undo’ reality? These are the fundamental questions addressed in this thesis.

In this introduction chapter, I begin by defining counterfactuals, discussing their use in language and reviewing what is currently understood about counterfactual reasoning. This is followed by a review of current models that have been applied to language comprehension in general and consequently how these models relate to the comprehension of counterfactuals. I end this chapter by describing the general aims of the current work. Subsequent chapters discuss specific methodological issues (eye-tracking, event-related potentials and visual- world paradigm) and related research on topics such as negation and theory of mind. This is for clarity of exposition due to the large amount of research relevant to the questions addressed in this thesis.

What are counterfactuals and how are they used in language?

Counterfactual reasoning, an understanding of events that are counter to reality, or false, is an essential ingredient of our everyday cognition. Counterfactual situations are frequently depicted through language, yet surprisingly little is known of how they are processed during reading or listening. This thesis attempts an exploration of counterfactual processing during language comprehension. Counterfactuals are cases of possibly valid reasoning from premises that are false in actuality (Fauconnier & Turner, 2003), and require the comparison of reality to a model-based alternative. People understand a counterfactual statement, such as, *If money grew on trees then we’d all be millionaires* by keeping in mind two possibilities from the outset: the conjecture, *money*

grows on trees and *we are all millionaires*, and the presupposed facts, *money does not grow on trees* and *we are not all millionaires* (Byrne & Tasso, 1999). The counterfactual thus requires that a person represent false information that is temporarily supposed to be true, and allows them to attach a label to their models to keep track of their epistemic status. Research has shown that subjects' memory for counterfactuals tends to be for the presupposed facts, for example that *money does not grow on trees* and *we are not all millionaires* (Fillenbaum, 1974).

An ability to reason counterfactually develops from a young age, as children as young as two years old can understand the consequent meaning of *nearly* or *almost* and are able to apply counterfactual thinking to pretend play (e.g. Riggs & Peterson, 2000). In fact, developmental researchers have suggested that counterfactual reasoning could account, at least in part, for theory of mind understanding. Studies of healthy and autistic children have revealed that children's ability to reason counterfactually is a necessary and predictive component of successful performance in false belief tasks, regardless of age and language skills (Riggs, Peterson, Robinson & Mitchell, 1998; Peterson & Bowler, 2000). Thus, on the basis of these preliminary investigations, it appears plausible to assume that consistent specialized cognitive processes are required to comprehend counterfactuals and the beliefs of others. This is supported by evidence that we are immediately able to use relevant linguistic and non-linguistic information, such as the wider discourse and its genre, as well as the intensions, beliefs and desires of others, to enhance comprehension of an unfolding sentence (Hagoort & Van Berkum, 2007).

Counterfactual reasoning patterns

An acceptance of some counterfactual alternative is commonly associated with storytelling and literature. For example, readers must accommodate a counterfactual, magical

world to make sense of flying broomsticks and talking animals in J.K. Rowling's *Harry Potter* books, or Elves and Orcs in J.R.R. Tolkien's *Lord of the Rings* trilogy.

Counterfactual thinking also serves important social functions, for instance in reflecting on past events with negative outcomes [the "if-only..." effect; of Kahneman and Tversky (1982); see also Byrne, 2007; Kahneman, 1995]. People tend to think not only about the events that actually happened but also how those events might have been different. For example, if you get stuck in traffic and are late for an important job interview, you might wonder if you would have been on time if you had left earlier, taken a different route or if you had taken the train. These sorts of counterfactual thoughts are pervasive in adult mental life and play an integral role in higher-level cognition such as deductive reasoning (Johnson-Laird & Byrne, 1991; Gilovich & Medvec, 1994). In sum, counterfactuals have been implicated in diverse cognitive activities, ranging from simple imagination beyond reality, and fantasy (e.g., Sternberg & Gastel, 1989) to the exploration of possibilities in reasoning (e.g. Byrne & Tasso, 1999; Johnson-Laird & Byrne, 2002).

There has been a very large amount of research on reasoning with counterfactuals (c.f., Byrne, 2002), and on what sort of constraints there are on the kinds of counterfactual thoughts people are likely to generate in a variety of circumstances (e.g., Kahneman & Miller, 1986; Byrne, 1997; Markman & Tetlock, 2000). Many studies have revealed that counterfactuals are generated most frequently following a bad outcome, or goal failure (Roese, Sanna & Galinsky, 2005). Specifically, 'upward' counterfactuals consider how a situation could have turned out better and thus serve a preparatory function to learn from mistakes. 'Downward' counterfactuals describe how a situation could have been worse, serving an affective function to make a person feel better. Psychological studies have indicated that there are considerable regularities in the sorts of counterfactuals people generate most readily, despite the infinite number of

ways that past events could have happened differently. Their counterfactual thoughts tend to mentally undo the most recent event in an independent sequence. A temporal order effect has been proposed to explain why, for example, an individual is judged to be lucky when a good outcome is described after a bad one or why a second penalty in a football match is well rated after a first one that was poorly rated (Teigen, Evensen & Samoilow, 1999). Walsh and Byrne (2004) suggest five principles that explain the temporal order effect observed when people generate counterfactual statements. The first two assumptions are that people keep in mind the true possibilities, and that people think about just a subset of the possible counterfactual models. The third principle is that the subset of counterfactual possibilities that people keep in mind is guided by the winning conditions. The fourth principle is that people mutate the crucial elements of the facts to be like the winning conditions. Finally, the fifth principle is that the first element in the facts is an 'anchor' that is presupposed and remains relatively immutable (Byrne, Segura, Culhane, Tasso & Berrocal, 2000).

Walsh and Byrne (2004) carried out three experiments that provided the first empirical evidence that people think counterfactually about the same set of facts in different ways depending on the alternatives that have been made available. The participants' task was to reason on the outcome of a colour card game scenario under different descriptions of the winning conditions. Results showed that the temporal order effect can be produced or reversed by different descriptions of the winning conditions. In a similar study, Meehan and Byrne (2005) investigated how the temporal order effect found in adults extends to children's counterfactual thoughts. The experiment showed that children aged six and eight years exhibited the standard temporal order effect when they were asked to think about what might have been, but they differed in their judgements of guilt and blame. While 8-year olds, like adults, judged that the second player will feel more guilt and be blamed more by the first player, the temporal order

effect does not occur for 6-year olds' judgements of guilt and blame. This dissociation of counterfactual thoughts and social judgements in 6-year olds indicates that their creation of counterfactual alternatives has not yet fully developed.

How are counterfactual situations established?

Fauconnier (1994) has catalogued a number of ways in which counterfactual worlds may be triggered, employing two dimensions of counterfactuality. The first is a lexical dimension, on which negatives are strongest as they automatically cancel an implicature, as in (1), followed by verbs like *wish* or *hope*, as in (2). Lower on the lexical dimension, counterfactuality can be imposed or implied using conditionals (*If-then* constructions) (3) and modal terms, such as, *could* or *might* (4).

- (1) Luckily John did not fail the exam. He would have been thrown off the course.
- (2) I wish Dave were strong like superman. He could rescue me if I was in trouble.
- (3) If Sarah were transferred to an office in France, then she would need to learn to speak French.
- (4) John would have bought the expensive car if he had lots of money in the bank.

It is also known that tense influences the plausibility of counterfactual interpretation (e.g. Cowper, 1999; Kratzer, 1991). Consider, for example, the sentences in (5). All three sentences express the same logical relationship between *Bill coming tomorrow* (the protasis *B*) and *Susie making dinner*. However, counterfactuality is produced in different ways according to the distribution of tenses. Specifically, for (5a) to make sense, *B* must either be valid or undetermined, but it can not be used if we are certain that Bill is not coming tomorrow. In contrast, (5b) can be used if *B* is undetermined or if it has been established that Bill is not coming tomorrow (counterfactual), but not if *B* is

valid. Finally, (5c) can only be used counterfactually as it directly implies that we know that Bill is not coming tomorrow.

- (5) a. If Bill comes tomorrow Susie will make him dinner.
- b. If Bill came tomorrow Susie would make him dinner.
- c. If Bill had come tomorrow Susie would have made him dinner.

In the studies reported in this thesis, I have relied on *If-then* constructions because they clearly signal a counterfactual world for consideration.

Neurological correlates of counterfactual thinking

Preliminary investigations have attempted to link counterfactual thinking to its underlying neural correlates, particularly examining cognitive processes such as regret. Regret can be defined as the experience when a previous decision conflicts to our disadvantage with what we would have obtained had we opted for a rejected alternative (Kahneman & Tversky, 1982; Kahneman & Miller, 1986). Thus, it is a cognitively enriched emotion embodying a feeling of responsibility for negative outcomes of choices (Bell, 1982; Loomes & Sugden, 1982). Camille, Coricelli, Sallet, Pradat-Diehl, Duhamel and Sirigu (2004) employed a simple gambling task to look at the involvement of the orbitofrontal cortex in the experience of regret. The orbitofrontal cortex is a structure that is connected with the dorsolateral prefrontal regions active in reasoning and planning, with limbic areas such as the amygdala important for emotion, and with other areas providing direct or indirect access to multiple sensory modalities (Rolls, 2000). Comparison of normal subjects and a patient group with orbitofrontal cortical lesions revealed that the experience of regret or anticipation of a negative outcome was severely impaired in the patient group. This suggests that the orbitofrontal cortex has a

fundamental role in counterfactual thinking. Recently, neuroimaging studies have supported the role of the orbitofrontal cortex in counterfactual reasoning (e.g. Elliott, Newman, Longe & Deakin, 2003; Coricelli, Critchley, Joffily, O'Doherty, Sirigu & Dolan, 2005) and have also shown enhanced activity in the hippocampus and the anterior cingulate cortex, an area consistently activated during theory of mind tasks (see Gallagher and Frith, 2003, for a review), with increasing regret.

How might Counterfactuals be represented during comprehension?

However, in contrast to research within the framework of reasoning and its social concomitants, there has been very little research on how counterfactuals are understood during language comprehension, for instance of what kinds of representations they set up. To tackle this issue, we first discuss some issues that have been raised by philosophers concerning the logic of counterfactuals. Then, theories of language comprehension will be considered in general terms and subsequently, we will consider how these models may fit with the comprehension of counterfactuals.

Attempts have been made to evaluate the logical truth conditions of counterfactual statements. Goodman (1947) investigated the problem of determining which true statements are combined with the false premises to carry out the reasoning, while Lewis (1973) considered the problem of determining when and which logical laws apply to counterfactuals. However, cognitive-semantic speculations about how counterfactual spaces are set up and structured have been initiated by Fauconnier (1985; 1997) who applied a 'mental spaces' approach to the comprehension of counterfactuals. Mental spaces are defined as structured, incremental sets that include elements and relationships between them, with availability for new elements to be added and new interactions between the elements to be created. Thus, these mental spaces, and the relationships between them, are a way of specifying an interpretation of a discourse.

the laws of physics (e.g. gravity, time) that exist in reality will also apply in the hypothetical counterfactual space, although the *H*-space may include some explicitly specified elements that are counter to reality. By this logic, a counterfactual conditional construction results in a hypothetical space that possesses the same constraints as those in reality. In sum, although Fauconnier presents some very interesting analyses of what is entailed with counterfactual worlds, his analyses do not really provide any basis for predicting how propositions are processed with respect to real world and counterfactual world spaces.

Counterfactuals and standard accounts of comprehension

There have been several general approaches to text comprehension in the discourse processing literature. We now explore what these accounts, as they stand, have to say about the representation of counterfactuals. One problem in the current literature is that some of the mental ‘entities’ are used in an almost interchangeable way, often making it difficult to comprehend the differences between the accounts. Here, I will attempt to discuss the different approaches individually, drawing particular attention to how those models fit with the mental representation of counterfactual situations.

Schema Theory

The notion of a schema as a mental representation of information in a text originates from the work of Bartlett (1932). Bartlett proposed that our perceptual, understanding and memory experiences are guided by expectations based on prior knowledge, where schemas refer to the basic units of prior knowledge. Thus, the main premise of the schema theory is that comprehension of new information, and texts in particular, requires the reader to relate the current input to some mental representation based on relevant prior knowledge or experience. A large literature shows that input is related to

world knowledge. A particular idea related to schema theory is the use of situation-specific knowledge, for example Schank and Abelson's (1977) theory of scripts to represent information and the more psychological version suggested by Sanford and Garrod (1981; 1998; see also Sanford & Moxey, 1995; 1999). According to Sanford and Garrod, when comprehending an utterance a fundamental process maps that information onto situation-specific background knowledge in order to aid understanding. For example, a sentence such as (6) maps into experiential knowledge about a bride in a wedding situation. However, integration problems are likely to emerge as the conjecture that *the bride was wearing a black dress* does not fit with our situation model of what brides wear to their wedding (i.e. a white dress). Thus, in order to make sense of this, readers try to relate that information to a different scenario, for example reasoning that the bride was a Goth, making it 'appropriate' for her to wear black to her wedding.

(6) The bride walked down the aisle in her black dress.

Although the schema approach has been criticised for defining such strict divisions of background information (see Sadoski, Paivio & Goetz, 1991, for a review), it is compatible with a mental representation where world knowledge is available and where any unexpected entities are not integrated immediately in the conjecture. Therefore, while the schema theory has not been directly related to the comprehension of counterfactuals, it does make some sensible assertions about how language is represented, which can be applied to counterfactual situations. Specifically, counterfactuals can require the reader to overrule their knowledge of the world in order to make sense of an utterance, which suggests that comprehension is grounded in reality at some level.

Situation models

Growing evidence in the literature suggests that comprehending a text involves the construction of a mental representation of the information, defined as a *situation model* (Glenberg, Meyer & Lindem, 1987; Graesser, Millis & Zwaan, 1997; Zwaan & Radvansky, 1998). Situation models are non-linguistic representations that are composed of four primary types of information: a spatial-temporal framework, entities (e.g. people, objects, ideas), properties of those entities and the relationship between the given information (e.g. spatial, temporal, causal). The information is then represented across three levels, from the situation model (event-specific), to the episodic model (coherent sequences of events) and finally to the comprehensive model (a complete collection of episodes). Thus, these mental simulations are considered to be experiential in nature as they implicate embodiment and are assumed to be grounded in perception and action. According to this proposal, understanding language entails recapitulating motor or perceptual activity as a ‘simulation’ of the language input.

A number of findings have been produced over the last decade to demonstrate the validity of this mental-simulation view, many of which will be discussed presently (see Zwaan, 2004 for an overview). Neuroimaging studies have revealed that processing action words associated with specific body parts (e.g. arm- pull) activates consistent brain regions, including areas of the motor and pre-motor cortex, that are involved in perceiving or performing those motor actions with the same effectors (e.g. Martin & Chao, 2001; Pulvermüller, 1999; 2002). Thus, this supports the view that understanding language can involve an embodied component, perhaps a mental simulation of actions using specific effectors.

This work has been extended with data showing that simulation is an important part of understanding, such that the mental representations set up during language comprehension can be related to performance on some motor task. For example, in an

eye-tracking study, Spivey, Tyler, Richardson and Young (2000) showed that while listening to a complex description of a visual scene, participants' eye movements were consistent with physically perceiving that scene. Perceptual tasks have also shown processing costs associated with switching between different modalities, with longer response times to targets in an unexpected modality (e.g. Spence, Nicholls & Driver, 2001). Pecher, Zeelenberg, and Barsalou (2003) revealed similar results using a semantic priming task. Participants were asked to verify that concepts had particular properties (e.g. that a blender is *loud*). Reaction times were shorter for trials where the perceptual dimension relating the two concepts was the same as in the previous trial (e.g. leaves - rustle) than when the previous trial tapped into a different perceptual dimension (e.g. apple - sweet). Thus, reflecting on the meaning of these concepts appears to prime access to perceptual information.

Recently, researchers have relied on the facilitation or interference effects due to the degree of similarity between the experimental task and the linguistic input to investigate this issue. These studies rely on the idea that language understanding entails running a mental simulation of a described event, in which the comprehender activates motor representations corresponding to what participants in the scene might do and perceptual representations of images they might perceive. Therefore, processing information could be facilitated if the perceived action matches an action required by the experimental task. In contrast, processing could be impeded either if these two mismatch or if processing of one interferes with processing of the other, for example in a speeded decision task. Glenberg and Kaschak (2002) compared sensibility judgements as participants were presented with sentences such as *He closed the drawer* versus *He opened the drawer*. Importantly, half the experimental items described a movement towards the participant ('opened'), while half involved a movement away from the participant ('closed'). Thus, in one condition, participants made their 'sensible'

response by moving a lever away from their body while in another condition, a ‘sensible’ response required a movement towards their body. Responses were faster when the movement for a ‘sensible’ judgement matched the movement implied by the language input (i.e. *He closed the drawer* with a movement towards the comprehender) than when there was a mismatch (i.e. movement away from the comprehender).

Similarly, responses to a visually presented stimulus (see Figure 1.2) were faster when the depicted object’s shape and orientation matched information implied in a preceding sentence (Stanfield & Zwaan, 2001; Zwaan, Stanfield & Yaxley, 2002). Specifically, responses were facilitated when a sentence such as, *The ranger saw an eagle in the sky* was followed by an image of an eagle with its wings outstretched (a), compared to trials where this information mismatched, such as an image of an eagle with folded wings (b).



Figure 1.2: Example images used in Zwaan and colleagues’ studies (Stanfield & Zwaan, 2001; Zwaan, Stanfield & Yaxley, 2002).

Another finding was reported by Zwaan and Yaxley (2003a; 2003b), extending the mismatching results to single words rather than sentences. Participants were asked to judge the semantic relatedness of two words (e.g. *attic* - *basement*) presented one above the other on computer screen. Responses were faster when the spatial relation on the screen was consistent with the spatial relationship in the real-world (i.e. *attic* on top) than when the two were inconsistent (i.e. *basement* on top). These studies therefore provide more support for the suggestion that thinking about the meaning of a word

makes perceptual information available. Finally, studies on the comprehension of negatives reveals that information that is involved in a given situation is more available in the comprehender's brain than information that is not directly involved (e.g. Glenberg, Meyer & Lindem, 1987; Kaup & Zwaan, 2003; Zwaan, Madden & Whitten, 2000). This issue will be addressed in more detail in Chapter 4.

Recently, the issue of embodiment has been investigated in relation to counterfactual information (Urrutia, Moreno, de Vega & Morera, 2005; see also de Vega, in press). Experimental items described a transference situation, either *away from me* or *towards me*, within a factual or counterfactual sentence. Thus, items were either factual away from me (7a), factual towards me (7b), counterfactual away from me (7c) or counterfactual towards me (7d).

- (7) a. Because I am generous I've lent you the novel of Harry Potter.
- b. Because the jeweller is a good friend of mine he has shown me the imperial diamond.
- c. If I had been generous I would have lent you the novel of Harry Potter.
- d. If the jeweller had been a good friend of mine he would have shown me the imperial diamond.

Participants were asked to respond to the transfer word (e.g. 'lent' or 'shown') by pressing either a towards- or an away- key according to the perceived motion of that visually presented word. The inter-stimulus interval (ISI) between the transient word presentation and its apparent motion was manipulated between participants (100ms versus 200ms) so that the temporal overlapping between the word and perceived motion varied. Response times to the animated word showed a similar mismatching advantage for both factual and counterfactual sentences. In other words, at these short ISIs, where

word animation and semantic integration processes overlapped, responses were slower when the animation matched the meaning of the transfer word than when the perceptual and semantic information mismatched (e.g. towards- away conditions > away- away conditions). However, for factual sentences these effects were revealed in the 200ms interval whereas the effects for counterfactual sentences emerged in the 100ms interval and had disappeared by the 200ms interval. These results suggest that when a transference construction is embedded in a counterfactual sentence, an embodied simulation of its literal meaning is automatically generated, at least temporarily.

Taken together, these findings suggest that the ‘simulation’ aspect of situation models plays a role in comprehension so that when comprehenders process some linguistic input they mentally simulate the described state of affairs in a way that is similar to if they were experiencing them directly. However, evidence to date does not support a view where embodied meaning is a necessary, real-time component of language comprehension in general (Sanford, in press). As such, it is difficult to relate situation models to the representation of counterfactuals as they make no clear proposals about how possibly valid information, that does not contain an embodied concept (e.g. lend), could be represented within this framework.

Mental models

A theory of mental models has been proposed by Johnson-Laird (1983; see also Garnham, 1981). Mental models are often referred to alongside situation models, with little distinction between the two (e.g. Kaup, Zwaan & Lüdtke, in press), however, clear differences separate the two accounts. Namely, while situation models describe representations of language as a mental simulation of the states of affairs described in the text, mental models focus on the way mental representations correspond to information about the real or imaginary world, thus focusing on the logical structure of

events. As such, mental models are mental representations that are structurally close to a model of the world rather than a model of the language that describes it. Extensive research has been conducted on mental models and has demonstrated that mental models play an integral role in the comprehension and representation of written texts (e.g. Bower & Rinck, 1999; Garnham, 1996; 1997; Garnham & Oakhill, 1996; Gernsbacher, 1995; Oakhill, 1996; Rickheit & Habel, 1999).

The mental models theory has been developed within a simple information processing framework, spanning concepts such as position, spatial layout and time. This model attempts to capture representations of reality and to enable inferences between concepts, thus it has proved particularly useful in deductive reasoning. However, growing evidence suggests that reasoning about factual and counterfactual situations relies on similar mental processes and that inferences are drawn from imaginary situations just as they are from real situations, by constructing mental models (e.g. Byrne & Tasso, 1994; Byrne, 1997). Consider the example in (8):

(8) If it had rained, the children would have played indoors.

In cases such as these, Byrne (1997) suggests that readers do not represent the false alternative in which it rained and the children played indoors as this conflicts with the counterfactual conditional framework. Instead, representations are made of the factual situation, as indexed by the counterfactual conditional, where it did not rain and the children did not play indoors. This supports an earlier suggestion that typically, people use mental models to represent information that is true (Johnson-Laird & Byrne, 1991).

In summary, because the mental models theory handles deductive reasoning, it naturally offers possibilities for representing counterfactuals. Furthermore, this theory has a “core” *extensional* account of conditionals, making a conditional ‘if p then q ’

logically equivalent to ‘not- p or q ’, as demonstrated in (8). Consequently, when this account is applied to the case of counterfactual conditionals, it is proposed that both factual and counterfactual possibilities are represented by the reader.

Suppositional Theory

An alternative view to that of how mental models might be applied to counterfactual processing follows from work by Ramsey (1931) and has gained increasing interest in the last few years. This account proposes that when comprehending a conditional statement, people “hypothetically add p to their stock of knowledge and argue on that basis about q ”. This practice is commonly known as the *Ramsey test*. Recent literature has challenged the mental model theory (Evans & Over, 2004; Evans, Over & Handley, 2005). Specifically, problems with the mental model account emerge from studies that allow participants to express degrees of confidence in their conclusions to conditional arguments. In these cases, levels of confidence directly relate to their belief in the conditional premise (George, 1995; 1997; Liu, Lo & Wu, 1996; Stevenson & Over, 1995; 2001), suggesting that peoples’ mental representations of conditional statements involve varying degrees of association between p and q and between q and p . However, the mental model theory does not allow for both directional links and belief tendencies.

As a substitute, Evans, Over and Handley (2005; see also Evans & Over, 2004) have proposed a *suppositional theory* where a conditional of the form “if p then q ” directs attention to possibilities following from p , and *not* to “not- p or q ” possibilities. According to the suppositional account, when a person encounters a counterfactual possibility they temporarily add this possibility to their store of beliefs by creating a model via a process of minimal change to reality. So, in a counterfactual statement such as *If cats were vegetarians*, people will make a minimal change to their representation of what a cat is in order to suppose that cats are vegetarian. Then one can ask how

confident they are in the consequent (e.g. feeding a cat a bowl of carrots). Importantly, when applied to counterfactual reasoning, the suppositional view makes very different predictions to the mental model view as it suggests that people will, under some circumstances, consider a case where the supposed antecedent holds but the consequent does not. Thus, the supposition is about the closest appropriate possibility, according to a person's judgement, meaning that counterfactual statements should be evaluated with respect to suppositional or hypothetical possibilities first. However, this approach is still in the early stages of development and as such, many more empirical investigations are required before a complete psychological theory of reasoning can be concluded.

On-line processes underlying counterfactual representation

The experiments reported in this thesis are an attempt to examine the role played by real-world (factual) knowledge, and inferences from counterfactual-worlds during on-line comprehension of simple statements. This problem is illustrated with a simple example. In the real world, it is anomalous to say (9):

- (9) If the cat is hungry, the owner could feed the cat carrots and it would happily gobble them down.

If a counterfactual world is set up through a statement like (10), then statement (9) is not anomalous with respect to that counterfactual world, although it remains so with respect to the real world.

- (10) It would be great if cats were vegetarian.

According to the mental model theory, people have to keep in mind both the conjecture *If cats were vegetarians then* (9), and the presupposed facts that *cats are not vegetarian and do not like carrots* (e.g., Byrne & Tasso, 1999). Similarly, according to Fauconnier (1985; 1994), two spaces reflecting the real and the counterfactual world are set up.

However, according to the suppositional theory, people would hypothetically suppose that *cats are vegetarians* and then judge their degree of confidence in *feeding cats a bowl of carrots* given that supposition. If the conditional probability was high, they would confidently believe the statement and accept it. Conversely, if the conditional probability was low, they would have doubts about the statement and not accept it.

Although it is undoubtedly true that ultimately a proper appreciation of counterfactuals requires knowledge about both real and counterfactual worlds, it is unclear whether the two would both be present simultaneously in a representation of the discourse model associated with the introduction of a counterfactual situation. Alternatively, processing counterfactuals could involve a sequential process, in which the counterfactual was temporarily accepted as the true world, although the consequences of this are tested against the true world for inference either initially or sometime later.

This immediately gives rise to a processing question: can something that is anomalous given our real-world knowledge be “neutralised” as an anomaly if it is consistent within a pre-specified counterfactual world context? According to the mental model theory, this contextual integration process may be delayed so that it initially leads to typical anomaly detection responses, and later becomes accommodated by the counterfactual world representation. Alternatively, in line with the suppositional theory, the counterfactual world may be the only discourse representation against which a following statement is evaluated. Therefore, if an inferential statement with high conditional probability follows from the counterfactual world, it would not show as anomalous immediately (though there might be later consequences). This is the basic

question of this thesis. For the remainder of this thesis, the term ‘anomaly’ will be used with reference to real-world expectancies, while ‘consistency’ will be used to refer to the level of consistency with the prior context.

Empirical investigations of the on-line question

Recently, a limited number of studies have begun to investigate how counterfactuals are processed on-line. In an unpublished Masters thesis, Van de Ven (2001) tested a direct hypothesis that world knowledge would not interfere with counterfactual processing against an indirect hypothesis that accommodation of counterfactual information is delayed by an initial checking against real-world knowledge in two self-paced reading experiments. Participants read a single sentence, that either depicted a realistic context with mismatching information, as in (11a), or a counterfactual context where information in the continuation made sense within the context, as in (11b).

- (11) a. If Shakespeare had wanted to work more quickly, he could have used the latest word processor to write all his works.
- b. If Shakespeare had the benefit of modern technology, he could have used the latest word processor to write all his works.

Results showed that participants were faster to read (11b) than (11a), suggesting that readers have rapidly integrated the counterfactual context into their interpretation of the sentence. This study therefore supports a model of counterfactual comprehension where checking against reality is not necessary.

Another set of experiments has used on-line methods to explore how updating processes are modified for counterfactuals embedded in narratives (de Vega, Urrutia & Rizzo, in press). Updating occurs when readers modify their representation of events

according to the evolving language input (e.g. Glenberg, Meyer & Lindem, 1987; de Vega, 1995; Zwaan & Madden, 2004). In a self-paced reading task (Experiment 1), participants were asked to read either a factual (12a) or counterfactual sentence (12b) embedded in a short narrative.

(12) a. Since Mary won the lottery she bought a Mercedes car.

b. If Mary had won the lottery she would have bought a Mercedes car.

Reading times were measured during a final continuation sentence that was either congruent or incongruent with the preceding context (e.g. *Mary got into the Mercedes car and she felt like a queen* versus *Mary tore the ticket to pieces and started to clean the kitchen*). Compared to factual stories, reading times were shorter for counterfactual stories when the continuation referred to non-updated information (i.e. referred to the old situation) and longer when the final sentence was a continuation of the ongoing situation (i.e. referred to the new situation). In a second experiment, de Vega et al. presented participants with the same types of stories and asked them to respond to a test probe word that could have either appeared in the initial (old situation) or final (new situation) sentence. Results showed that the initial situation was less accessible in factual than in counterfactual contexts, although access to recent information was equal for factual and counterfactual stories. However, a third experiment showed that these effects can vary in strength and direction depending on the structure of the experimental stories. On the basis of these results, the authors argue that while reading a counterfactual sentence initially makes available both a factual and a counterfactual interpretation of events, counterfactual events are later suppressed as the readers' attention shifts back to the initial events in a story.

It is important to note that both Van de Ven and de Vega et al.'s studies were limited by several factors. Most importantly, the reading time and probe recognition methodologies do not allow a thorough investigation of the time course for processing counterfactual processing. Processing difficulties from real-world knowledge may be very localised and fast and as such may have been missed by a reading time analysis spanning several words or an entire sentence. Therefore, eye-movement analysis and ERPs have been employed in the experiments discussed here, as they have proved to produce highly accurate data on the temporal nature of language comprehension (see chapter introductions for a full discussion of each methodology). Additionally, the experimental items used in Van de Ven's study were not controlled for length, frequency or position of the critical word. Similarly, the critical final sentences used in de Vega et al's study (e.g. 'Mary got into the Mercedes car and she felt like a queen' versus 'Mary tore the ticket to pieces and started to clean the kitchen') contained completely different information, meaning that effects in reading times may have been directly influenced by the differing lexical or structural content. Thus, for the experiments in this thesis, care was taken to construct a real-world or counterfactual-world context in a separate sentence. Target sentences, depicting a consequence from the counterfactual or factual world, were identical except for the critical word, which appeared in the same position across conditions and comparable positions across items. Furthermore, to establish the strength of counterfactual contexts within a discourse, these studies specifically examine how a counterfactual context might influence anomalies of real-world (factual) knowledge during on-line comprehension of simple statements. Thus, if counterfactuals cancel discourse updating, as suggested by de Vega et al., then we might expect to see persistent effects of a world knowledge violation regardless of a counterfactual world context.

Effects of local and global cues for anomaly detection

Anomalies provide a useful tool to investigate the integration of new linguistic input into existing representations. For example, a semantic anomaly such as, *The girl drank her tea from a book* is obviously noticed, as the features of a book are inappropriate for the concept of drinking tea. However, the likelihood of detecting anomalies can be modulated by other factors, such as the *closeness* of a word's meaning to the 'correct' word. In the so-called Moses Illusion (Erickson & Matteson, 1981; Van Oostendorp and De Mul, 1990; Van Oostendorp and Kok, 1990; Hannon & Danneman, 2001), participants were more likely to miss the anomaly (i.e. it was Noah who put the animals on the Ark) in (13) when 'Moses' was replaced by 'Adam'. This detection rate difference can be explained in terms of semantic relatedness, specifically that 'Moses', as a biblical character, is more semantically similar to 'Noah' than 'Adam'.

(13) Moses put two of each animal on the ark.

Similarly, Barton and Sanford (1993) investigated the impact that situation- descriptions have on anomaly detection. Participants were given a description of an air crash and asked to suggest *where the survivors should be buried*. Subsequently, only half of participants recognised that you simply don't bury survivors, suggesting that a word's lexical meaning is not always incorporated into the sentence interpretation. Additional research established that the fit of the word to the depicted context as well as the core meaning of a word plays a greater role than what the use of the word presupposes. Thus, we can see that knowledge of the wider discourse (e.g. an air crash) and semantic meaning of a word (e.g. survivors) can both influence detection of anomalies during language comprehension. These two aspects of language comprehension have an

important bearing on the issues at hand, where we introduce a counterfactual discourse and examine how this interferes with the normal semantic processing of a word.

Psycholinguistic research has considered the interplay between lexical-semantic constraints and discourse context in terms of ‘local’ and ‘global’ factors (Hess, Foss & Carroll, 1995). The issue of when and how these two sources of information are used during language comprehension has been a controversial topic (e.g. Graesser, Millis & Zwaan, 1997; Carpenter, Miyake & Just, 1995; McKoon & Ratcliff, 1998). Some accounts of language comprehension suggest that the meaning of a sentence is initially derived from local information, independent of discourse context, prior to integration with the preceding discourse (e.g. Fodor, 1983; Forster, 1979; Kintsch, 1988; Millis & Just, 1994). According to these ‘two-stage’ models, global contextual information can not initially override local semantic factors. Thus, a sentence such as *we could feed our cat a bowl of carrots* should consistently lead to disruptions in the comprehension system, even in an appropriate counterfactual discourse context.

Interactive models have challenged this distinction between local and global factors for language comprehension and have proposed an alternative ‘single-step’ model, where local semantic information does not have a precedent over the global context (e.g. Bates & MacWhinney, 1989; Jackendoff, 2002; Marslen-Wilson & Tyler, 1980). Specifically, both local and global constraints can simultaneously guide language comprehension as a function of relevance and strength. Thus, according to this model, a sentence like *we could feed our cat a bowl of carrots* might be very easy to understand within an appropriate discourse context.

Empirical investigations to date have employed a range of techniques, including cross-modal naming, lexical decision, eye-tracking and ERP, but have provided contradictory evidence of how local and global factors interact during language comprehension. On one hand, some studies have revealed a relatively late influence of

global context on language processing (e.g. Millis & Just, 1994; Rayner, Pacht & Duffy, 1994), while others have suggested that global factors have a very early impact (e.g. Hess, Foss & Carroll, 1995; Altmann & Kamide, 1999; Niewlands & Van Berkum, 2006). However, none of these studies has investigated the interplay between local and global factors with a discourse context as pervasive and powerful as counterfactuals.

In this thesis I present a series of experiments, using techniques ranging from eye- movements and ERPs during reading to language comprehension in a visual world, in an attempt to begin empirical investigations into the comprehension of counterfactuals. Specifically, to examine the processing of counterfactual *versus* factual knowledge, I have created experimental items that are anomalous with respect to the real-world, but not with respect to some counterfactual world. The question was whether a counterfactual setting, making the anomaly acceptable, would result in the removal of all difficulties associated with the anomaly occurring in the absence of a counterfactual setting, or whether there would still be a difficulty observed because the proposition is compared with real-world information despite the counterfactual setting.

Thesis structure

As I have demonstrated, the on-line study of counterfactual comprehension has been largely neglected by psycholinguistics and discourse researchers. However, this area of research is potentially hugely valuable due to the prominence of counterfactuals in everyday language, to accomplish communicators' personal goals and the need to be understood by others. To date, on-line investigations of counterfactual comprehension have produced contradictory evidence for updating in counterfactual sentences (Van de Ven, 2001; de Vega et al., in press). While de Vega et al. provide preliminary evidence suggesting that readers do not update their mental model following some counterfactual context, the results from Van de Ven's study suggest that the counterfactual context *has*

been integrated into the sentence interpretation. However, this difference might simply be due to the types of counterfactuals used in each study. Specifically, Van de Ven used counterfactuals that required the comprehender to alter some knowledge of reality whereas the counterfactuals in de Vega et al.'s studies updated situation-specific information without any change to reality. The studies reported in this thesis use much more precise methodologies applied to the comprehension of 'reality-altering' counterfactuals.

Therefore, the aim of this thesis was to investigate how counterfactual statements are represented in the brain during language comprehension. Furthermore, this thesis attempts to determine how and when comprehenders use counterfactual information to make sense of some consequent that might require real-world knowledge to be suppressed for it to be accommodated within the pre-specified counterfactual model. The first experimental chapter reports three eye-movement studies examining how local pragmatic anomalies can be influenced by a prior counterfactual context. These studies investigated whether the introduction of a counterfactual context would result in the removal of all difficulties typically associated with local world-knowledge violations occurring in the absence of a counterfactual setting. Alternatively, a difficulty could still be observed because the proposition is compared with real-world information despite the counterfactual setting. Experiment 2 expanded the findings in Experiment 1 with the introduction of a fourth condition that examined processing of information that is congruent in terms of the real world but is inconsistent within the counterfactual world context. Experimental items in this experiment also ensured that semantic priming was not influencing the results. Finally, a third experiment attempted to replicate earlier findings and further investigated the role of the modal verb (*could*) in the critical sentence.

A similar paradigm was employed in Chapter 3, but now using Event Related brain Potentials (ERPs) to establish the neural mechanisms and their time course during the comprehension of counterfactuals. Thus, Experiment 4 examined whether typical N400 effects to local semantic violations can be deactivated, or reversed, by introducing an appropriate single-sentence counterfactual context. Additional evidence is also reported from time- frequency analyses of the Electroencephalogram (EEG) data.

Chapter 4 explored the similar phenomena of negation (e.g. *If cats were not carnivores...*). It has been suggested that counterfactuals are special cases of negation, as a counterfactual statement (e.g. *If cats were vegetarians...*) implicitly negates the antecedent (in fact *cats are not vegetarians*) and the consequent (in fact *cats do not eat carrots*) of a sentence. Thus, in an eye- tracking study (Experiment 5) and an ERP study (Experiment 6), I compared whether and at what stage of processing a negative context influences interpretation of a target sentence.

The final empirical chapter investigated the build- up of expectations in a counterfactual context (Experiment 7) and extends this to a study of theory of mind (ToM) reasoning (Experiment 8) in two visual- world paradigm experiments. This work relates to developmental theorists' proposal that ToM is a special case of counterfactual thinking, and as such may engage a network of consistent specialized cognitive processes (Leslie, 1987; Riggs et al., 1998), as discussed earlier in this chapter. The visual- world paradigm provides valuable information on top-down expectations accrued during the language comprehension process, and as such is ideal to examine how and when comprehenders update their model with incoming linguistic input.

Chapter 2

Anomalies in Real and Counterfactual Worlds: An eye- movement
investigation

Introduction

Three experiments in this chapter present a novel approach to studying counterfactual reasoning. In particular, the use of an on-line measure such as eye-movements, rather than a traditional response-based measure (see Chapter 1 for a full review), has allowed a potentially exciting look into the unfolding process of counterfactual thinking. As I will now summarise, a large body of eye-tracking research is available, making conclusions about the nature of eye-movements during reading and as a consequence of anomaly detection.

For over a century, eye-movements have been considered as a sensitive indicator of the reading process (Huey, 1908; Javal, 1879; Tinker, 1958). When readers process a page of text, their eyes do not move in a continuous sweep across the page, but instead the movement, called a *saccade*, tends to be quite jerky, occasionally stopping to fixate a word. The eyes generally move forward about 7 to 9 character spaces with each saccade and fixations typically last between 150 and 500ms, but there is a considerable amount of variation within this range. Although most saccades in reading move forward, about 10 to 15 percent move backward and are termed *regressive saccades* (or *regressions*). Regressive eye-movements go largely unnoticed during normal reading; however, they serve important functions for language comprehension. Thus, while the majority of regressive eye-movements are quite short, only going back a few characters, others require the reader to go back a considerable distance in the text to make sense of a major confusion (Rayner & Pollatsek, 1989). Therefore, variations in fixation times and regressions provide information on the level of difficulty for processing a piece of text.

Rayner (1998) suggests that the ease or difficulty associated with processing a word is accurately reflected in the amount of time that readers spend looking at that word. Variations of word length and word frequency demonstrate this effect, as well as

constraints of the preceding context to ambiguous words (Inhoff & Rayner, 1986; Rayner & Duffy, 1986; Rayner & Well, 1996). Recently, evidence has been presented to suggest that eye- movement patterns during reading identify costs associated with relating sentence meaning to real world probabilities. Thus, pragmatic anomalies like (1) have been found to induce longer reading times prior to a gradual increase in regressive eye- movements, reaching a maximum at the sentence conclusion (Ni, Fodor, Crain & Shankweiler, 1998; Braze, Shankweiler, Ni, & Palumbo, 2002).

(1) This exotic spice might possibly *seek* the subtle flavour she craves.

In another study, Rayner, Warren, Juhasz and Liversedge (2004) compared anomalous, implausible, and plausible sentences using eye- tracking. The results showed evidence of differential processing with anomalous target words leading to immediate disruption in gaze duration on critical words, while implausible target words showed considerably delayed effects. This pattern of results has been replicated with 10 to 14 year old children (Joseph, Liversedge, Blythe, White, Gathercole & Rayner, in press), demonstrating that the delayed effects of plausibility on lexically driven eye movement control in reading are present from a young age. So, eye- tracking is a useful tool for investigating the time-course of disruption due to anomalies, and provides evidence for the early detection of anomalies.

According to this existing literature using an eye- tracking paradigm, if an anomaly is detected on-line, an increase in fixation durations and higher incidence of regressive eye movements should point at where disruptions in eye fixation behaviour first occurred (see also, Carpenter & Daneman, 1981; Daneman, Reingold & Davidson, 1995; Frazier & Rayner, 1982). Therefore, if detection is immediate, we might expect disruptions in the eye tracking behaviour when the reader first encounters the

anomalous word. If detection is delayed, then disruptions should occur only after the reader has proceeded beyond the anomalous word (post-critical regions). It is anticipated that inconsistencies following a real-world context will lead to immediate effects in reading, similar to those revealed by semantic/ pragmatic anomalies, with longer reading times and increased regressive eye- movements compared to consistent continuations.

Recently, the effects of context on language processing have been investigated using various methodologies (e.g., Altmann & Kamide, 1999; Camblin, Gordon & Swaab, 2007; Hess, Foss & Carroll, 1995; Kamide, Altmann & Haywood, 2003; Pickering & Traxler, 1998; Tanenhaus, Spivey-Knowlton, Eberhard & Sedivy, 1995; Rayner & Duffy, 1986), specifically, demonstrating how context can guide participants' eye movements around specific words or linguistic referents prior to upcoming linguistic input. Pickering and Traxler (1998) monitored readers' eye- movements while they read sentences, such as (2).

(2) While the janitor was polishing(.) the professor that the principal hated reviewed the spring term teaching schedule.

Interpretation of *the professor* was manipulated by discourse context so it was either literal (the professor was a person) or non-literal (the professor was a statue). Greater difficulty was observed at *the professor* in literal conditions (as a janitor wouldn't polish a person), and greater difficulty at *reviewed* in the non-literal condition (as a statue can not review something). Thus, contextual information is rapidly accessed when parsing sentences in discourse. Furthermore, this study confirms that eye movement measures are sensitive to contextual influences.

More recently, Warren and McConnell (in press) have examined eye movements to compare the disruption effects caused by world knowledge and semantic violations. Participants read sentences describing events that were either plausible and possible (3a), extremely implausible but possible (3b), or extremely implausible and impossible (3c).

- (3) a. The man used a strainer to drain the thin spaghetti yesterday evening.
- b. The man used a blow-dryer to dry the thin spaghetti yesterday evening.
- c. The man used a photo to blackmail the thin spaghetti yesterday evening.

Disturbance to the reading pattern was evident in the implausible-impossible condition, which showed lengthened first fixation times on the critical word ('spaghetti') and the post-critical region. In comparison, the possible conditions did not differ in fixation durations on the target word, although the implausible-possible condition revealed delayed effects of world knowledge with increased regression path times (a measure of the time needed to go past this word) at the critical word. On the basis of these results, the authors argue that semantic information is processed before more general world knowledge about plausibility.

However, to date, no research is available to investigate how the processor resolves a *conflict* between real-world knowledge and a prior context. The studies reported in this chapter examine whether or not a counterfactual discourse context can override the difficulty normally associated with processing information that is anomalous with the readers' knowledge of the world. Thus, for events set in a counterfactual world, two predictions are tested here. First, if the previously found faster reading times for real-world knowledge violations that are consistent within a counterfactual world (van de Ven, 2001) are a true reflection of how readily context is

used to make sense of a real-world violation, then the counterfactual world could be the only discourse representation against which a following statement is evaluated. In this case, typical anomaly detection effects for RW-violations could be ‘neutralised’ within an appropriate pre-specified CW context, and RW-congruent items could lead to the experience of an anomaly following an inconsistent CW context. Alternatively, according to the model theories of reasoning discussed in Chapter 1 and previous eye movements evidence showing delayed effects of context, this contextual integration process may be delayed so that it initially leads to typical anomaly detection responses, and becomes accommodated by the counterfactual world representation at some later stage of processing. This is the basic question of the experiments reported here.

Chapter 2 is a report of three eye- movement studies in which the materials utilize propositions that are anomalous with respect to the real-world, but not with respect to some counterfactual world. Prior context depicts a counterfactual-world (CW), or real-world (RW), while a second sentence was manipulated to create RW anomalous continuations, where events included a violation of RW knowledge, and RW congruent continuations, where the events described were congruent with RW knowledge. The question was whether a counterfactual setting, making the anomaly acceptable, would result in the removal of all difficulties associated with the anomaly occurring in the absence of a counterfactual setting, or whether there would still be a difficulty observed because the proposition is compared with real-world information despite the counterfactual setting.

Experiment 1

Method

Participants

Thirty-six participants from the undergraduate population of Glasgow University were paid to take part in the study. All participants were native speakers of English, who did not have dyslexia and with vision that they reported to be normal or corrected to normal using soft contact lenses. Participants were naïve to the purpose of the study and had no previous exposure to the test materials.

Materials and Design

Twenty-four experimental items were constructed as in Table 2.1. In each condition, the first sentence acts as a context. In the RW-inconsistent condition, the first sentence introduces a setting that fits with the real world. The second sentence is then inconsistent, in that the critical word, *carrots*, does not fit RW expectations. In the RW-consistent case, the first sentence sets up a proposition that fits with the real world, and the critical word of the second sentence is changed to one that fits with RW (*fish*, instead of *carrots*). In the case of the CW material, this first sentence introduced a counterfactual world. The second sentence then contained a statement that is consistent with the CW (...*could feed their cat a bowl of carrots*...). The basic design is aimed at comparing the eye-tracking record in response to *carrots* under the inconsistent and consistent conditions with each other, and with *fish* in the consistent condition.

<p><i>RW-inconsistent</i></p> <p>If cats are hungry they usually pester their owners until they get fed. Families could feed their cat a bowl of carrots and it would gobble it down happily. Cats are loving pets when you look after them well.</p>
<p><i>RW-consistent</i></p> <p>If cats are hungry they usually pester their owners until they get fed. Families could feed their cat a bowl of fish and it would gobble it down happily. Cats are loving pets when you look after them well.</p>
<p><i>CW-consistent</i></p> <p>If cats were vegetarians they would be cheaper for owners to look after. Families could feed their cat a bowl of carrots and it would gobble it down happily. Cats are loving pets when you look after them well.</p>

Table 2.1: Examples of experimental sentences (Experiment 1).

The critical nouns were matched across conditions for length, and for frequency using the British National Corpus and no significant differences were found. The nouns in CW-consistent and RW-inconsistent conditions averaged 5.96 (min.= 3, max.= 9) characters, while the nouns in RW-consistent conditions averaged 6.0 (min.= 3, max.= 11) characters. The nouns in CW-consistent and RW-inconsistent conditions averaged 81.1 appearances per million words, whereas the nouns in RW-consistent conditions averaged 63.0 appearances per million words. Hence, any difference in reading times between conditions will not to be due to discrepancies in length or frequency of the nouns.

One version of each item was assigned to one of three presentation lists, with each list containing twenty-four experimental items, eight in each of the three conditions, blocked to ensure that they were evenly distributed. By rotation over the three lists, all materials appeared in all conditions, but in only one condition within a list. In addition, eighty-two filler materials of different types were added to each list. Twelve participants were randomly assigned to read each list. The twenty-four experimental items in each list were interspersed randomly among the eighty-two filler sentences to create a single random order and each subject only saw each target

sentence once, in one of the three conditions. At least one filler item intervened between each experimental item. Comprehension questions followed half of the experimental (i.e., 12) and 41 of the filler trials. Participants did not receive feedback for their responses to these questions. Only participants scoring at or above 90% accuracy on the comprehension questions were used in the data analysis.

Eye tracking

Participants' eye movements were recorded during reading using a Forward Technology Dual Purkinje Image (DPI) generation 5.5 eye-tracker. The eye-tracker recorded participants' gaze location and movement from the right eye, although viewing was binocular. Recordings were taken every millisecond. A forehead rest and head strap, along with a bite-bar, were used to stabilize participants' head position and to minimise interference to the signal caused by head movements (see Figure 2.1). All sentences were presented in size 10 Courier New font style through a PC, on a VDU screen, 60cm from the participants' eyes.

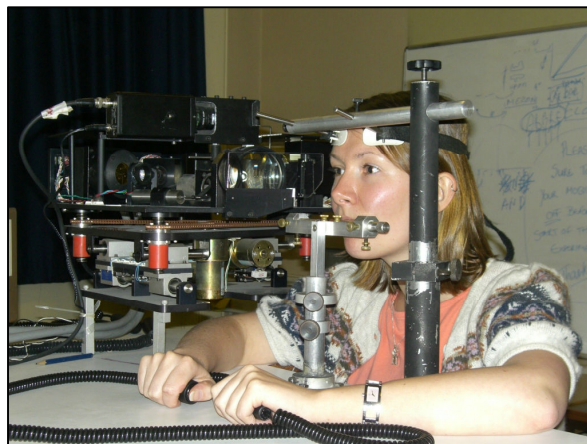


Figure 2.1: Image of participant in the DPI eye-tracker used in these studies, showing forehead rest, head strap and bite-bar used to stabilize participants' head position.

Procedure

The eye tracker was calibrated using a series of nine fixed targets distributed across the display, during which the participant was asked to fixate on each point on the computer screen as they appeared in order to establish the correlation between x/y voltages and screen position. Calibration was monitored and adjustments to the calibration were made throughout the experiment as necessary.

Prior to the presentation of each sentence, a pattern of fixation points appeared on the screen, spanning the position to be occupied by the sentences. Participants were instructed to fixate on a sequence of fixation points ending at the top left side, where the first character of the text would be displayed. Once this calibration check was completed accurately, the experimenter pressed a button to advance the screen to display the next item. This procedure ensured that participants were consistently tracking well, and that eye- movement records began uniformly with the initial words in each sentence. Adjustments to the calibration were made at this stage if necessary. Materials appeared individually on the screen, spanning a maximum of four lines of text, with each line separated by two blank lines and a maximum of 75 characters per line. Participants were instructed to read at their normal rate and to read to comprehend the sentences, in order to answer the questions. After reading each sentence, they pressed a button that led to the presentation of a comprehension question or the next trial. Comprehension questions followed 50% of target and filler trials in a pseudo-random order. Participants responded to the questions by clicking either the button in their left hand or the button in their right hand when given a choice of two answers on either left or right side of the screen. Adjustments to the calibration were made during the experiment when the experimenter deemed it necessary.

Plausibility Norming. The experimental items were pre-tested for plausibility by a set of 24 raters, who did not participate in the eye- tracking experiment. These people

judged each sentence based on how acceptable they believed the events described in the passage were. Sentences were presented to the raters in a randomised order. Raters assigned a number from 1 (the event described in the sentence is highly unacceptable) to 5 (highly acceptable) to the sentences in each list. Mean plausibility ratings were 4.6 (RW-consistent), 1.2 (RW-inconsistent) and 3.6 (CW-consistent).

Results and Discussion

Regions of analysis

The critical second sentence was divided into four regions for the purpose of aggregating reading times and classifying eye- movements, as shown in (5). For each sentence frame, corresponding regions contained the same number of words in all three versions.

- (5) If cats were vegetarians they would be cheaper for owners to look after.
 |Families could₁| feed their cat a bowl of₂| carrots and₃| it would gobble it down
 happily.₄| Cats are loving pets when you look after them well.

The first sentence created a RW or CW context for the critical sentence. Region 1 introduced an agent followed by the modal verb *could*. Region 2 (pre-critical) contained material that that led to the critical region. Region 3 (critical) always consisted of the inconsistent or consistent noun, plus the connective *and*, and thus this region was always two words long. Region 4 (post-critical) comprised the critical sentence wrap-up.

The following measures were used to analyse the tracking patterns. **First-pass reading time**, the sum of the duration of fixations made on first entering a region of text until an eye- movement exits the region to either the left or right. First-pass reading

times can provide an indication of the difficulty experienced when participants initially process a region of text. **First-pass regressions out** is the sum of regressive saccades made from the current most rightward fixation with a region of text, indicating the degree to which left to right movement was disrupted during the first sweep of the eyes through a region of text. By examining the location of this disruption it is possible to establish particular regions in a text that cause difficulty for semantic processing.

Regression path times is the sum of fixations from the first entry into that region from the left to the time the region was first exited to the right. This measure includes fixations made to re-inspect earlier portions of text and therefore provides an indication of the time spent re-reading after the initial detection of a problem. **Total reading time** is the sum of the of all fixations made within a region and provides an indication of the overall amount of time spent processing text in that region. Finally, **regressions-in** convey information on the percent of regressive movements from the right into each region and consequently present researchers with details of the regions of text that readers need to revisit in order to make sense of a piece of text.

An automatic procedure pooled short contiguous fixations. Fixations shorter than 80ms were integrated with larger adjacent fixations within one character and fixations shorter than 40ms that were not within three characters of another fixation were excluded. Fixations longer than 1200ms were truncated. Trials where participants failed to read the sentence or there had been tracker loss were eliminated prior to analysis. Specifically, trials where two or more adjacent regions had zero first-pass reading times were removed, which accounted for less than 1% of the data for any of the experiments reported here.

Table 2.2 displays mean values for each measure in each condition and region.

	Region				
	Context sentence 1	1 <i>Families could</i>	2 <i>feed their cat a bowl of</i>	3 <i>carrots and</i>	4 <i>it would gobble it down happily.</i>
<i>First-pass reading time (ms)</i>					
RW-inconsistent	3207 (159.5)	504 (27.2)	833 (43.7)	327 (11.9)	856 (48.2)
RW-consistent	3132 (153.1)	473 (27.7)	804 (39.6)	296 (9.7)	890 (33.0)
CW-consistent	3357 (162.7)	485 (31.1)	740 (28.4)	328 (12.4)	912 (40.7)
<i>Regression path time (ms)</i>					
RW-inconsistent	3207 (159.5)	589 (32.1)	1026 (40.4)	453 (24.5)	1379 (95.0)
RW-consistent	3131 (153.1)	567 (39.2)	1057 (57.9)	389 (17.3)	1074 (67.0)
CW-consistent	3357 (162.7)	577 (35.0)	977 (36.2)	413 (14.9)	1082 (69.2)
<i>First-pass regressions out (%)</i>					
RW-inconsistent	-	7.8 (1.6)	18.4 (2.4)	23.3 (3.0)	31.6 (3.9)
RW-consistent	-	6.9 (1.6)	17.3 (2.0)	21.8 (2.9)	11.8 (2.4)
CW-consistent	-	9.0 (1.4)	19.8 (3.1)	17.5 (2.6)	8.8 (2.2)
<i>Total reading time (ms)</i>					
RW-inconsistent	3398 (191.1)	612 (33.7)	1233 (67.5)	504 (30.4)	1184 (49.0)
RW-consistent	3345 (177.2)	555 (31.9)	1055 (52.7)	357 (14.8)	1029 (36.4)
CW-consistent	3545 (175.8)	604 (39.3)	985 (36.4)	385 (17.1)	1036 (50.2)
<i>Regressions-in (%)</i>					
RW-inconsistent	13.8 (2.1)	26.2 (3.0)	40.2 (3.6)	23.9 (3.2)	5.8 (1.3)
RW-consistent	15.6 (2.6)	22.3 (2.8)	24.4 (2.8)	9.7 (2.2)	6.4 (1.7)
CW-consistent	16.4 (2.6)	22.9 (3.4)	22.1 (3.0)	7.5 (2.0)	7.2 (1.5)

Table 2.2: Mean eye- movement measures for regions 1 to 4 (standard errors in parentheses).

First-pass reading times In critical region 3, first-pass reading times showed a significant difference over conditions [$F_1(2, 35) = 5.2, p < 0.01$; $F_2(2, 23) = 3.7, p = 0.03$]. Further analysis using Bonferroni comparisons showed that RW-inconsistent sentences resulted in significantly longer first-pass reading times than RW-consistent sentences ($t_1(35) = 2.8, p < 0.05$; $t_2(23) = 2.4, p < 0.05$). Thus the effect of anomaly in the RW context is as predicted, and appears in an early measure. However sentences in the CW-consistent conditions led to longer first-pass reading times than those in the RW-consistent condition ($t_1(35) = 2.8, p < 0.05$; $t_2(23) = 2.3, p < 0.05$). Furthermore, there were no differences between CW-consistent and RW-inconsistent conditions ($t_s < 0.2$). This early measure thus provides evidence that violations of real-world knowledge are important whether they appear as a direct violation (in the RW-inconsistent condition) or in the context of a counterfactual (the CW-consistent condition, which is of course RW – violating). Thus there is evidence that real-world violations were not

neutralised by a counterfactual context. These data are illustrated in Figure 2.2. Even within a counterfactual context, participants appear to still automatically process information in terms of their real-world knowledge.

In the post-critical region there were no effects of condition on first pass reading times [$F_s < 1.2$].

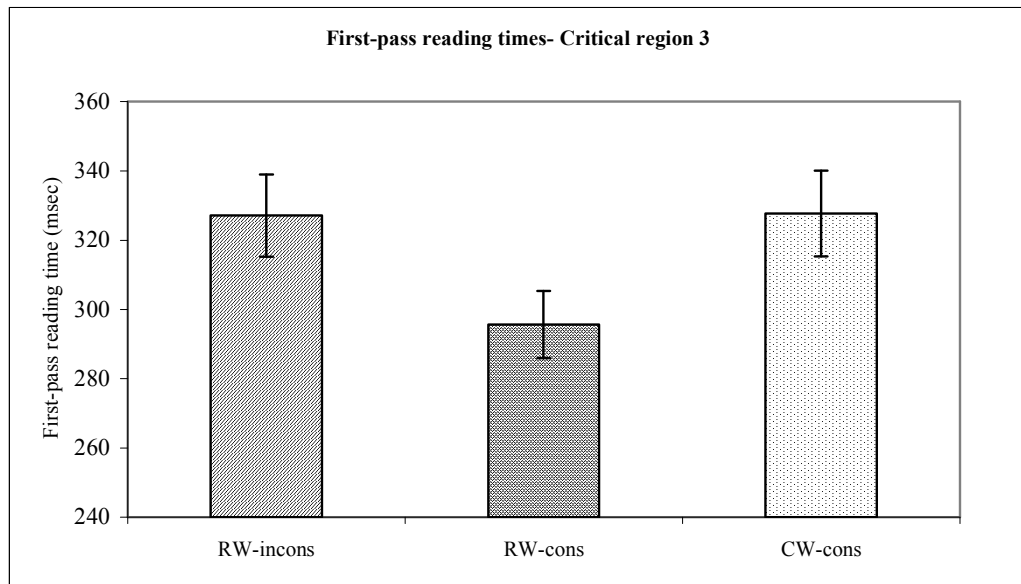


Figure 2.2: Mean first-pass reading times in critical region showing standard error bars.

First-pass regressions out Figure 2.3 illustrates how each condition affected the mean first-pass regressions out of each region as the sentence progressed.

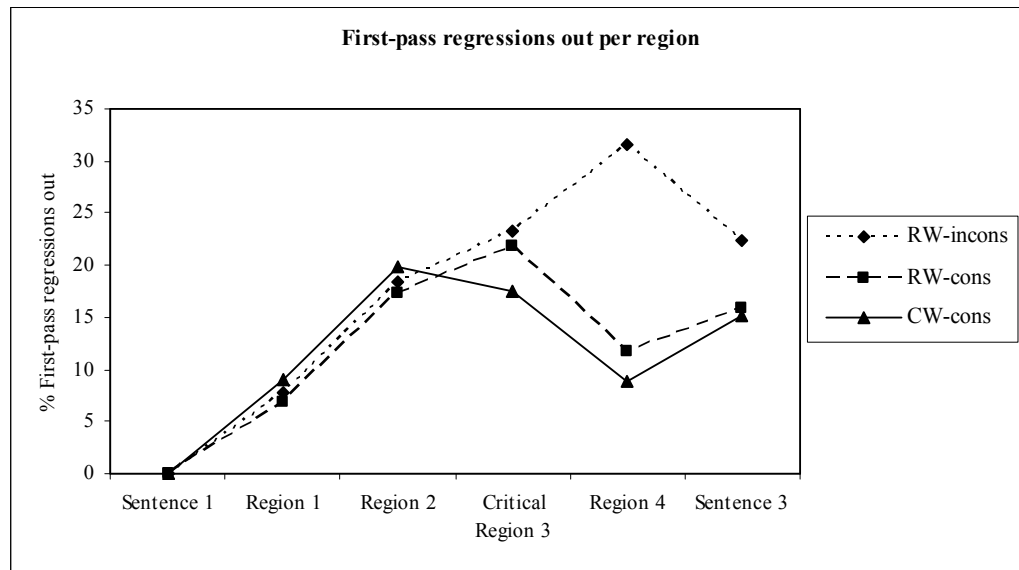


Figure 2.3: Percentage first-pass regressions out per region.

In the critical region 3, there was no evidence of any effect of condition on regressions out [$F_s < 1.8$]. In the post-critical region 4, clear effects emerged amongst conditions [$F_1(2, 35) = 24.0, p < 0.001$; $F_2(2, 23) = 24.7, p < 0.001$]. Planned contrasts showed more first-pass regressions for the RW-inconsistent condition than the RW-consistent condition ($t_1(35) = 5.5, p < 0.001$; $t_2(23) = 5.6, p < 0.001$), and for the RW-inconsistent condition than the CW-consistent condition ($t_1(35) = 6.4, p < 0.001$; $t_2(23) = 6.5, p < 0.001$). However, no significant difference was found between CW-consistent and RW-consistent conditions with this measure ($t_s < 1.3$). This data suggests that by the time readers encounter the post-critical region, they are already using the CW context to make a real-world anomaly acceptable.

Regression path times Regression path times showed a difference between conditions in the critical region 3 [$F_1(2, 35) = 4.3, p = 0.02$; $F_2(2, 23) = 3.7, p = 0.03$]. The RW-inconsistent condition led to longer regression path times than the RW-consistent condition ($t_1(35) = 2.9, p < 0.05$; $t_2(23) = 2.7, p < 0.05$), as expected. However, there was no reliable difference between the RW-inconsistent and CW-

consistent conditions ($t_s < 1.8$), or between the RW-consistent and the CW-consistent conditions ($t_s < 1.1$) on this measure. This may be because the CW-consistent condition is still being checked against real-world knowledge, though this did not show up in the number of regressions out of region 3. The fact that readers are regressing equally often, but spending more time re-reading in the RW-inconsistent condition suggests differential recovery and integration strategies for RW-inconsistent and CW-consistent conditions following a real-world anomaly.

Differences over conditions in the post-critical region 4 reflect a clearer effect of processing on the basis of prior context. The three conditions differ from one another, [$F_1(2, 35) = 25.1, p < 0.001$; $F_2(2, 23) = 12.6, p < 0.001$], and times were longer following the RW-inconsistent than RW-consistent condition ($t_1(35) = 6.2, p < 0.001$; $t_2(23) = 4.4, p < 0.001$) and longer for RW-inconsistent than the CW-consistent condition ($t_1(35) = 6.1, p < 0.001$; $t_2(23) = 6.1, p < 0.001$). No differences were found between RW-consistent and CW-consistent conditions ($t_s < 0.2$). As with the regressions out measure, this suggests that by the post-critical region, readers are using the CW context to ‘neutralise’ the RW violation.

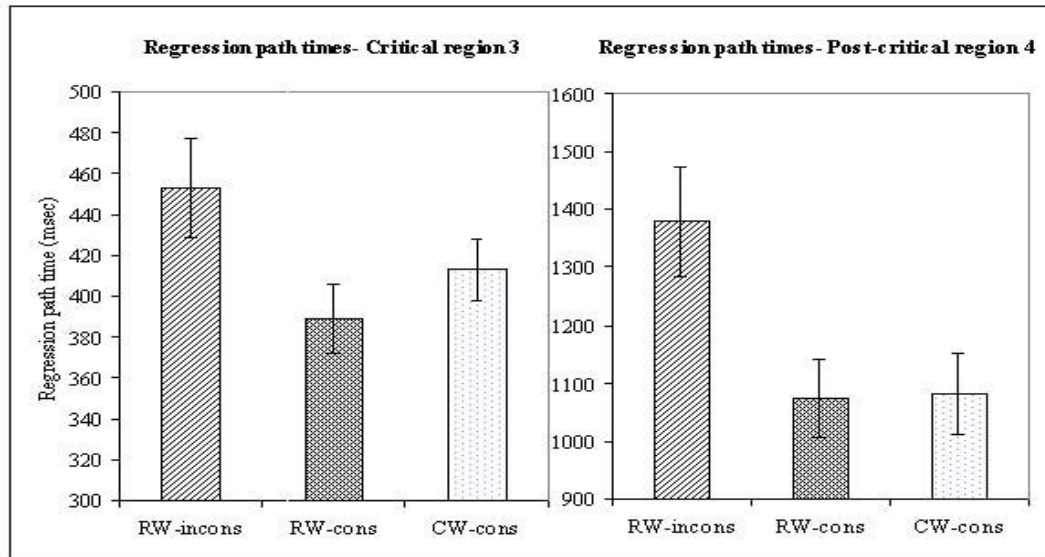


Figure 2.4: Mean regression path reading times in critical and post-critical regions, showing standard error bars.

Total reading times Reading times in the pre-critical region 2 showed a significant difference between conditions [$F_1(2, 35) = 16.5, p < 0.001$; $F_2(2, 23) = 17.4, p < 0.001$]. There were longer total reading times in the RW-inconsistent condition than the RW-consistent condition ($t_1(35) = 4.0, p < 0.001$; $t_2(23) = 4.1, p < 0.001$) and longer in the RW-inconsistent condition than in the CW-consistent ($t_1(35) = 5.6, p < 0.001$; $t_2(23) = 5.7, p < 0.001$). The CW-consistent and RW-consistent conditions did not differ ($t_s < 1.7$).

This pattern of total reading times between the conditions persisted in the critical region 3 [$F_1(2, 35) = 23.2, p < 0.001$; $F_2(2, 23) = 20.2, p < 0.001$] and into the post-critical region 4 [$F_1(2, 35) = 12.4, p < 0.001$; $F_2(2, 23) = 7.2, p < 0.001$]. Planned contrasts revealed longer total reading times in the RW-inconsistent condition than RW-consistent (region 3, $t_1(35) = 6.4, p < 0.001$; $t_2(23) = 5.9, p < 0.001$; region 4, $t_1(35) = 4.5, p < 0.001$; $t_2(23) = 3.4, p < 0.001$). The RW-inconsistent condition produced longer times than the CW-consistent (region 3, $t_1(35) = 5.2, p < 0.001$; $t_2(23) = 4.9, p < 0.001$; region 4, $t_1(35) = 4.1, p < 0.001$; $t_2(23) = 3.2, p < 0.001$). CW-consistent and RW-

consistent did not differ in these regions (region 3, $t_s < 1.2$; region 4, $t_s < 0.3$).¹ Thus, over this later measure of processing in the pre-critical, critical and post-critical regions, there is evidence that the RW anomaly is processed as acceptable following a CW context because readers have integrated the CW context into their current model. In contrast, within a RW context, this violation leads to processing difficulties.

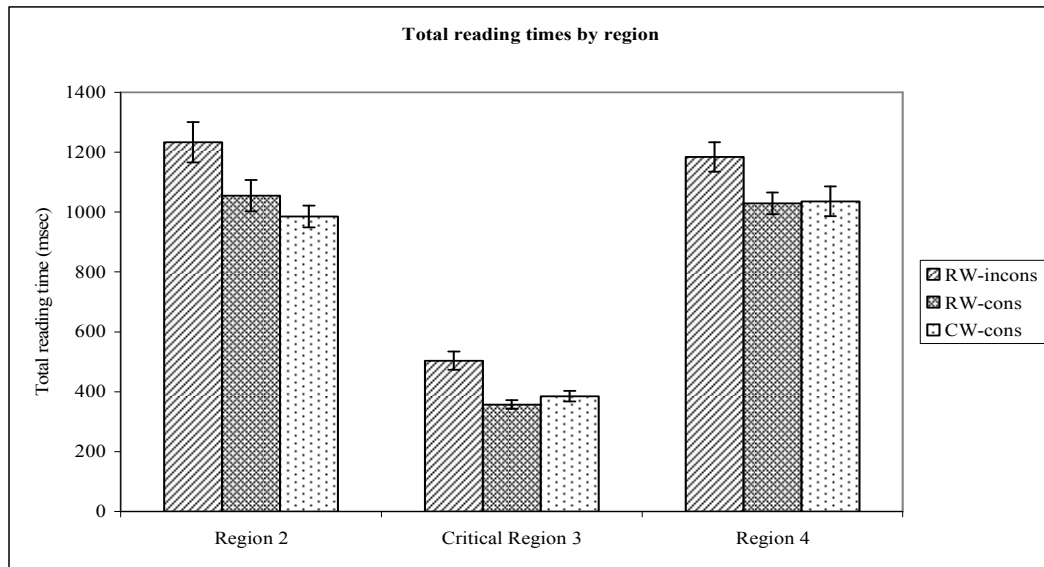


Figure 2.5: Mean total reading times in pre-critical, critical and post-critical regions, showing standard error bars.

Regressions in

Figure 2.6 shows the mean number of regressions into each region for each condition.

¹ Number of fixations data mirrored total reading times with significant differences between conditions in pre-critical [$F_1(1, 35) = 11.5, p < 0.001$; $F_2(1, 23) = 10.7, p < 0.001$], critical [$F_1(1, 35) = 16.6, p < 0.001$; $F_2(1, 23) = 16.2, p < 0.001$] and post-critical [$F_1(1, 35) = 6.5, p = 0.004$; $F_2(1, 23) = 3.6, p = 0.05$] regions, reflecting more fixations in RW-inconsistent and CW-consistent conditions than RW-consistent.

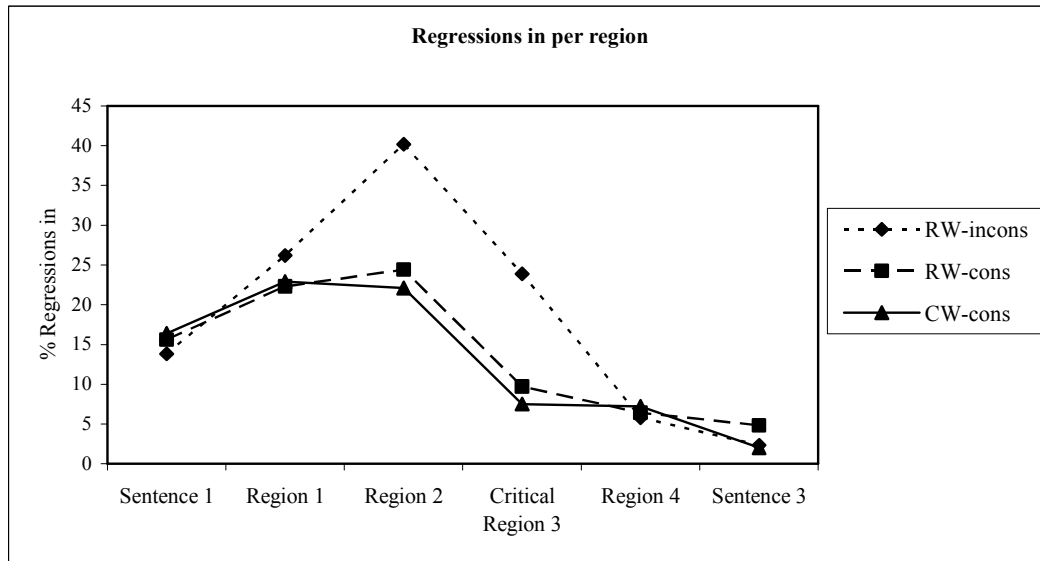


Figure 2.6: Percentage regressions in per region

Significant main effects of condition were detected in the pre-critical region 2 [$F_1(2, 35) = 12.5, p < 0.001$; $F_2(2, 23) = 12.4, p < 0.001$] and critical region 3 [$F_1(2, 35) = 21.2, p < 0.001$; $F_2(2, 23) = 17.2, p < 0.001$]. More regressions were made into the pre-critical region in the RW-inconsistent condition than the RW-consistent ($t_1(35) = 4.0, p < 0.001$; $t_2(23) = 4.0, p < 0.001$) and CW-consistent ($t_1(35) = 4.6, p < 0.001$; $t_2(23) = 4.6, p < 0.001$) conditions. CW-consistent and RW-consistent conditions did not differ significantly from each other ($t_s < 0.6$). The critical region replicated this effect as the RW-inconsistent condition led to significantly more regressions in than RW-consistent ($t_1(35) = 5.2, p < 0.001$; $t_2(23) = 4.6, p < 0.001$) and CW-consistent ($t_1(35) = 6.0, p < 0.001$; $t_2(23) = 5.5, p < 0.001$) conditions that did not differ from each other ($t_s < 0.9$).

To summarise, a significantly longer first-pass reading time was recorded at the critical region for the CW-consistent and RW-inconsistent conditions compared to RW-consistent. Further, CW-consistent and RW-inconsistent conditions did not differ from each other. This result suggests that processing in terms of real-world knowledge remains active even after the introduction of a counterfactual world. Thus, the present

data suggests that statements within the scope of a counterfactual interpretation are initially evaluated against real-world knowledge prior to being accommodated within the counterfactual context. Beyond that, later in processing, and on the basis of all measures considered, the CW-consistent condition does not differ from the RW-consistent condition, and only the RW-inconsistent condition shows a high level of disruption. This shows that after the initial check against the real-world, the CW context becomes the basis of CW processing.

Experiment 2

The question arises as to whether a word that is inconsistent with CW, but is consistent with RW would disrupt processing. It should if CW contexts, when present, are indeed adopted as the basis of processing, after the early use of real-world knowledge. An example of such an inconsistency is shown in (6) where eating fish is inconsistent with cats being vegetarians.

(6) If cats were vegetarians they would be cheaper for owners to look after.

Families could feed their cat a bowl of fish and it would gobble it down happily.

In Experiment 2 we examined such processing of CW-inconsistent information that is congruent in terms of the real world. The aim was to allow a fuller investigation into whether CW information is processed differently from RW information. Additionally, we hoped to explore whether CW inconsistencies are processed in the same way as RW inconsistencies, and specifically whether there is a different pattern or time-course of inconsistency detection for RW and CW information. We expected to replicate the findings of Experiment 1, and additionally to find that the new CW-inconsistent condition led to processing difficulties over the CW-consistent condition.

Furthermore, Experiment 2 ensured that the early effects for RW violations were not the result of semantic priming. Specifically, that information in the CW context sentence was not priming readers' access to the critical word in the critical sentence (i.e. *carrots* being primed by *vegetarians*). Therefore in Experiment 2, RW context sentences contained the same critical words as CW context sentences, but in a realistic framework, as shown in (7).

(7) Evolution dictates that cats are carnivores and cows are vegetarians.

In fact, it was not anticipated that the early processing effect would be eliminated by these changes for two reasons. First, both consistent and inconsistent critical words have been equally primed in CW context sentences (i.e. *cats* primes *fish* and *vegetarians* primes *carrots*). And secondly, evidence suggests that contextually constrained words are fixated for less time than words not constrained by the semantic context (e.g. Altarriba, Kroll, Sholl & Rayner, 1996; Rayner & Well, 1996; Schustack, Ehrlich & Rayner, 1987). In contrast, the results described above showed increased first-pass reading times in the CW-consistent condition, when the critical word was constrained by prior CW context.

Method

Participants

Thirty-six participants were recruited from the undergraduate population of students from the University of Glasgow and were paid to participate in the study. They were selected through the same criteria as in Experiment 1, and had not taken part in Experiment 1.

Materials and Design

Modified versions of the twenty-four experimental materials used in Experiment 1, plus eight new items, were used. The thirty-two experimental items were as shown in Table 2.3. A 2x2 within subjects design crossed two context conditions with two consistency conditions. The context condition was split into two levels: a real-world (RW), where the first sentence depicted a realistic circumstance, and counterfactual-world (CW), where the first sentence created a counterfactual alternative. Here, RW context sentences contained the same critical words as the CW context sentences (e.g. *cats* and *vegetarians*) in a realistic scenario, to eliminate possible priming effects. The consistency condition also had two levels and was manipulated by changing the noun in the second sentence: inconsistent, such that events described in the second sentence were inconsistent with the prior context; or consistent, whereby the critical noun was consistent with the pre-specified context. This created a fully crossed experiment with four conditions: RW-inconsistent, RW-consistent, CW-inconsistent, and CW-consistent, as shown in Table 2.3. Note that the third ‘continuation’ sentence from Experiment 1 was removed for Experiments 2 and 3 for the sake of brevity and since no significant effects were found here.

RW-inconsistent

Evolution dictates that cats are carnivores and cows are vegetarians.
 Families could feed their cat a bowl of carrots and it would gobble it down happily.

RW-consistent

Evolution dictates that cats are carnivores and cows are vegetarians.
 Families could feed their cat a bowl of fish and it would gobble it down happily.

CW-inconsistent

If cats were vegetarians they would be cheaper for owners to look after.
 Families could feed their cat a bowl of fish and it would gobble it down happily.

CW-consistent

If cats were vegetarians they would be cheaper for owners to look after.
 Families could feed their cat a bowl of carrots and it would gobble it down happily.

Table 2.3: Examples of experimental sentences (Experiment 2).

The length and frequency of the critical nouns was matched across conditions. Nouns in the RW-inconsistent and CW-consistent conditions averaged 5.7 (min.= 3, max.= 9) characters, while nouns in the RW-consistent and CW-inconsistent conditions averaged 5.9 (min.= 3, max.= 11) characters. Mean frequency was 87.0 occurrences per million words for the RW-inconsistent and CW-consistent conditions and 64.5 for the RW-consistent and CW-inconsistent conditions.

One version of each item was assigned to one of four lists. The 32 experimental items were assigned to lists so that equal numbers of each condition appeared on each list, with one version of each item appearing on each list, and so that participants did not see more than one version of any given item. The items were displayed with seventy-six filler sentences of various types. At least one filler item intervened between each experimental item. A comprehension question was presented after half of the experimental (i.e., 16) and filler (38) items. Participants did not receive feedback for their responses. All participants used in the data analysis scored at or above 90% accuracy on the comprehension questions.

Eye tracking and Procedure

The eye tracking and experimental procedures were identical to those in Experiment 1.

Results and Discussion

Regions of Analysis

Each target sentence was divided into four regions, as in Experiment 1 and illustrated in (4). Table 2.4 displays means for each measure for each condition and region.

	Region				
	Context sentence 1	1 <i>Families could</i>	2 <i>feed their cat a bowl of</i>	3 <i>carrots and</i>	4 <i>it would gobble it down happily.</i>
<i>First-pass reading time (ms)</i>					
RW -inconsistent	3399 (132.2)	493 (24.7)	990 (37.9)	342 (14.3)	921 (41.5)
RW -consistent	3506 (121.2)	480 (22.3)	976 (32.9)	346 (15.5)	1008 (52.6)
CW -inconsistent	3686 (169.4)	482 (23.8)	960 (52.1)	344 (16.2)	988 (58.2)
CW -consistent	3667 (161.3)	485 (22.8)	931 (40.8)	343 (14.7)	955 (57.9)
<i>Regression path time (ms)</i>					
RW -inconsistent	3400 (132.2)	590 (29.1)	1179 (42.1)	421 (20.7)	1426 (95.6)
RW -consistent	3506 (121.2)	603 (47.8)	1218 (53.1)	382 (15.9)	1285 (69.6)
CW -inconsistent	3686 (169.4)	548 (27.3)	1139 (51.7)	391 (21.6)	1338 (77.8)
CW -consistent	3667 (161.3)	557 (35.6)	1105 (44.6)	392 (19.0)	1193 (62.9)
<i>First-pass regressions out (%)</i>					
RW -inconsistent	-	9.8 (1.9)	13.1 (2.0)	14.6 (2.6)	28.2 (3.9)
RW -consistent	-	10.2 (1.8)	15.2 (2.7)	8.1 (1.9)	23.6 (3.8)
CW -inconsistent	-	6.8 (1.7)	13.7 (2.0)	8.1 (1.8)	30.3 (3.6)
CW -consistent	-	8.4 (1.7)	11.5 (2.0)	10.1 (2.6)	22.3 (3.0)
<i>Total reading time (ms)</i>					
RW -inconsistent	3583 (137.1)	606 (27.9)	1298 (52.5)	427 (21.3)	1117 (59.7)
RW -consistent	3700 (121.0)	582 (30.5)	1227 (45.6)	379 (16.2)	1115 (58.2)
CW -inconsistent	3853 (172.3)	555 (27.3)	1175 (55.6)	399 (19.6)	1125 (56.1)
CW -consistent	3775 (166.6)	343 (24.9)	1109 (40.4)	394 (18.4)	1076 (57.2)
<i>Regressions In (%)</i>					
RW -inconsistent	21.3 (3.3)	21.4 (2.9)	23.9 (2.9)	10.9 (1.8)	4.6 (1.3)
RW -consistent	20.4 (3.1)	21.9 (2.9)	10.9 (2.4)	9.6 (1.9)	3.8 (1.4)
CW -inconsistent	18.6 (2.6)	19.7 (2.7)	17.2 (1.8)	12.5 (2.1)	2.5 (1.0)
CW -consistent	16.4 (2.5)	12.7 (1.9)	16.2 (2.8)	12.7 (2.1)	2.7 (1.2)

Table 2.4: Mean eye- movement measures for regions 1 to 4 (standard errors in parentheses)

First-pass reading times In the critical region 3, no main effects or interactions were detected [all $F_s < 0.2$].

First-pass regressions out Figure 2.7 illustrates how each condition affected the mean first-pass regressions out of each region as the sentence progressed.

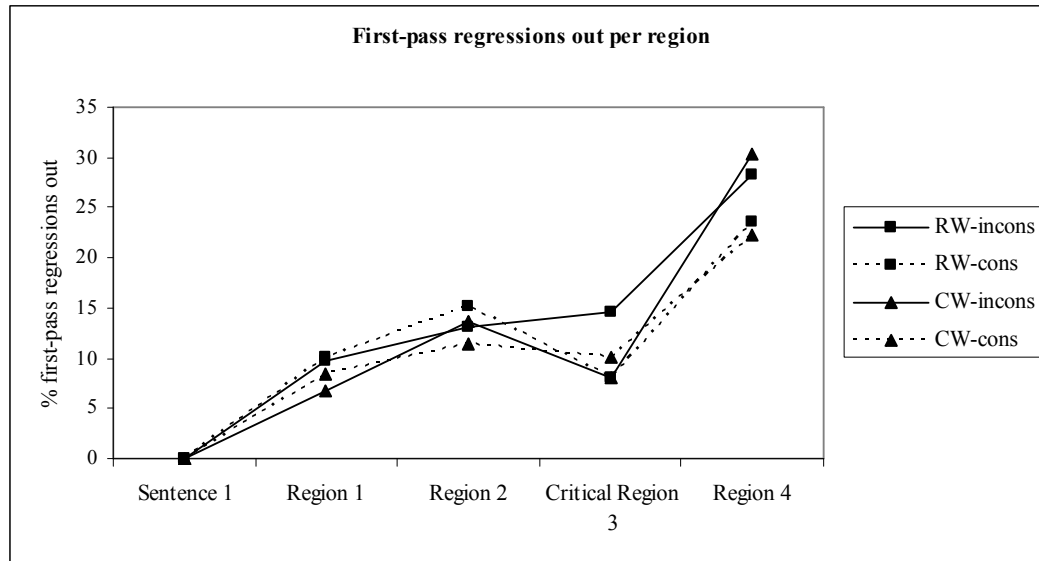


Figure 2.7: Percentage first-pass regressions out

At the critical region 3, a significant interaction emerged in first-pass regressions-out [$F_1(1, 35) = 4.17, p = 0.05$; $F_2(1, 31) = 6.23, p = 0.02$]. Analysis of the simple main effects revealed that more regressions were made out of the critical region in the inconsistent than the consistent condition at the level of RW [$F_1(1, 35) = 4.00, p = 0.05$; $F_2(1, 31) = 10.64, p < 0.005$], however this trend was not significant at the level of CW [$F_s < 1.7$]. Furthermore, RW led to increased regressions out compared to CW for inconsistent conditions [$F_1(1, 35) = 5.69, p < 0.03$; $F_2(1, 31) = 4.76, p < 0.04$] but there was no difference between RW and CW consistent conditions [$F_s < 0.5$]. The results reflect the findings from Experiment 1 that when the critical word is anomalous with respect to the real world, this leads to a significant early disturbance in the tracking record within a RW context. Since this effect is apparent in the early measure of first-pass regressions out, we can assume that processing information within a realistic context involves an automatic process of comparing incoming information to world-knowledge. Additionally, it is important to note that processing difficulties are not evident on this measure following a CW-inconsistency, which suggests that at the

critical region, participants have not yet integrated the target word with the wider, non-factual, discourse context.

The post-critical region 4 revealed a main effect of consistency [$F_1(1, 35) = 4.90, p = 0.03$; $F_2(1, 31) = 5.27, p = 0.03$], but no interaction [$F_s < 0.4$], showing that by this region, there was no longer any interference in terms of this measure from real world knowledge in the CW context case. The two inconsistent conditions (RW-inconsistent and CW-inconsistent) led to an increased incidence of first-pass regressions out. These increased regressions out of the post-critical region are likely to be due to readers regressing back in the text to attempt to make sense of the contextual inconsistency. Additionally, it can be noted that, compared to Experiment 1, this study leads to higher incidence of first-pass regressions out of the post-critical region in all conditions. We suggest that this increase is due to several factors, including modification and increase in experimental items, particularly the removal of ‘continuation’ sentence 3, which may have accumulated ‘wrap-up’ processes in Experiment 1.

Regression path times The pre-critical region 2 revealed a main effect of context [$F_1(1, 35) = 6.55, p = 0.01$; $F_2(1, 31) = 5.13, p = 0.03$], with longer reading times following RW than CW contexts. The critical region 3 showed no main effects or an interaction between factors [all $F_s < 3.0$]. However, by the post-critical region 4, times were longer when the critical word had been inconsistent with the prior context [$F_1(1, 35) = 6.42, p = 0.02$; $F_2(1, 31) = 8.13, p < 0.01$]. A main effect of context was also found, that was marginal by participants and significant by items [$F_1(1, 35) = 3.63, p = 0.06$; $F_2(1, 31) = 4.34, p = 0.05$]. This effect was largely due to greatly increased reading times in the RW-inconsistent condition. There was no reliable interaction between consistency and CW/ RW [$F_s < 0.1$]. Thus, by the post-critical region, CW

context is being used without apparent conflict from CW-consistent condition materials being inconsistent with the real world.

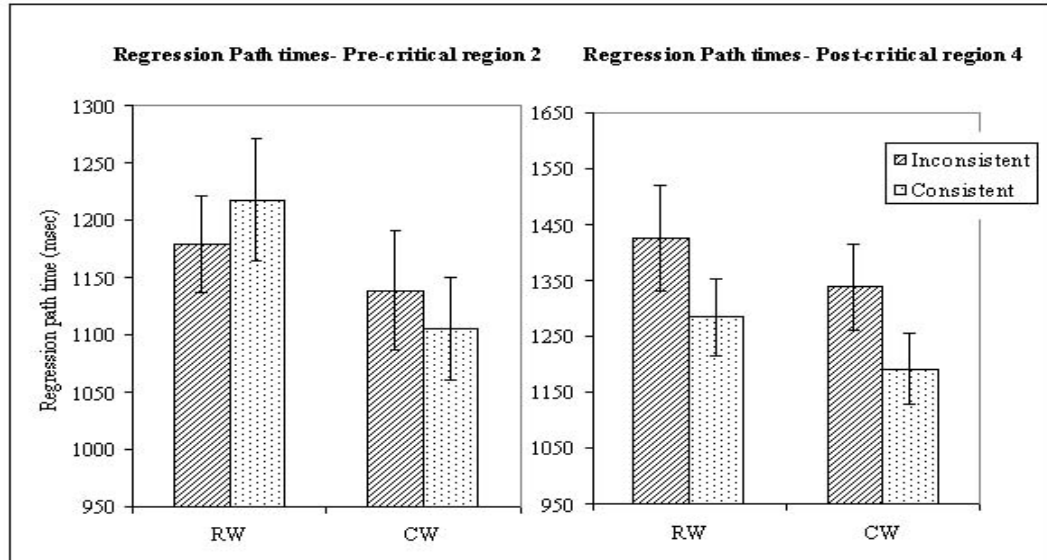


Figure 2.8: Mean regression path reading times in pre-critical and post-critical regions, showing standard error bars.

Total reading times

Similar to Experiment 1, total reading times at the pre-critical region 2 showed a main effect of consistency [$F_1(1, 35) = 4.21, p = 0.05$; $F_2(1, 31) = 4.03, p = 0.05$] and a main effect of context [$F_1(1, 35) = 14.08, p = 0.001$; $F_2(1, 31) = 14.47, p = 0.001$]. Inconsistent conditions led to longer total reading times than consistent conditions and longer total reading times when the critical sentence followed a RW context than a CW context. The consistency effect persists into the critical region 3 [$F_1(1, 35) = 4.22, p = 0.05$; $F_2(1, 31) = 4.23, p = 0.05$], and an interaction between conditions, significant by participants and marginal by items, emerges here [$F_1(1, 35) = 5.18, p = 0.03$; $F_2(1, 31) = 2.85, p = 0.1$].² Analysis of the simple main effects revealed longer total reading times in the inconsistent than the consistent condition at the level of

² Number of fixations data reflected total reading times with main effects of context [$F_1(1, 35) = 9.26, p < 0.005$; $F_2(1, 31) = 8.07, p < 0.01$] and consistency [$F_1(1, 35) = 5.07, p < 0.05$; $F_2(1, 32) = 5.14, p < 0.05$] in pre-critical region. Consistency effects persisted into the critical region [$F_1(1, 35) = 6.86, p < 0.01$; $F_2(1, 31) = 4.03, p < 0.05$].

RW [$F_1(1, 35) = 6.54, p < 0.02$; $F_2(1, 31) = 7.08, p < 0.02$], however this was not significant at the level of CW [$F_s < 0.2$]. Similar to effects in regressions out data, RW led to longer total reading times compared to CW for inconsistent conditions [$F_1(1, 35) = 5.03, p < 0.03$; $F_2(1, 31) = 2.30, p = 0.14$] but there was no difference between RW and CW consistent conditions [$F_s < 2.1$]. Thus, the effects reported in the pre-critical and critical regions were principally led by increased total reading times for the RW-inconsistent condition and support the suggestion of a larger disruption to the reading process following RW inconsistencies and delayed inconsistency-detection following CW inconsistencies. In sum, over later measures of processing in the pre-critical and critical regions, there is evidence that readers have integrated the CW context into their current knowledge as the RW congruent information is processed as anomalous following a CW context. Similarly, the RW anomaly is processed as acceptable within a CW context.

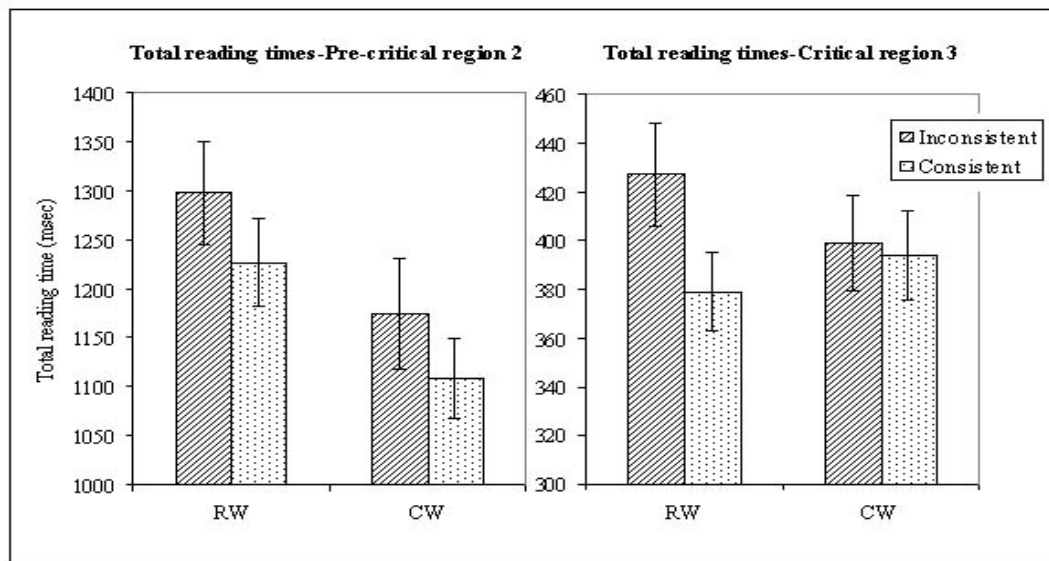


Figure 2.9: Mean total reading times in pre-critical and critical regions, showing standard error bars.

Regressions in A main effect of consistency was found at the pre-critical region [$F_1(1, 35) = 12.75, p = 0.001$; $F_2(1, 31) = 16.75, p < 0.001$], revealing increased incidence of regressions into the region following contextually inconsistent than consistent information. Additionally, a significant interaction between context and consistency was found [$F_1(1, 35) = 6.16, p = 0.02$; $F_2(1, 31) = 6.40, p = 0.02$]. Analysis of the simple main effects revealed that more regressions were made into the pre-critical region in the inconsistent than the consistent condition at the level of RW [$F_1(1, 35) = 22.07, p < 0.001$; $F_2(1, 31) = 28.83, p < 0.001$], however this was not significant at the level of CW [$F_s < 0.2$]. Additionally, RW led to increased regressions in compared to CW for inconsistent conditions [$F_1(1, 35) = 5.19, p = 0.03$; $F_2(1, 31) = 3.35, p = 0.08$] and CW led to marginally more regressions in than RW in consistent conditions [$F_1(1, 35) = 3.14, p = 0.08$; $F_2(1, 31) = 1.91, p = 0.17$]. Thus, incidence of regressions into the pre-critical region was considerably increased within a RW context when the critical word had been anomalous to our world knowledge.

It should be noted that across most measures of reading (namely regressions out, regression path times, total reading times, number of fixations and regressions in) the RW inconsistent condition caused a larger disruption to the reading process than any other condition (including CW-inconsistent), and suggests that RW inconsistencies may have a more powerful effect than CW inconsistencies.

In sum, Experiment 2 showed that world-inconsistent conditions (RW-inconsistent and CW-inconsistent) led to later effects of longer reading times, more fixations and a higher incidence of regressive eye movements around the critical noun than world-consistent conditions (RW-consistent and CW-consistent). This supports findings from Experiment 1 that prior context is rapidly comprehended so that words are processed in terms of that counterfactual world, thus leading to clear inconsistency effects. In addition, an early disruption, that was significant within a RW context, was

observed in response to critical words that violated real world expectations. Such effects were revealed by lengthened first-pass reading times on the critical word in Experiment 1, but in the present study, they were characterised by an increased incidence of regressive eye- movements from and around the critical region. Consequently, we can also claim that RW inconsistencies were detected earlier than CW inconsistencies, as effects of the CW inconsistency were revealed later in the eye- movement record, in regressions from the post-critical region and total reading time measures.

Thus, the results from Experiment 2 allow us to reject the possibility that the effects in initial reading measures are due to priming in the CW conditions, as this effect is still clear when the critical word has been primed by the same critical words in CW and RW conditions. This decision is supported by existing literature (Altarriba et al., 1996; Rayner & Well, 1996; Schustack et al., 1987) showing that contextual priming leads to shorter reading times, while our results show increased first-pass reading times in the CW-consistent condition.

Experiment 3

The purpose of Experiment 3 was to confirm that the early effects for RW violations can be replicated, and also to further investigate the role of the modal verb in the critical sentence. Experiments 1 and 2 used an ‘If... then...could...’ construction to create counterfactual scenarios. However, it was considered that since *could* expresses a conditional possibility or ability, it may imply that a few options are available to the situation, and therefore lends more to a counterfactual interpretation. For example, if a cat were hungry then we *could* feed it bowl of carrots but it would walk away disdainfully. Therefore, Experiment 3 used the modal verb *would* to express that the event is a repeated or habitual action. The use of an ‘If...then...would...’ composition should draw stronger associations to real-world expectancies. Thus, we examine the strength of a counterfactual context and whether contextual consistency effects can still be identified under these conditions.

Method

Participants

Thirty-six participants from the undergraduate population of Glasgow University took part in the study for a small payment. Participants were selected according to the same criteria as in experiments 1 and 2 and additionally they had not taken part in Experiments 1 or 2.

Materials and Design

Thirty-two experimental items were used in this study. A 2x2 within subjects design crossed two context conditions with two consistency conditions, as described in Experiment 2. Here, the modal verb *could* in the critical sentence was replaced by *would* to investigate the strength of a counterfactual context on comprehension. Additionally,

since Experiment 2 found that the early disruptions to the reading process following RW anomalies (regardless of context) were not due to priming in the CW conditions, Experiment 3 used the original RW context design from Experiment 1. An example experimental item is shown in Table 2.5.

<i>RW-inconsistent</i>
If cats are hungry they usually pester their owners until they get fed. Families would feed their cat a bowl of carrots and it would gobble it down happily.
<i>RW-consistent</i>
If cats are hungry they usually pester their owners until they get fed. Families would feed their cat a bowl of fish and it would gobble it down happily.
<i>CW-inconsistent</i>
If cats were vegetarians they would be cheaper for owners to look after. Families would feed their cat a bowl of fish and it would gobble it down happily.
<i>CW-consistent</i>
If cats were vegetarians they would be cheaper for owners to look after. Families would feed their cat a bowl of carrots and it would gobble it down happily.

Table 2.5: Examples of experimental sentences (Experiment 3).

Length and frequency of the critical nouns were matched across conditions. Mean frequency was 79.0 occurrences per million words for the RW-inconsistent and CW-consistent conditions (mean length = 5.8 characters (min.= 3, max.= 10)) and 65.5 for the RW-consistent and CW-inconsistent conditions (mean length = 6.0 characters (min.= 3, max.= 11)).

One version of each item was assigned to one of four lists for the eye-movement monitoring stage of the experiment. The items were displayed alongside 152 filler sentences of various types.³ At least one filler item intervened between each experimental item. Comprehension questions occurred after half of experimental (i.e., 16) and half of the filler (76) items. Participants did not receive feedback for their responses and scored at or above 90% accuracy on the comprehension questions.

³ The higher number of filler items in Experiment 3 is attributable to larger experiments serving as filler items for this study.

Eye tracking and Procedure

The eye tracking equipment and experimental procedure were identical to that in the previous experiments.

Results and Discussion

Regions of analysis

Regions of analysis were as in (4), for consistency with earlier studies. The data were analysed in terms of first-pass reading times, first-pass regressions, regression path times, total reading times and regressions in as shown in Table 2.6.

	Region				
	Context Sentence 1	1 <i>Families could</i>	2 <i>feed their cat a bowl of</i>	3 <i>carrots and</i>	4 <i>it would gobble it down happily.</i>
First-pass reading time (ms)					
RW-inconsistent	2710 (125.4)	471 (26.1)	779 (35.0)	302 (9.2)	861 (50.0)
RW-consistent	2699 (137.0)	465 (22.1)	785 (37.0)	288 (10.9)	845 (43.4)
CW-inconsistent	2736 (130.8)	462 (21.1)	766 (39.9)	285 (10.4)	893 (41.0)
CW-consistent	2816 (146.6)	483 (23.2)	766 (39.8)	324 (11.4)	870 (44.5)
Regression path time (ms)					
RW-inconsistent	2710 (125.4)	513 (33.4)	892 (43.5)	358 (15.5)	1119 (64.0)
RW-consistent	2699 (137.0)	496 (26.4)	877 (45.1)	338 (16.4)	1089 (74.7)
CW-inconsistent	2736 (130.8)	518 (26.1)	868 (43.8)	344 (21.0)	1158 (62.6)
CW-consistent	2816 (146.7)	517 (26.1)	901 (39.3)	367 (14.5)	1063 (62.2)
First-pass regressions out (%)					
RW-inconsistent	-	3.3 (1.2)	9.1 (2.0)	10.7 (2.3)	22.2 (2.3)
RW-consistent	-	3.3 (1.2)	7.8 (1.8)	12.3 (3.2)	17.1 (3.1)
CW-inconsistent	-	5.1 (1.3)	8.3 (2.0)	11.3 (2.6)	24.1 (3.7)
CW-consistent	-	4.2 (1.1)	11.0 (2.0)	11.9 (2.4)	17.9 (2.7)
Total reading time (ms)					
RW-inconsistent	2782 (130.5)	526 (30.4)	944 (47.7)	360 (17.0)	972 (50.9)
RW-consistent	2781 (143.0)	518 (26.0)	919 (48.3)	327 (14.4)	940 (52.7)
CW-inconsistent	2842 (133.5)	529 (23.9)	916 (45.7)	327 (13.4)	994 (47.6)
CW-consistent	2899 (154.6)	544 (26.0)	916 (41.3)	353 (11.1)	928 (48.7)
Regressions In (%)					
RW-inconsistent	8.8 (2.0)	12.5 (2.1)	19.8 (3.0)	12.7 (2.6)	0.7 (0.5)
RW-consistent	9.6 (2.2)	11.3 (2.2)	13.2 (2.3)	8.0 (1.9)	0.7 (0.5)
CW-inconsistent	13.9 (2.2)	15.6 (3.0)	15.6 (2.6)	8.1 (1.8)	0.6 (0.4)
CW-consistent	10.0 (2.3)	17.4 (2.5)	13.5 (2.5)	6.1 (1.6)	0.7 (0.5)

Table 2.6: Mean eye- movement measures for regions 1 to 4 (standard errors in parentheses)

First-pass reading times The critical region 3 reveals a significant interaction between context and consistency [$F_1(1, 35) = 12.45, p = 0.001$; $F_2(1, 31) = 5.22, p = 0.03$]. Analysis of the simple main effects revealed that first-pass reading times were longer in the inconsistent than the consistent condition at the level of CW [$F_1(1, 35) = 9.85, p = 0.003$; $F_2(1, 31) = 8.19, p = 0.008$], however this was not significant at the level of RW [$F_s < 1.2$]. Furthermore, CW led to increased first-pass reading times compared to RW for consistent conditions [$F_1(1, 35) = 7.45, p < 0.01$; $F_2(1, 31) = 12.05, p < 0.001$] but there was no difference between CW and RW inconsistent conditions [$F_s < 1.7$]. Thus, these results provide further support that the effects of real-world anomalies may be picked up in measures of very early processing in this experiment despite the presence of a counterfactual discourse context making that anomaly acceptable. These data are illustrated in Figure 2.10.

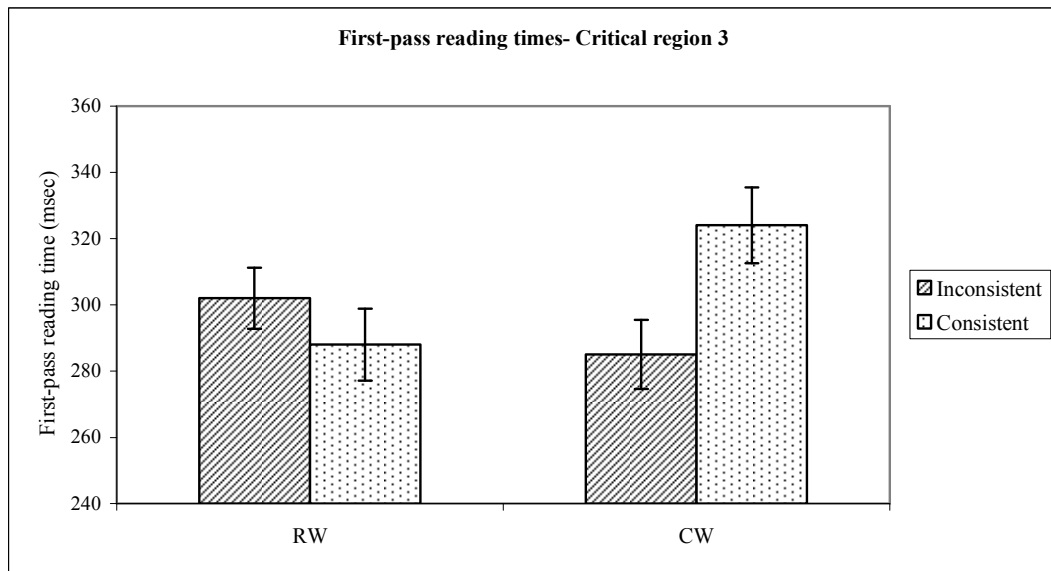


Figure 2.10: Mean first-pass reading times in critical region showing standard error bars.

First-pass regressions out Figure 2.11 illustrates how each condition affected the mean first-pass regressions out of each region as the sentence progressed.

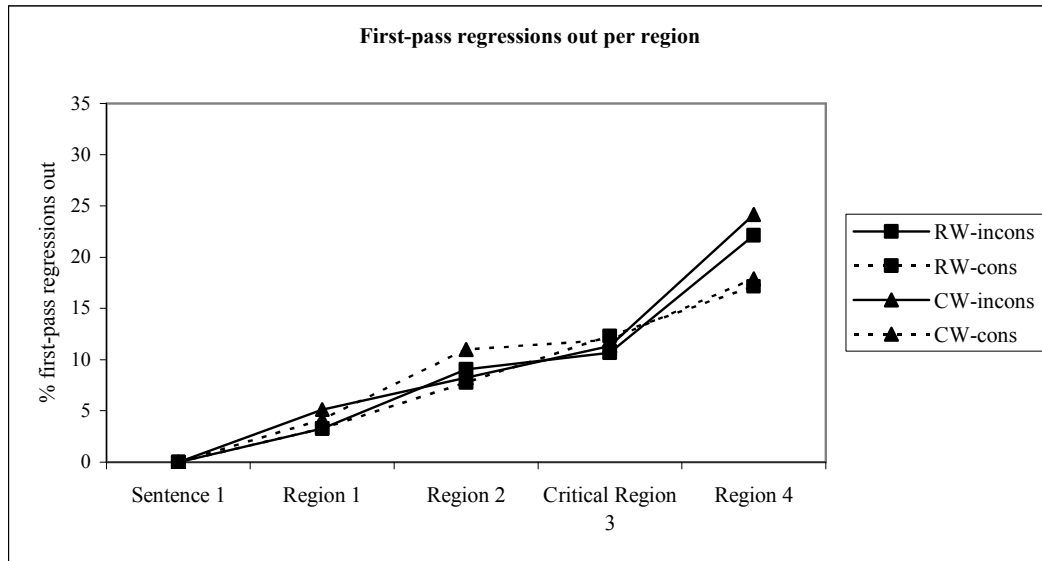


Figure 2.11: Percentage first-pass regressions out

No main effects or an interaction between context and consistency variables was found at the critical region 3 (All F 's < 0.3). However, a main effect of consistency was revealed at the post-critical region 4 [$F_1(1, 35) = 5.51, p = 0.02$; $F_2(1, 31) = 6.21, p = 0.02$], with increased incidence of first-pass regressions out from this region when the critical word had been inconsistent with prior context. These increased regressions out are likely to be due to readers regressing back in the text to attempt to make sense of the inconsistency. Thus, this provides evidence that by the post-critical region, participants are using the CW context to interpret the text, making a real-world anomaly acceptable and real-world congruent information unacceptable.

Regression path times No main effects or interactions were revealed in the regression path measure at any region (All F 's < 3.66).

Total reading times Total reading time indicated a significant interaction at the critical region 3 [$F_1(1, 35) = 7.40, p = 0.01$; $F_2(1, 31) = 4.33, p = 0.05$]. Similar to the first-pass reading time data, analysis of the simple main effects showed that total

reading times were longer in the inconsistent than the consistent condition at the level of RW [$F_1(1, 35) = 4.23, p < 0.05$; $F_2(1, 31) = 5.12, p < 0.03$], and was marginal at the level of CW [$F_1(1, 35) = 2.57, p = 0.1$; $F_2(1, 31) = 2.75, p < 0.1$]. Furthermore, total reading times were longer for RW compared to CW for inconsistent conditions [$F_1(1, 35) = 7.28, p < 0.01$; $F_2(1, 31) = 2.98, p = 0.09$], but were longer for CW than RW for consistent conditions [$F_1(1, 35) = 4.50, p < 0.04$; $F_2(1, 31) = 2.65, p = 0.1$]. In sum, this effect, lasting into later measures, suggests that the use of *would* in the critical sentence has led participants to process the passage according real-world expectancies for an extended period, and to be particularly sensitive to world knowledge violations within a CW context.

The anticipated main effect of consistency was found at the post-critical region 4, with longer total reading times in the RW-inconsistent and CW-inconsistent conditions than in the RW- and CW-consistent conditions [$F_1(1, 35) = 4.87, p = 0.03$; $F_2(1, 31) = 4.41, p = 0.04$].⁴ Thus, by the post-critical region there is evidence that readers have integrated the CW context into their current knowledge.

⁴ Data from number of fixations reflects total reading times, with an interaction at the critical region [$F_1(1, 35) = 9.97, p = 0.003$; $F_2(1, 31) = 4.06, p = 0.05$] and a main effect of consistency at the post-critical region [$F_1(1, 35) = 9.11, p = 0.005$; $F_2(1, 31) = 4.76, p = 0.04$].

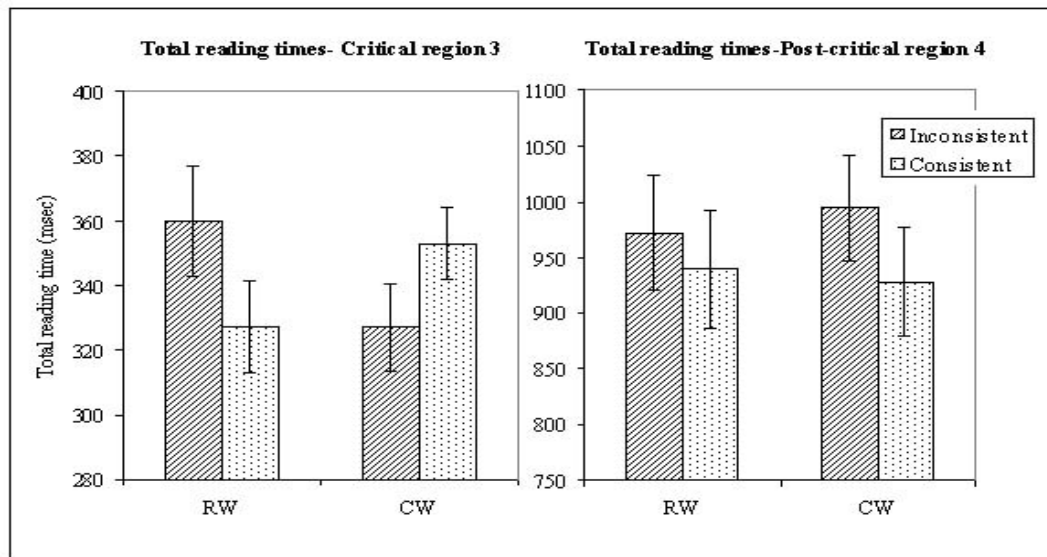


Figure 2.12: Mean total reading times in critical and post-critical regions, showing standard error bars.

Regressions in Region 1, that introduced the critical sentence, showed a main effect of context [$F_1(1, 35) = 5.76, p = 0.02$; $F_2(1, 31) = 4.00, p = 0.05$]. This region was more likely to be revisited following a CW context than a RW context. Later at the critical region, a main effect of consistency was revealed [$F_1(1, 35) = 3.97, p = 0.05$; $F_2(1, 31) = 4.96, p = 0.03$], with more regressions into this region when the critical word had been inconsistent with the prior context.

The findings in the present study follow those from Experiments 1 and 2. Lengthened reading times at the critical region following a real-world anomaly provides further support for an initial processing mechanism using real-world knowledge. Nevertheless, readers quickly accommodate input to the CW context when one is present. The effects of real-world knowledge are longer lasting in Experiment 3, extending into total reading times and number of fixations at the critical region. We propose that this is due to the use the modal verb *would* to introduce the real-world/counterfactual event. This prolonged effect was anticipated as *would* suggests that an event is a repeated or habitual, therefore, representing stronger associations to real-

world expectancies. However, the fact that counterfactual-world consistency effects were still identified under these conditions provides further evidence that a prior CW context plays an integral, if delayed, role in comprehension.

Discussion

In Experiment 1, we used an anomaly paradigm to investigate whether the presence of a counterfactual context would eliminate the effects of a statement that was anomalous with respect to the real world, but which fits the counterfactual context. The results showed that, initially, there was a disruption to eye-tracking even when the anomaly fitted the counterfactual world context, showing as an increase in first-pass reading time at the critical point where the anomaly emerged. Shortly after that, and on measures of later processing, the CW context accommodated the fact completely. Thus within the limits of the paradigm, language input is indeed tested against real-world knowledge, even in the presence of a counterfactual world context. Experiment 2 further showed that when a fact that does not fit the CW is presented in the CW context, that too creates a disruption of processing similar in nature to that obtained in the RW-inconsistent condition, a result replicated in Experiment 3.

Further evidence for the delayed integration of language input with a preceding CW discourse context was found in both Experiment 2 and 3. In Experiment 2, the effect of violating real-world knowledge within a RW context was revealed in the number of first-pass regressions out of the critical region, however, detection responses to the CW inconsistency were not revealed until later regions of analysis. An additional purpose of this experiment was to rule out the possibility of priming effects influencing first pass reading times in the four conditions. Therefore, it is possible that because reality in the RW context was not only implied, but explicitly stated (e.g. 'Evolution dictates that cats are carnivores and cows are vegetarians') participants were more alert

to the RW anomaly, causing them to immediately regress back in the text to make sense of the anomaly, rather than to seek more information at the critical region. In Experiment 3, a similar effect to Experiment 1 was found, with increased first-pass reading times on the critical word following a real-world anomaly, notably following a CW context that should make this anomaly acceptable. In this experiment, the effects of the RW anomaly were longer lasting and persisted into later eye-movement measures of total reading time and number of fixations. This is likely to be due to the use of the modal verb *would* in the critical sentence, which requires the reader to accept some event as a usual or repeated behaviour under given conditions. Consequently, it is believed that this should draw stronger associations to real-world expectancies. However, regressions and later effects in the post-critical region revealed that contextual information, though delayed, was used to process the passages. Regardless of the fact that the effects occur across slightly different measures of reading in the three experiments, the statistical analyses led to robust effects on early measures of reading (extending to later measures in Experiment 3), at the same critical region in all three studies. Therefore, we consider the results reported here to support a dual, possibly two-stage, discourse comprehension process (Garrod & Sanford, 1999; Garrod & Terras, 2000; Sanford & Garrod, 2005; Cook & Myers, 2004).

Clearly, when the use of a word violates real-world knowledge, this creates a very early effect upon reading, while contextual information influences later discourse resolution. Thus the basic underlying claim, that language input is compared initially against real-world knowledge even in the presence of a CW context, appears to hold. This effect could, in different ways, fit with both a mental model account and a suppositional account of counterfactual conditional processing. Specifically, the mental model theory suggests that people hold in mind the factual possibility that cats are carnivores and therefore do not eat carrots and the counterfactual possibility that cats

are vegetarians who do eat carrots. Thus access to either mental space is available.

Additionally, within the mental model theory of conditionals, Santamaria, Espino & Byrne (2005), show that a counterfactual conditional statement primes both factual and counterfactual possibilities whereas a factual conditional primes only the real-world possibility. The effects reported here, where RW-inconsistent information takes longer to process than CW-inconsistent information, support the idea that both possibilities are primed by a counterfactual context while only one is primed by a factual conditional.

This suggests that some degree of conflict between reality and the counterfactual world is occurring in a counterfactual scenario. In contrast, the suppositional theory predicts that during the context sentence, readers temporarily add the counterfactual possibility to their store of beliefs by creating a model through a process of *minimal change to reality*. Later processing of events following this context sentence are then dependent on whether that event (e.g. eating carrots) is consistent with the available model. In cases where a violation is initially detected, the suppositional account suggests that participants must refer back to the CW context to evaluate whether it would fit with the alternative world. Accordingly, the early interference caused by RW violations might reflect this extra stage of processing in the case of counterfactuals. It is also interesting to note that given a particular minimal change, some consequents may be easier to infer from the counterfactual state of affairs than others (e.g. *cats eating carrots* given the CW that *cats are vegetarians*). This gives rise to an interesting test of the suppositional theory, as the closeness of the counterfactual to reality will affect the construction of a counterfactual world representation. Consequently, the presence of early effects on processing of real-world violations within a counterfactual context could be predicted by the suppositional model in relation to the distance of change to reality. In comparison, the mental model theory does not make such predictions based on closeness and thus far contains no explanation for the processes by which readers create

a counterfactual and factual model. However, the experimental items used in these studies were not constructed to enable a systematic analysis of counterfactual closeness effects on comprehension. Therefore, while this is an interesting issue for future study we feel that involvement in such a debate is not justified at this stage. In sum, we do not commit to either of these theories, only that clearly, for a full understanding of a counterfactual statement, readers must create a representation of both reality and the counterfactual alternative.

A two-stage process of discourse resolution has also been reported by Garrod and Terras (2000). Their study investigated the contribution of purely lexical semantic factors (e.g., that *write* implies using a *pen*) compared to more general contextual factors (e.g., writing on a *blackboard*). They suggest that initial processing of a word is driven by the lexical link between a verb and a dominant role-filler. Thus, dominant role-fillers, such as *the pen*, are integrated automatically with previous material about writing, whereas non-dominant role-fillers, such as *the chalk*, are not and rely on a later process. Further, this early integration process is not influenced by the context in which the role was introduced. Thus *writing on a blackboard* is just as effective for initial integration of *the pen* as is *writing a letter*. Prior context makes an important contribution only at the later second, resolution, stage. The experimental items in the current studies used unbiased verbs to introduce the critical sentence (e.g. *feed* could imply either *carrots* or *fish*). According to Garrod and Terras, the noun in the critical sentence should not influence initial processing. Thus, in terms of lexical priming, *feeding a cat* should be equally effective for the initial integration of *carrots* and *fish*. Additionally, the fact that the strength of associations can be influenced by changing the modal verb in the target sentence (Experiment 3) suggests that more sophisticated language representations are occurring during the comprehension of counterfactuals. On this basis, we believe that the effects reported here, with an early disruption to the

reading process following a real-world anomaly, are a genuine consequence of access to real-world knowledge and not simply lexical semantic effects. In sum, access to world knowledge could go on in parallel to the development of a counterfactual representation, or could be a preliminary stage. We are not committed either way at this point, though the next two chapters suggest some constraints on the possibilities.

These three eye-tracking studies of reading provide evidence implying that processing strategies are different for real-world and counterfactual-world information. The fact that RW inconsistencies are detected immediately in the eye-tracking record, extending into later measures, with lengthened reading times and increased regressions, implies that readers are seeking more information around the critical region following RW-inconsistent items, perhaps re-evaluating the model or reparsing the text. In contrast, Experiments 1 and 3 reveal that while the CW-consistent items also lead to initial problems in processing with lengthened reading times at the critical region, increased regressive eye-movements do not accompany this disruption. Thus, the slowed reading following CW-consistent conditions may reflect extra time required to integrate the counterfactual context. For example, a real-world situation develops strong expectations towards a real-world event, causing immediate and comprehensive reanalysis. In contrast, a counterfactual-world situation might produce 'digging-in' effects involving a series of attempted attachments to semantically relevant CW expectancies, which may in turn compete with typical attachments to RW expectancies. Tabor & Hutchins (2004) have suggested a similar model applied to syntax, where reanalyzing text becomes harder the more committed the parser has become to a particular syntactic choice.

Another consideration is the time readers spent processing in a CW context. In order to provide a fair test of the idea that CW contexts would readily accommodate facts congruent with CW, we took care to introduce the counterfactual world in a

separate prior sentence, and provided a rationale for the introduction of CW into the discourse. We considered this to be important because firmly establishing the counterfactual would be necessary to fairly answer our initial question. However, the vignettes used in our experiments were very short, and one question is whether with continued exposure to a counterfactual world, continued checking against real-world knowledge would continue. Ultimately, only further experimentation will tell.

Nieuwland and Van Berkum (2006) carried out an experiment in which an event impossible in the real world (e.g., *The peanut fell in love*) initially produced the large N400 effect in the EEG commonly found with such anomalies. However, when a story was produced in which the peanut was firmly established as “a character”, the N400 effect ultimately disappeared. This observation fits well with the findings presented here that real-world inconsistent information can be accommodated readily within a counterfactual framework when one is clearly provided. Building up the characterisation of a peanut as an animate, feeling entity is one way of doing this (and is commonplace in the world of animated cartoons, for instance). However, it is not at all clear that these results mean that no check against the real world is actually taking place. This issue is examined more closely in Chapter 3, using EEG techniques to investigate whether CW inconsistencies are revealed in the same way as RW inconsistencies in the ERP components, and specifically whether there is a different pattern or time-course of inconsistency detection for RW and CW information.

To conclude, Chapter 2 presents three experiments showing that when a new counterfactual situation is asserted, people will readily assimilate new input into this situation. If a fact fails to fit the counterfactual world, then it disrupts eye-tracking. If the situation depicted is part of the real world, then a subsequent input that fails to match leads to a similar disruption of eye-tracking. Most interesting, however, is the finding that just prior to the accommodation of a proposition into a counterfactual world

representation, the proposition is rapidly evaluated against real-world knowledge. This has the effect of delaying accommodation in the counterfactual world case. Thus, even in the setting of a counterfactual world context, evaluation against real-world knowledge takes place. Finally, the very early influence of situation-specific information provides some very good evidence for the general argument that language comprehension is founded on the fast access to world knowledge.

Chapter 3

N400 evidence for detection of Counterfactual World Inconsistencies

Introduction

In this chapter I describe a single study using Electroencephalographic (EEG) methodology that attempts an exploration of the neural mechanisms and their time course during the comprehension of counterfactuals. The multidimensional nature of ERPs means that a great deal of potentially relevant information can be gained that would not be possible using behavioural response tasks (Van Berkum, 2004). Specifically, ERPs can reveal detailed information on the sensitivity of our brains to certain linguistic features as well as possible differences in the temporal nature, polarity, morphology and topography of such effects. These features and the relatively non-invasive nature of ERP make it an ideal technique for investigations of language comprehension.

Background

EEG entails the recording of small brain-electrical potentials at the scalp by means of electrodes. Most experimental psychologists are interested in the EEG signal elicited in response to a particular critical event, such as the onset of a word or picture. The assumption is that cognitive sub-processes are modulated by different anatomical and physiological substrates and as such they will generate distinct patterns of neuronal activity. However, the raw EEG has not proven to be sensitive or specific enough to distinguish between fine-grained changes in mental activity, and as such is of limited use in studying moment-by-moment human cognitive activity. Therefore, the average Event-Related brain Potential (ERP) is the most commonly used measure in psycholinguistic research. The ERP primarily reflects waveforms in the raw EEG signal that are specifically elicited by the onset of the critical stimulus and show a consistent morphological structure. To visualise the ERPs in the EEG signal, the experimenter must time-lock the EEG recording to multiple presentations of given events then

average these signals together to decrease the influence of random activity (i.e. background or non-event related activity). The ERP waveform generally contains a series of positive and negative deflections. These peaks are commonly referred to as *components* and much research in cognitive psychology has attempted to define their functional significance. ERP components can be classified according to various characteristics of the waveform, particularly their *polarity*, which can be positive or negative, their *latency*, the time point where the component reaches its highest amplitude, and their *scalp distribution* (or topography). Generally, components occurring before 200ms are thought to reflect late sensory and early perceptual processes, whereas those occurring after 250ms are thought to reflect higher level cognitive processes, such as memory or language. See Figure 3.1 for a schematic illustration of how ERPs are derived.

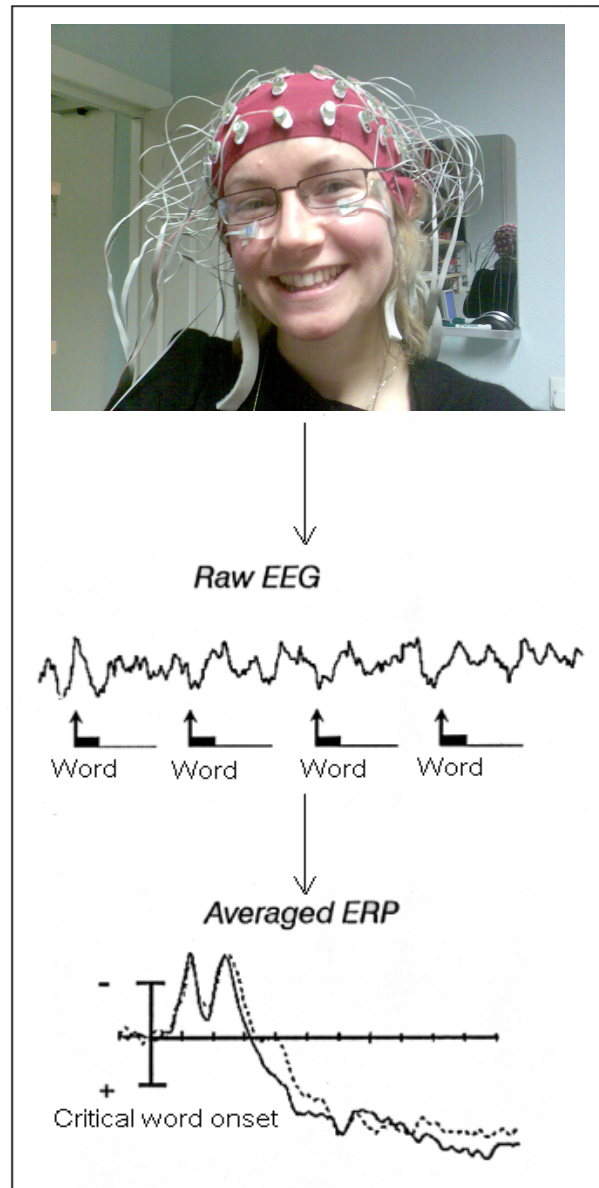


Figure 3.1: Illustration of participant during the EEG recording phase (showing electro-cap and electrodes), the raw EEG signal and the ERP averaged time-locked to the onset of a pre-specified critical word.

Research using ERPs supports the findings from eye-tracking studies that pragmatically anomalous words are detected as soon as they occur. Specifically, the processing of semantic information has been found to influence the amplitude of a negative-going ERP component between roughly 250 and 550 ms, and with maximal amplitude at about 400 ms over centroparietal scalp sites (Kutas & Hillyard, 1980).

This N400 is elicited by every content word in an unfolding sentence and the modulation of the N400's amplitude is commonly referred to as the N400 effect. This N400 effect, elicited in response to pragmatic violations, is observed all over the scalp although it is larger over posterior electrode sites than over frontal sites and is usually larger on the right side of the head than the left (Kutas, 1988). The N400 is elicited by words in all modalities, including word-by-word written presentation, listening to continuous speech, and sign language (e.g., Conolly & Phillips, 1994; Holcomb & Neville, 1990; Kutas & Kluender, 1994). The amplitude of the N400 is sensitive to lexical factors, such as word frequency, semantic priming, and repetition (Smith & Halgren, 1989; Holcomb, 1988; Van Petten, Kutas, Kluender, Mitchiner & McIsaac, 1991), but importantly it is especially sensitive to semantic integration processes (Brown & Hagoort, 1999; Brown, Hagoort & Kutas, 2000; Kutas & Van Petten, 1994). In fact, a large N400 is the default for words that are unpredictable, or do not fit a context well. Various degrees of contextual support have been shown to reduce the N400 effect (Kutas, Van Petten, & Kluender, 2006; Van Berkum, in press), and an important finding is that simply adding an appropriate title to a paragraph leads to smaller N400 components for each word within that paragraph (St. George, Mannes & Hoffman, 1994). Figure 3.2 depicts typical N400 waveforms following local semantic and discourse anomalies.

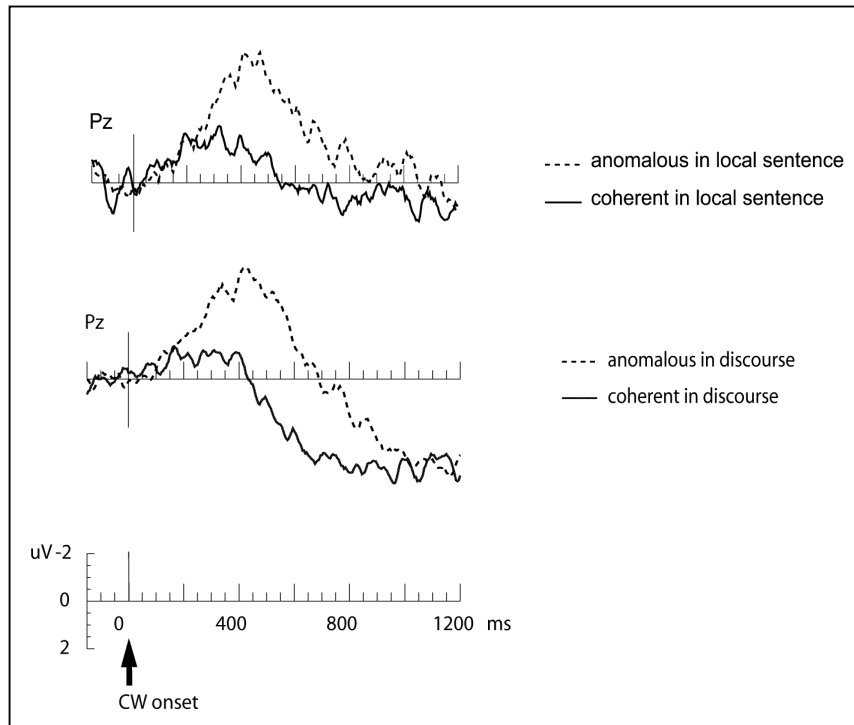


Figure 3.2: N400 waveform at electrode Pz. *Top:* N400 effect elicited by words that are semantically coherent (solid line) or anomalous (dotted line) with respect to the local sentence context. *Bottom:* N400 effect elicited by words that are semantically coherent (solid line) or anomalous (dotted line) with respect to the discourse context. Note that in these figures, negativity is plotted upwards. (Graphs taken with permission from Van Berkum et al., 2003)

An important effect was demonstrated by Van Berkum, Hagoort and Brown (1999; see also Van Berkum, Zwitserlood, Hagoort & Brown, 2003), who used ERPs to investigate semantic integration of information in text. Participants were presented with short stories, some of which contained a critical word that, although acceptable in the local sentence context, was semantically anomalous with respect to the wider discourse, as in (1).

(1) Jane told her brother that he was exceptionally *slow*.

While the word *slow* is not anomalous in this sentence, it becomes anomalous when (1) follows a discourse context highlighting the idea that Jane's brother had been very quick, in fact. Relative to coherent control words, the discourse-dependent context

anomalies elicited a large N400 effect, similar in surface form to pragmatic anomalies, showing that immediate anomaly detection is not confined to the constraints of the local sentence. In addition, follow up investigations have revealed that the N400 effect emerges even for more subtle differences in discourse-fit using gender-marked adjectives (Van Berkum, Brown, Zwitserlood, Kooijman & Hagoort, 2005). Thus, because of its established sensitivity to local semantic factors as well as discourse-level global context, the N400 component allows us to examine the interplay between the two, particularly in cases where local and discourse information are in direct conflict.

However, successful language comprehension does not necessarily require information to map directly onto our real-world expectations. Recent studies have used descriptive discourse (Nieuwland & Van Berkum, 2006) to create contexts that normalise violations of real-world principles. In these cases, readers happily accept events that violate their real-world expectations, when they are acceptable given the prior context. Nieuwland & Van Berkum carried out two ERP experiments investigating how locally presented animacy requirements interact with the wider discourse context. In Experiment 1, participants listened to short narratives in which a character was engaged in conversation with either another character or an inanimate object (e.g. *a suitcase*). Results showed that while a large N400 effect was elicited by the animacy violation in the initial sentence, subsequent exposure to comparable animacy violations did not produce such an effect, suggesting that an alternative ‘cartoon-like’ interpretation has completely overruled the effects of the local lexical-semantic animacy violation. Experiment 2 tested whether an appropriate cartoon-like interpretative context (e.g. a dancing peanut) can reduce the amplitude of the N400 effect to animacy violations (e.g. ‘The peanut was *in love*’). This was indeed the case as locally anomalous critical words that are appropriate to the wider discourse context elicited a smaller N400 than locally plausible but contextually inappropriate critical words (e.g.

salted). Thus, taken together, these studies provide strong evidence that discourse context can apparently completely overrule local semantic violations.

More recently, researchers have considered the integration of word meaning and world knowledge in language comprehension. It has been suggested that the semantic interpretation of a sentence is separate from and precedes the integration with real-world knowledge information (Clark, 1996). Hagoort, Hald, Bastiaansen and Petersson (2004; see also Hald, Hagoort & Van Galen, 2004; Hald, Bastiaansen & Hagoort, 2006; Hald, Steenbeek-Planting & Hagoort, in press) have investigated this issue using EEG and functional Magnetic Resonance Imaging (fMRI) techniques. Participants read sentences like (2).

- (2) a. The Dutch trains are yellow and very crowded. (correct)
- b. The Dutch trains are white and very crowded. (world knowledge violation)
- c. The Dutch trains are sour and very crowded. (semantic violation)

In this example, the description of Dutch trains being *white*, as in (2b), violates the reader's world knowledge, as it is a well-known fact among Dutch people that Dutch trains are in fact yellow, as in (2a). In contrast, the description word *sour* violates semantic constraints as its core meaning is related to taste and food, and thus is anomalous when applied to a description of trains, as in (2c). ERP results showed a clear and sizeable N400 effect, with equivalent onset and peak latencies for semantic and world knowledge violations. Similarly, an event-related fMRI experiment using the same materials, revealed increased activation in the left inferior prefrontal cortex (an area known to contain one of the N400 generators (e.g. Halgren, Baudena, Heit, Clarke, Marinkovic, Chauvel & Clarke, 1994; Halgren, Dhond, Christensen, Van Petten, Marinkovic, Lewine & Dale, 2002)), when compared to correct sentences, that was

common for both semantic and world- knowledge violations. However, clear distinctions between all conditions were identified using time- frequency analysis. Time- frequency analysis is a relatively new technique that has been shown to enable differentiation of oscillatory activity in the EEG data, which is not evident in the ERP alone (Varela, Lachaux, Rodriguez & Martinerie, 2001). Amplitude increases of EEG oscillations occur in specific frequency bands, such as theta (4 to 7 Hz) and gamma (~30 to 70 Hz). According to Varela and colleagues, when these oscillations are induced by a cognitive event, they reflect the dynamic recruitment of the relevant neuronal networks engaged in cognitive processing. Thus, this analysis method is very useful to investigate oscillatory activity in relation to some linguistic violation. Using such methods, Hagoort et al. found that sentences containing a semantic violation resulted in an increase in power in the theta frequency range relative to other sentences. In contrast, world knowledge violations resulted in a clear gamma peak that was not seen for either other condition. Since both these effects were visible within the latency range of the N400, the authors suggest that while reading a sentence, the brain retrieves and integrates word meaning and world knowledge simultaneously.

In sum, the amplitude of the N400 can be used as a measure of processing difficulty: the more unpredictable a target word is in the preceding context and consequently the more demands it makes upon integration processes, the larger the N400 component will be. This feature of the N400 make it is an ideal dependent variable in language comprehension experiments.

Experiment 4

The question in this chapter is whether typical effects of a local semantic violation in the ERP components can be deactivated, or reversed, by introducing an appropriate single-sentence counterfactual context. Consider counterfactual sentences, such as those used in the experiments in Chapter 2. Investigations to date have either employed an extensive discourse context, spanning several sentences, to create a discourse anomaly (e.g. Van Berkum et al., 1999; Niewlands & Van Berkum, 2006) or have investigated issues of local semantics and world knowledge separately (e.g. Hagoort et al., 2004). The studies reported here directly investigate how a preceding context interacts with world knowledge as participants read real- world anomalous or real- world congruent information that conflicts with a pre-specified counterfactual world context.

On the basis of previous ERP studies reported above and results from Chapter 2, one might expect to see a typical N400 effect for the RW conditions. Specifically it was expected that RW-inconsistent items, containing information that is anomalous to the readers' world knowledge, would induce a more negative-going N400 waveform than RW-consistent items that do not violate world knowledge. In contrast, it was anticipated that CW conditions would show a 'reversed' N400 effect at the target word, as the target word is accommodated into the wider discourse context. This effect would be characterised by a larger negativity in the CW-inconsistent condition since the target word was anomalous with the preceding counterfactual context. Thus, the CW-consistent condition would show a reduced N400 effect since the world knowledge violation has been made acceptable by the preceding counterfactual context. Finally, we predicted that some interference from world knowledge might be observed during early processing of the target word in CW conditions, reflecting the conflict resolution between information from the preceding context and world knowledge.

Method

Participants

Nineteen undergraduate students from the University of Glasgow (13 males) were paid to take part in this study. Participants ranged in age from 18 to 27 years. All participants were right-handed native English speakers, who did not have dyslexia and with normal or corrected to normal vision. Participants were naïve to the purpose of the study and had no previous exposure to the test materials.

Materials and Design

Four versions of 160 experimental items were prepared, as exemplified by the example item in Table 3.1.

<i>RW-inconsistent</i>
If cats are hungry they usually pester their owners until they get fed. Families could feed their cat a bowl of carrots and it would gobble it down happily.
<i>RW-consistent</i>
If cats are hungry they usually pester their owners until they get fed. Families could feed their cat a bowl of fish and it would gobble it down happily.
<i>CW-inconsistent</i>
If cats were vegetarians they would be cheaper for owners to look after. Families could feed their cat a bowl of fish and it would gobble it down happily.
<i>CW-consistent</i>
If cats were vegetarians they would be cheaper for owners to look after. Families could feed their cat a bowl of carrots and it would gobble it down happily.

Table 3.1: Examples of experimental sentences.

The experimental items were configured to produce a 2x2 within subjects design. The context condition was split into two levels: a real-world (RW), whereby the first sentence depicted a realistic circumstance (e.g. ‘If cats are hungry...’), and counterfactual-world (CW), whereby the first sentence created a model-based alternative to reality (e.g. ‘If cats were vegetarians...’). The consistency condition also

had two levels and was manipulated by changing the noun in the second sentence: inconsistent, whereby events described in the second sentence were inconsistent with the prior context or consistent, whereby the critical noun was consistent with the pre-specified context (e.g. ‘Families could feed their cat a bowl of carrots/ fish’). This created a fully crossed experiment with four conditions: Counterfactual world-consistent (CW-consistent), counterfactual world-inconsistent (CW-inconsistent), real world-inconsistent (RW-inconsistent), and real world-consistent (RW-consistent).

These materials were then used to create four stimulus lists. Each list contained 40 exemplars of each of the four experimental item types. Items were counterbalanced such that only one version of each sentence was presented on a given list. In addition, 80 filler materials of different types were used in the experiment to ensure that participants were naïve to the purpose of the study. Thus, each subject saw a total of 240 sentences.

Participants were tested in an electrically shielded booth with ambient light kept at a low level. Word stimuli were presented in black 16 point Helvetica font on a white background at the centre of a 15” computer monitor at a viewing distance of 90 cm.

Procedure

Participants were informed about the EEG procedure and experimental task. After electrode application they were seated in a booth where they read the materials on a computer screen. There were six practice trials to familiarize them with the procedure, after which the experimenter answered any questions. Each trial consisted of the events, presented in Figure 3.3: A red fixation cross appeared for 500 ms, followed by another white fixation for 500ms, after which sentence 1 (context sentence) was presented on the screen. Participants were instructed to read this sentence so that they understood the context and press spacebar on a computer keyboard to move on when ready. Next,

sentence 2 (critical sentence) was presented in a word-by-word manner, with each word appearing on the centre of the screen for 300ms. A blank-screen interval of 200 ms separated words. Sentence-ending words appeared with a full stop. A 2500-ms blank-screen interval followed each sentence. There was no secondary task. Trials appeared in eight blocks of thirty trials. Each block was separated by a break, the duration of which was determined by the participant. Thus, participants were tested in a single session that lasted approximately one hour, during which they were seated in a comfortable chair located in an isolated room.

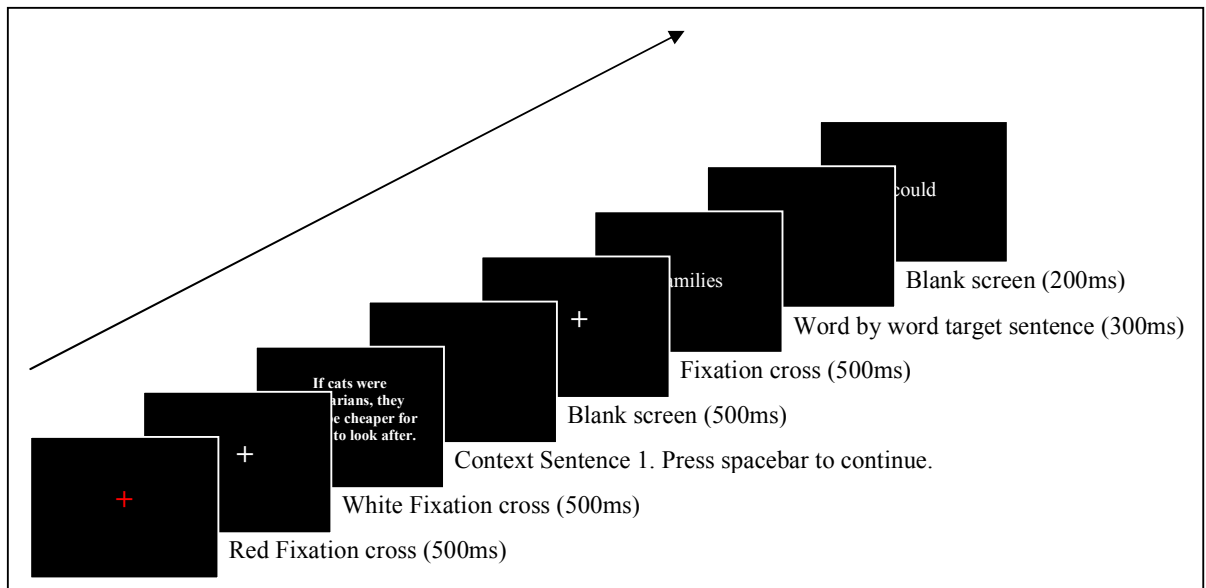


Figure 3.3: Schematic diagram of the experimental procedure.

Electrophysiological Measures

A BIOSEMI Active-Two amplifier system was used for continuous recording of electroencephalographic (EEG) activity from 72 Ag/AgCl electrodes over midline electrodes Fpz, AFz, Fz, FCz, Cz, CPz, Pz, POz, Oz, and Iz, over the left hemisphere from electrodes IO1, Fp1, AF3, AF7, F1, F3, F5, F7, F9, FC1, FC3, FC5, FT7, C1, C3,

C5, M1, T7, CP1, CP3, CP5, TP7, P1, P3, P5, P7, PO3, PO7, O1, two nonstandard positions PO9' and O9' which were located at 33% and 66% of the M1-Iz distance, respectively, and from the homologue electrodes over the right hemisphere (see Figure 3.4). EEG and EOG (eye blinks and eye movements) recordings were sampled at 256 Hz. Off-line, all EEG channels were recalculated to a linked mastoid reference. A mean horizontal EOG (hEOG) waveform was calculated as follows:

$$\text{(Eq. 1)} \quad \text{hEOG}(t) = F9(t) - F10(t)$$

Trials containing blinks were corrected using a dipole approach (BESA Version 5.1.6) and automatic artifact detection software (BESA) was run. Trials with non-ocular artifacts (drifts, channel blockings, EEG activity exceeding $\pm 120 \mu\text{V}$) were discarded. For all remaining trials, epochs of 1700 ms, starting 200 ms prior to the onset of the critical noun, were generated from the continuous EEG record. Thus, the post-stimulus epoch lasted for a total duration of 1500 ms (though these were extended from -1500ms to 2500ms for later time- frequency analyses).

electrodes where these deflections were maximal using pre-defined search intervals: P1 (90-140ms) and N1 (150-200ms). Additionally, visual inspection of the ERP waveforms directed us to measure mean ERP amplitudes of effects in the time intervals from 50-100ms, 200-350ms, 350-500ms (N400) and 500-700ms relative to critical word onset.

ERP amplitudes at midline electrodes (AFz, Fz, FCz, Cz, CPz, Pz, POz, Oz) were analysed separately from data recorded over lateral electrode sites. Specifically, regions of interest (ROIs) pooled data from lateral electrode sites, as recommended for the analysis of high-density electrode arrangements (cf. Dien & Santuzzi, 2005). The electrodes were divided along a left-right dimension, an anterior-to-posterior dimension, and a dorsal-ventral dimension. The six ROIs over the left hemisphere were: left-anterior-ventral (AF7, F7, FT7, F5, FC5), left-anterior-dorsal (AF3, F3, FC3, F1, FC1), left-central-ventral (C3, CP3, C1, CP1), left-central dorsal (TP7, T7, C5, CP5), left-posterior-ventral (PO9', O9', P7, PO7, O1), and left-posterior-dorsal (P3, PO3, P1, P5); six homologue ROIs were defined for the right hemisphere (see Figure 3.4).

Statistical analyses were performed by means of Huynh-Feldt corrected repeated measures analyses of variance (ANOVA). For the analysis of ERP amplitude data recorded from midline electrodes an ANOVA was performed with variables context (RW/ CW), consistency (consistent/ inconsistent), and electrode (AFz, Fz, FCz, Cz, CPz, Pz, POz, Oz). For the analysis of ERP deflections maximal over lateral electrode sites, an ANOVA was performed with variables context (RW/ CW), consistency (consistent/ inconsistent), hemisphere (left, right), ant-pos (anterior, central, posterior), and verticality (ventral, dorsal).

Results and Discussion

ERP Analysis

Grand average ERP waveforms are presented for the four conditions in Figure 3.5. No reliable topographic effects were found in the ANOVA in the 50-100 ms time interval [all $F_s < 2.1$, $p_s > 0.14$]. During this early time interval, mean amplitude was more positive for RW than CW conditions (0.5 vs. 0.1 μV) [$F(1, 18) = 5.0$, $p < 0.05$], whereas the main effect of consistency was not significant [$F < 1.4$, $p > 0.26$]. There were no significant interactions of context or consistency with each other or in interaction with any combination of the variables hemisphere, ant-pos, and verticality [all $F_s < 2.9$, $p_s > 0.09$].

An ant-pos x verticality interaction indicated that the initial P1 was largest over posterior scalp sites, and there largest over temporal compared to dorsal areas (4.0 vs. 2.8 μV , all other sites 0.3 μV) [$F(2, 36) = 8.4$, $p < 0.01$, $\epsilon = 0.63$]. This is the typical topography of the P1 component. P1 amplitude was larger for RW than CW conditions (1.6 vs. 1.0 μV) [$F(1, 18) = 13.9$, $p < 0.01$]. This context effect was strongest over anterior and central ROIs for consistent trials, while inconsistent trials showed a larger effect over posterior scalp sites, as indicated by the context x consistency x ant-pos interaction [$F(2, 36) = 5.3$, $p < 0.05$, $\epsilon = 0.65$]. In the following N1 time interval the ERP waveform was more negative over left posterior ventral areas, as indicated by a hemisphere x ant-pos x verticality interaction [$F(2, 36) = 6.4$, $p < 0.01$, $\epsilon = 1.0$]. A context x hemisphere x ant-pos x verticality interaction showed that the N1 topography was slightly influenced by context [$F(2, 36) = 4.4$, $p < 0.05$, $\epsilon = 0.98$]. However, context or consistency conditions did not influence the N1 component as a main effect or a context x consistency interaction in lateral or midline regions [all $F_s < 2.5$, $p_s > 0.13$].

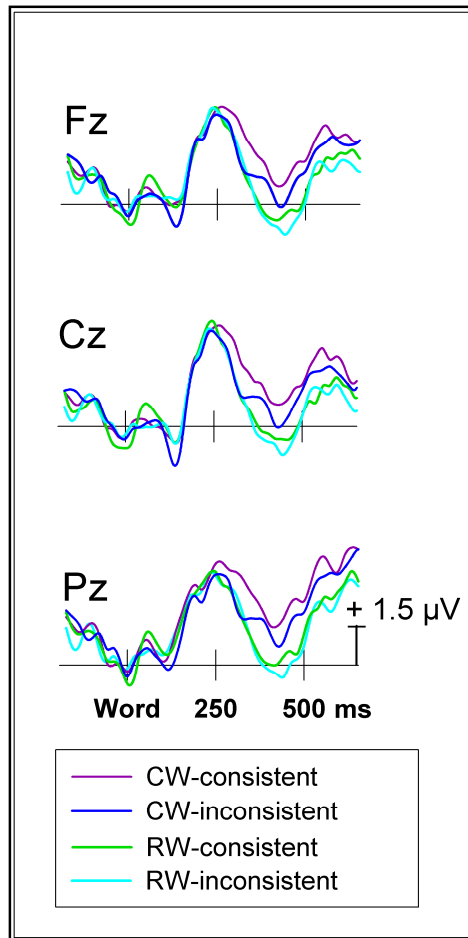


Figure 3.5: For three representative electrodes (Fz, Cz and Pz), grand average ERPs are shown, time-locked to the onset of the critical noun in sentence two. Note that negativity is plotted downwards.

The mean ERP amplitude in the 200-350ms interval after critical word onset was more positive over fronto-central ROIs [$F(1, 18) = 8.9, p < 0.01$], over dorsal ROIs, closer to the midline, than ventral sites (2.6 vs. 1.2 μV) [$F(1, 18) = 26.6, p < 0.001$], and over the right hemisphere [$F(1, 18) = 14.4, p < 0.01$]. The latter hemispheric asymmetry was largest over posterior scalp sites as indicated by a hemisphere x ant-pos interaction [$F(2, 36) = 9.0, p < 0.01, \epsilon = 0.92$]. Consistency did not influence the amplitude in this time interval as a main effect [$F(1, 18) = 0.3, p > 0.59$] but the consistency x verticality interaction revealed that inconsistent conditions were more negative over dorsal than ventral ROIs [$F(1, 18) = 5.3, p < 0.05$]. Moreover, the context x consistency x verticality interaction [$F(2, 36) = 5.2, p < 0.05, \epsilon = 0.82$] and the context

x consistency x ant-pos x verticality interaction were significant [$F(2, 36) = 6.0, p < 0.01, \epsilon = 1.0$]. A larger difference between consistent and inconsistent conditions over dorsal than ventral ROIs was found in posterior sites for the CW context and over anterior sites for the RW context (cf. Figures 3.6 and 3.7). In the midline electrode sites, a context x consistency x electrode interaction emerged [$F(7, 126) = 6.7, p < 0.001, \epsilon = 0.71$], showing a reliable consistency effect over posterior sites in the CW context [$F(7, 126) = 3.8, p < 0.05, \epsilon = 0.50$] but not the RW context [$F(7, 126) = 1.5, p > 0.20, \epsilon = 0.55$]. Analysis of the simple main effects demonstrated that CW-inconsistent conditions were significantly more negative-going than CW-consistent at electrodes POz [$F(1, 18) = 7.4, p = 0.01$] and Oz [$F(1, 18) = 7.0, p = 0.02$] and marginal at electrodes Cpz [$F(1, 18) = 2.9, p = 0.1$] and Pz [$F(1, 18) = 3.2, p = 0.09$].

The positive wave was followed by a slowly growing negative-going deflection. In the time interval 350-500 ms after target word onset, the widely distributed negative-going ERP waveform was more negative following a RW than a CW context (-1.4 vs. -0.45 μV) [$F(1, 18) = 5.0, p < 0.05$], and this effect was larger over dorsal than ventral electrodes, as indicated by a context x verticality interaction [$F(1, 18) = 6.3, p < 0.05$]. Once again, consistency did not influence the amplitude in this time interval as a main effect [$F(1, 18) < 1.7, p > 0.21$] but the consistency x verticality interaction revealed that inconsistent conditions were more negative-going than consistent conditions over dorsal than ventral scalp sites [$F(1, 18) = 4.6, p < 0.05$]. Specifically, as indicated by the Context x Consistency x Ant-Pos interaction [$F(2, 36) = 4.3, p < 0.05, \epsilon = 0.95$], the consistency effect was larger over centroparietal ROIs for CW conditions [$F(2, 36) = 4.6, p < 0.05, \epsilon = 1.0$] but not for RW conditions [$F = 1.1$]. Analysis of the midline electrodes further showed that RW contexts resulted in a more negative wave than CW contexts [$F(2, 36) = 7.0, p < 0.01$]. The context x consistency x electrode interaction was significant [$F(7, 126) = 3.3, p < 0.01, \epsilon = 0.71$], showing a reliable consistency

effect over posterior sites in the CW context [$F(7, 126) = 4.2, p < 0.01, \epsilon = 0.61$] but not the RW context [$F < 1$]. Analysis of the simple main effects confirmed that CW-inconsistent conditions were significantly more negative-going than CW-consistent at electrode Oz [$F(1, 18) = 5.7, p = 0.03$] and marginal at electrode POz [$F(1, 18) = 2.8, p = 0.1$].

Finally, the time window between 500 and 700ms post target word onset indicated a Type x Consistency x Ant-Pos interaction [$F(2, 36) = 6.1, p < 0.01, \epsilon = 0.83$]. Similar to the 350-500 ms interval, the ERP waveform was more negative for inconsistent than consistent CW conditions over posterior ROIs (2.7 vs 3.6 μV) [$F(2, 36) = 11.3, p < 0.001, \epsilon = 0.83$] but not for RW conditions [$F < 1$]. Analysis of ERP amplitude over the midline electrodes further revealed a significant consistency x electrode interaction [$F(7, 126) = 4.7, p < 0.01, \epsilon = 0.66$], which was further modulated by contexts [$F(7, 126) = 2.8, p < 0.05, \epsilon = 0.61$]. The latter interaction indicated a reliable consistency effect over posterior sites in the CW context [$F(7, 126) = 6.9, p < 0.001, \epsilon = 0.52$] but not the RW context [$F < 1$].

In sum, the results reported here show that RW conditions led to more positive deflections in the P1 component than CW conditions. This effect was influenced by consistency as a larger P1 amplitude was elicited over anterior and central regions for consistent trials and over posterior scalp sites for inconsistent trials. The topography of the following N1 component was marginally affected by context, though this did not emerge as a main effect. In the 200-350ms time window, context and consistency affected the amplitude with a large consistent- inconsistent difference over posterior sites for CW and a smaller difference over anterior sites for RW conditions. In the N400 time window (350-500ms) we revealed a more negative waveform for RW than CW items. However, both inconsistent conditions were more negative-going than their consistent counterparts, suggesting that consistency with the prior context has been

computed by this time point. Specifically, the N400 consistency effect was largest over typical centroparietal regions for CW conditions, but largest over anterior sites for RW conditions. Finally, between 500 and 700ms after critical word onset similar consistency effects emerge, again with stronger posterior effects in the CW conditions.

These effects and their topographical location are illustrated by the maps in Figure 3.6, 3.7, 3.8 and 3.9.

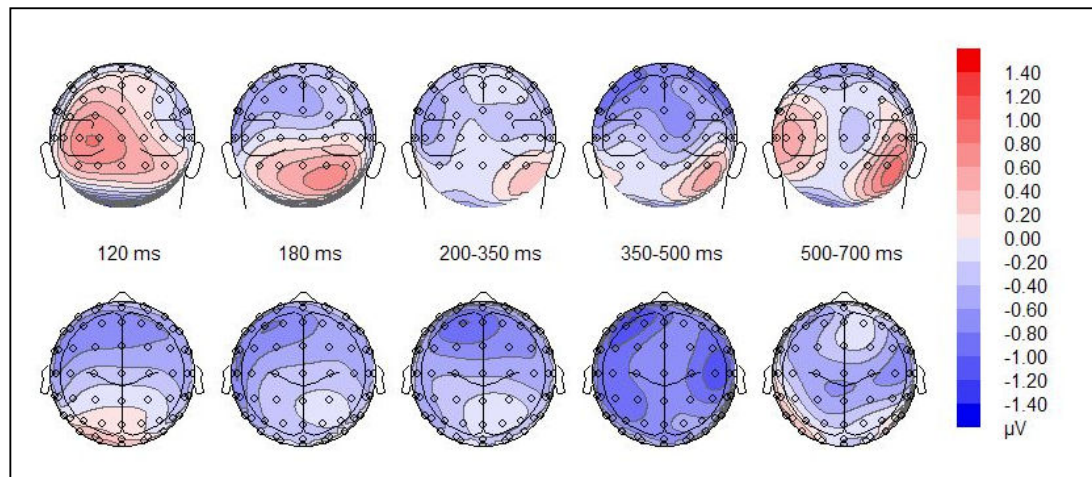


Figure 3.6: Topographic maps of ERP difference waveforms for each time interval of interest relative to critical word onset (RW-inconsistent condition minus RW-consistent condition): P1 (120ms) and N1 (180ms), 200-350ms, 350-500ms (N400) and 500-700ms.

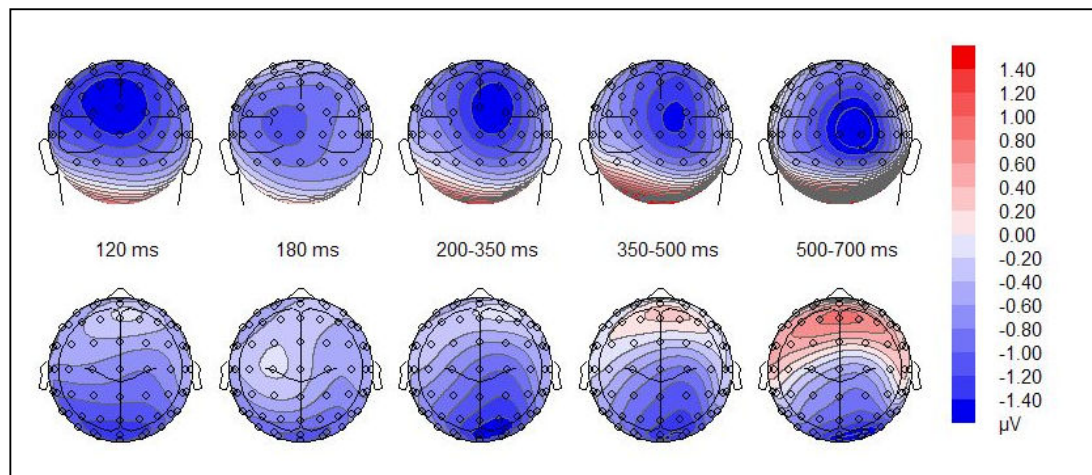


Figure 3.7: Topographic maps of ERP difference waveforms for each time interval of interest relative to critical word onset (CW-inconsistent condition minus CW-consistent condition): P1 (120ms) and N1 (180ms), 200-350ms, 350-500ms (N400) and 500-700ms.

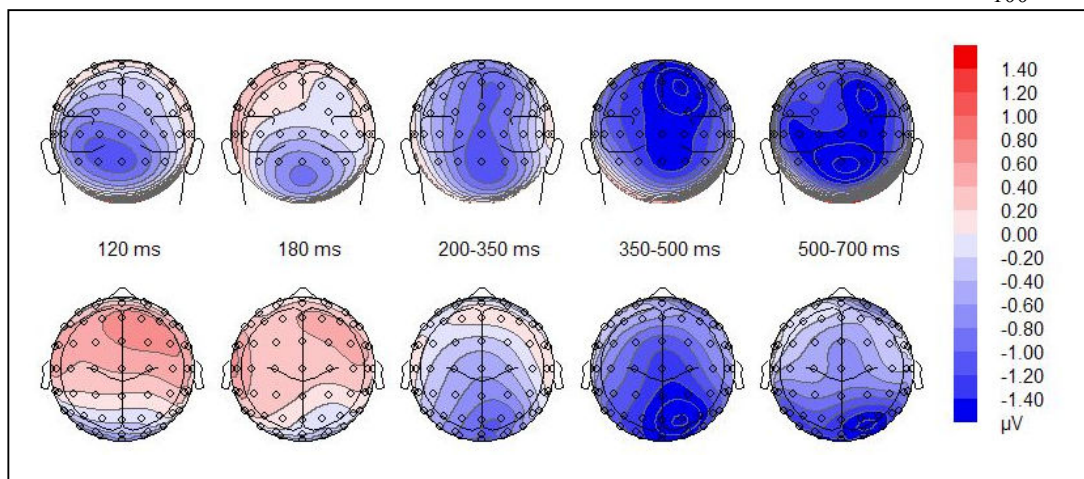


Figure 3.8: Topographic maps of ERP difference waveforms for each time interval of interest relative to critical word onset (CW-consistent condition minus RW-consistent condition): P1 (120ms) and N1 (180ms), 200-350ms, 350-500ms (N400) and 500-700ms.

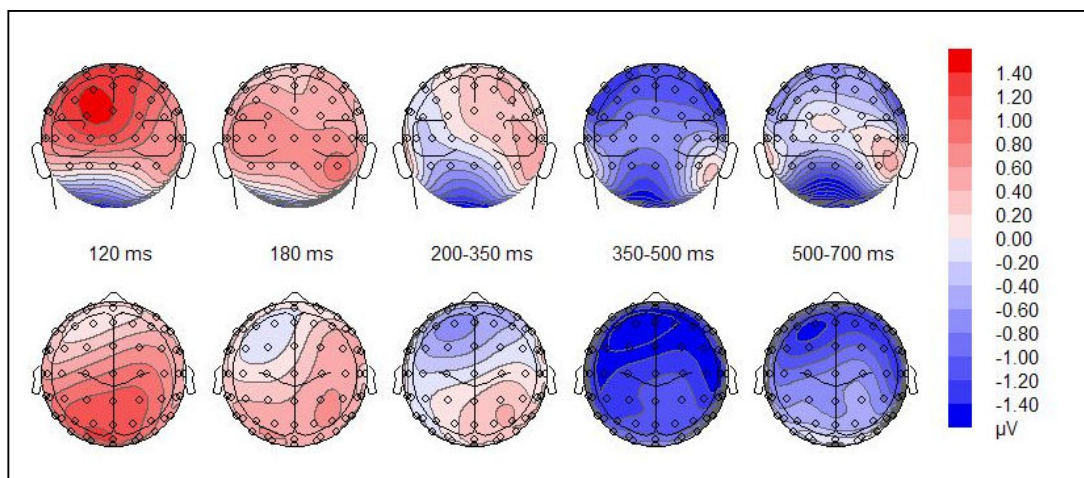


Figure 3.9: Topographic maps of ERP difference waveforms for each time interval of interest relative to critical word onset (CW-inconsistent condition minus RW-inconsistent condition): P1 (120ms) and N1 (180ms), 200-350ms, 350-500ms (N400) and 500-700ms.

Time-Frequency Analysis

EEG data were also analyzed to investigate oscillatory brain activity in a wide frequency range (2 to 70 Hz) in relation to the incoming consistent or inconsistent information. TFRs of the single-trial EEG data were obtained by convolving complex Morlet wavelets with the EEG data and computing the squared norm of the result of the convolution (Tallon-Baudry, Bertrand, Delpuech & Pernier, 1996). Wavelets had a 5-cycle width, with frequencies ranging from 2 to 70 Hz, in 1 Hz steps. Time-frequency representations (TFRs) were then averaged over trials for each subject, separately for

the four conditions. The resulting power values were expressed as a change relative to the power in a baseline interval, defined as 150 to 0 ms prior to the onset of the critical word. The purpose of this was to normalize for individual differences in EEG power and baseline power between different frequency bands.

To statistically analyze the modulation of power changes as a function of experimental condition, an adapted version of the randomization procedure suggested by Maris (2004) was employed, with a cluster-based approach that corrects for multiple comparisons. For practical reasons, the analysis window was limited from 2 to 50 Hz, and from 0 to 1000 ms post stimulus onset. Statistics were calculated in the following steps: 500 grand-average randomizations of the TFRs were calculated for each condition by random permutation, and subsequent averaging of RW-inconsistent, RW-consistent, CW-inconsistent and CW-consistent TFRs of individual participants' EEG data. For each randomization the grand-average of each condition was systematically subtracted from the grand-average of the others (thus, creating a total of 6 statistical comparisons). This revealed information on the distribution of the difference between conditions for each 'pixel' of the time-frequency representation. For each randomization and each pixel, the significance of the between-conditions difference was computed by comparing the observed difference in that specific randomization to the distribution of all other randomizations. This resulted in a probability (p value) for each pixel in each randomization.

The complete TFR with the probabilities of all pixels was thresholded at a 5% significance level (two-tailed) and clusters of spatially contiguous pixels (across three dimensions: time, frequency, channels) were identified. The cluster-level statistic was then derived from the sum of the t statistics of all the pixels in such a cluster. This data was then corrected for multiple comparisons by taking the largest cluster-level test statistic for each of the 500 randomizations to create a null distribution of the cluster-

level statistic. Finally, the cluster- level test statistic was computed for the actually observed grand average data and compared against the null distribution. Thus, clusters with a statistic falling in the highest or lowest 2.5th percentile were considered significant.

Figures 3.10, 3.11, 3.12 and 3.13 present the wavelet- based time- frequency representations of EEG power changes for RW-inconsistent, RW-consistent, CW- inconsistent and CW-consistent conditions respectively. Additionally, Figure 3.14 displays the time- frequency representations of the difference between conditions.

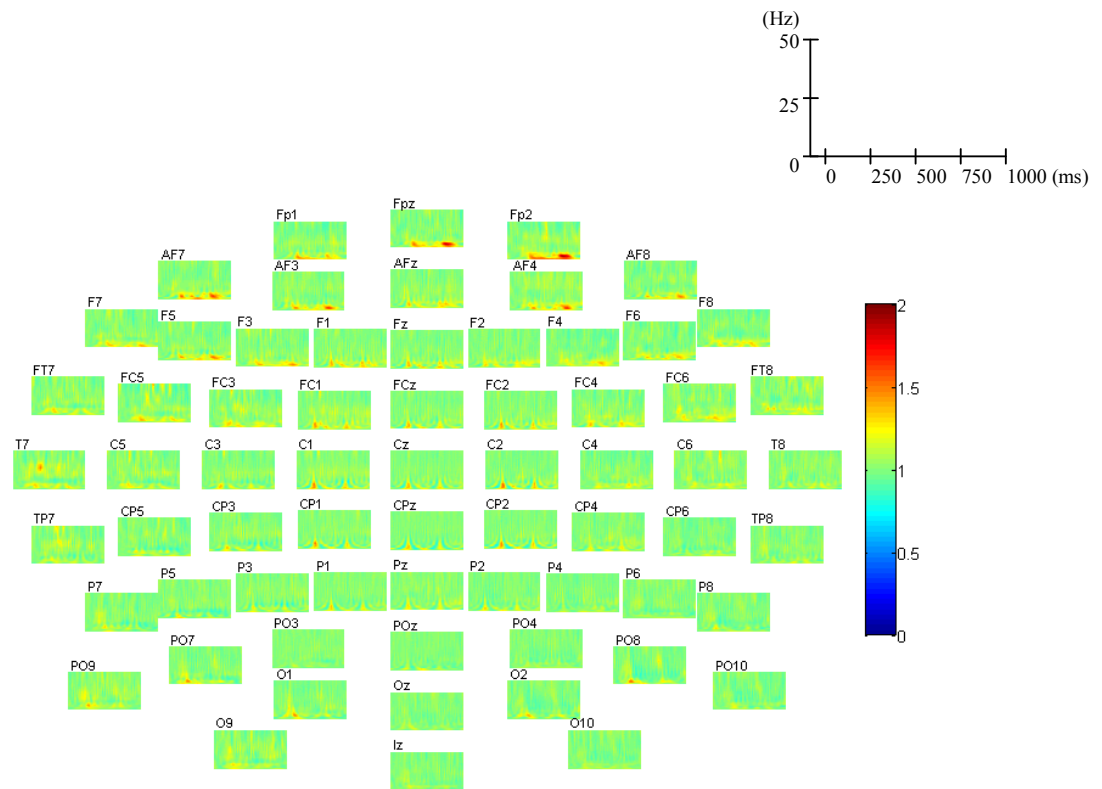


Figure 3.10: Time- frequency representation of the power changes at all scalp locations for RW- inconsistent condition. Note that power decreases are represented by blue and power increases are represented by red.

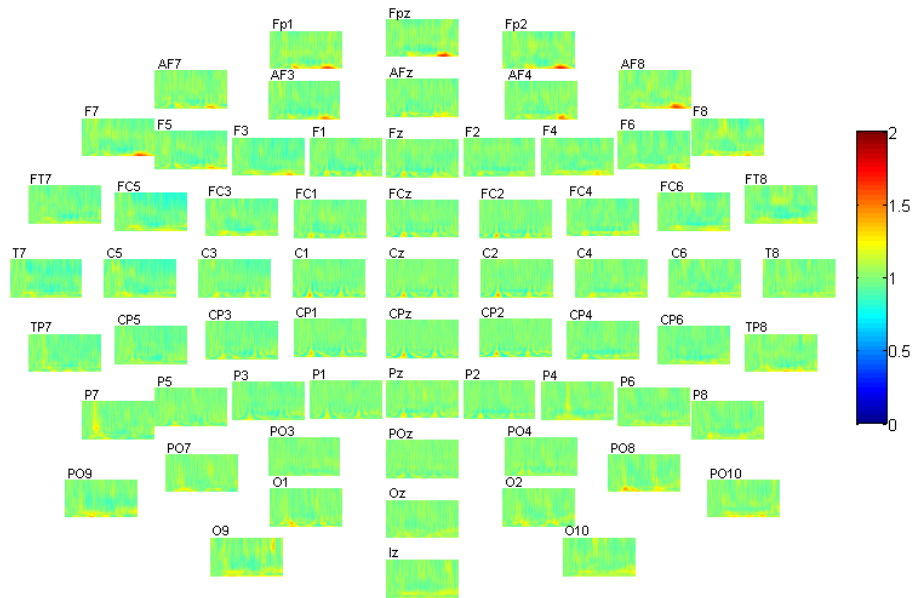


Figure 3.11: Time- frequency representation of the power changes at all scalp locations for RW-consistent condition. Note that power decreases are represented by blue and power increases are represented by red.

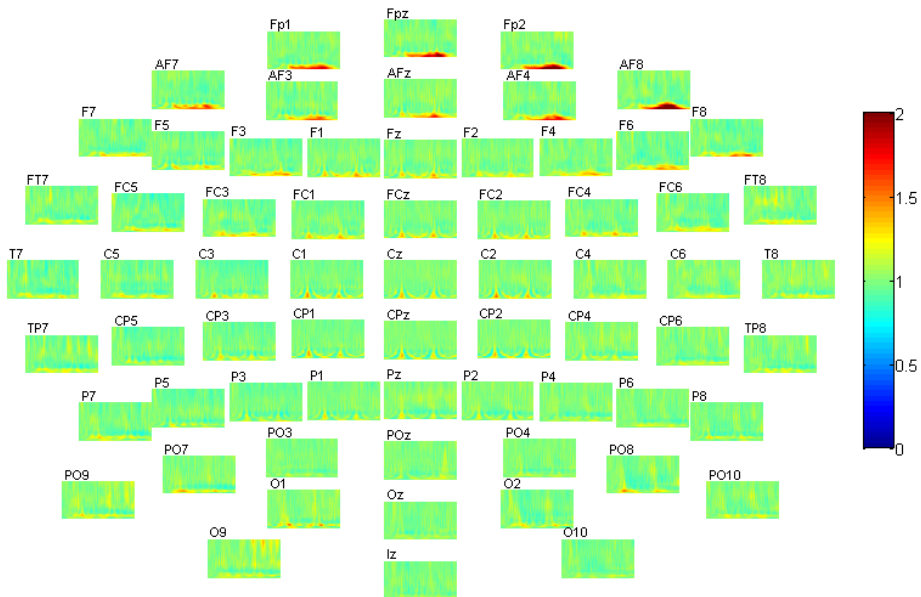


Figure 3.12: Time- frequency representation of the power changes at all scalp locations for CW-inconsistent condition. Note that power decreases are represented by blue and power increases are represented by red.

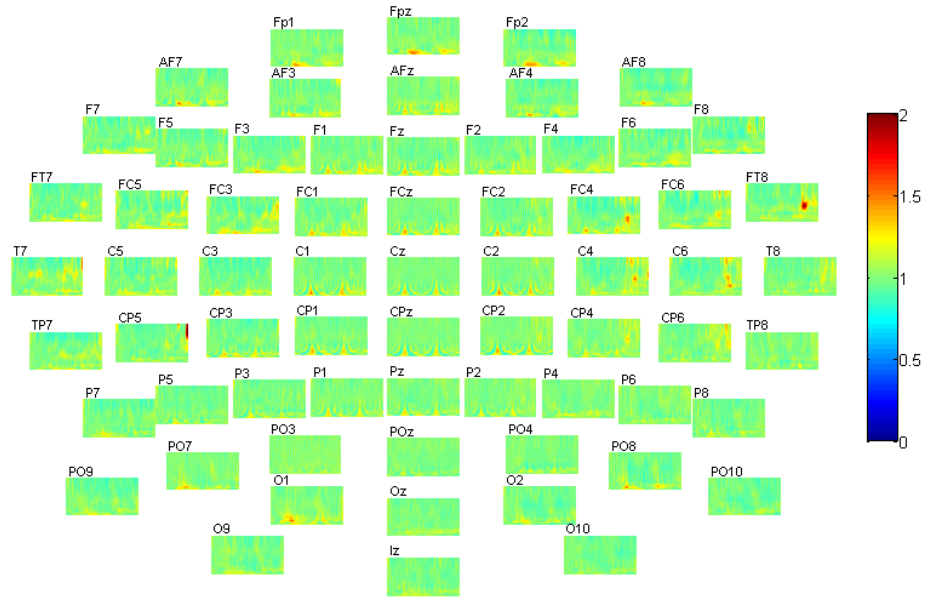


Figure 3.13: Time- frequency representation of the power changes at all scalp locations for CW-consistent condition. Note that power decreases are represented by blue and power increases are represented by red.

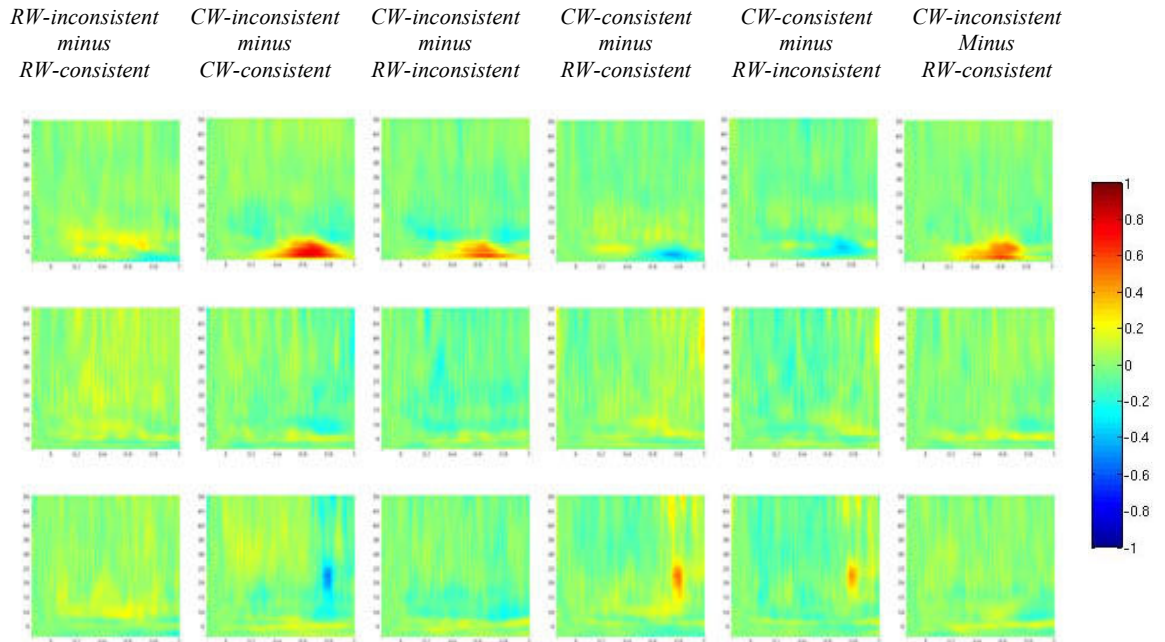


Figure 3.14: Time- frequency representations of the difference between conditions, as labelled. Three representative scalp locations are displayed, averaged across electrodes. *Top*: frontal electrodes (Fp1, AF7, AF3, Fpz, Fp2, AF8, AF4 and AFz); *Middle*: left temporal electrodes (FT8, FC6, FC4, C4, C6 and T8); *Bottom*: right temporal electrodes (FT7, FC5, FC3, C3, C5 and T7).

Descriptively, the results from the TFRs show increased frontal theta and a small left temporal gamma power increase in the RW-inconsistent condition, compared to small frontal theta and no gamma power changes in the RW-consistent condition. Conversely, the CW-inconsistent condition, containing real-world congruent information, showed much larger and sustained frontal theta (larger on the right than on the left) and no gamma power increases. Finally, the CW-consistent condition, including a world knowledge violation, showed a small frontal theta increase and a small temporal (larger on the right than the left) gamma power increase at around 30 Hz. Importantly, the theta effects are visible within the latency range of the N400, while the gamma effects seem slightly delayed, emerging around 700ms post target word onset. However, since the temporal resolution of the wavelet transform is somewhat poor, the relative onset difference between theta and gamma activity cannot be taken to reliably indicate onset differences of the underlying neurological events. Figure 3.15 displays topographical maps of the theta power changes (from 2 to 8Hz) for each condition, averaged into 100ms time intervals from 200 to 1000ms post target word onset.

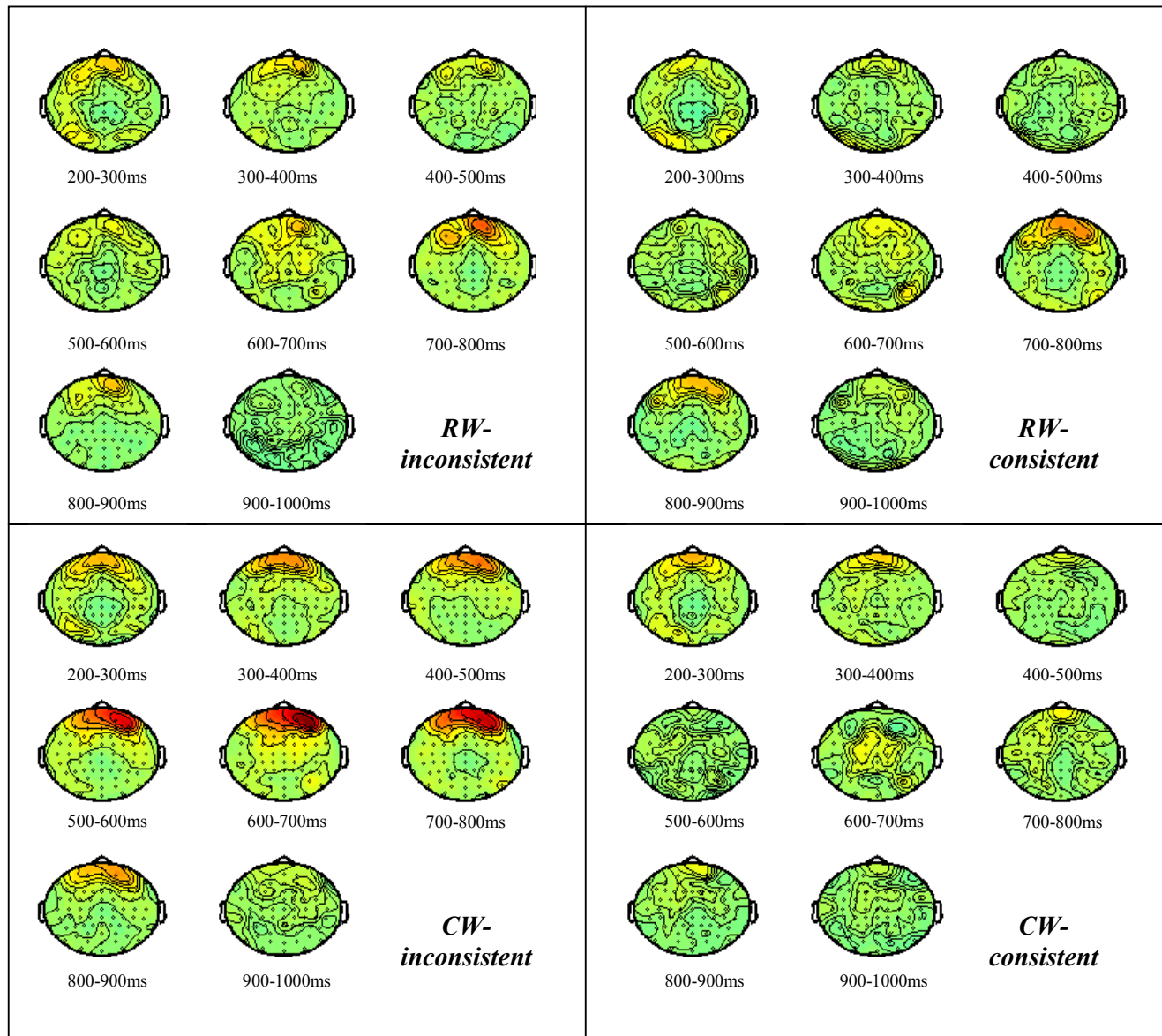


Figure 3.15: Scalp topography of the theta power changes (2 to 8Hz) for RW-inconsistent (top left), RW-consistent (top right), CW-inconsistent (bottom left) and CW-consistent (bottom right). Note that power is averaged into 100ms time intervals from 200 to 1000ms post target word onset.

The theta scalp topographies in Figure 3.15 show bilateral effects, with a striking theta peak over the frontocentral scalp sites for inconsistent conditions, particularly the CW-inconsistent condition. This finding is consistent with previous investigations, which have shown frontal theta related to language tasks (Bastiaansen,

Van Berkum & Hagoort, 2002; Bastiaansen, Van der Linden, Ter Keurs, Dijkstra & Hagoort, 2005; Hald, Bastiaansen & Hagoort, 2006).

The randomization analysis revealed one significant cluster in the time-frequency representation of power changes. This positive cluster ($t(18) > 3.48, p < 0.05$) indicated a larger power increase for the CW-inconsistent condition compared to the CW-consistent condition in the theta frequency range. The effect varied for the different channels, but ranged from 400 to 700ms onset and from 900 to 1000ms offset, in a frequency range of 2 to 8Hz. No significant cluster was found in the gamma frequency range ($t(18) < 1.5, p > 0.05$), although, descriptively, the CW-consistent condition, containing a world knowledge violation, showed increased gamma range power changes when compared with the CW-inconsistent condition, containing world knowledge congruent information. Additionally, no significant differences were revealed between other conditions either in the theta or the gamma frequency ranges ($t(18) < 1.5, p > 0.05$).

Discussion

In Experiment 4 an anomaly detection paradigm was used to investigate whether effects of local pragmatic information can be reversed by a preceding counterfactual context. Specifically, the question was how a preceding context interacts with world knowledge as participants read real- world anomalous or real- world congruent information that conflicts with a pre-specified counterfactual world context. Event-related potentials (ERPs) and oscillatory brain dynamics were studied to examine the nature of the resulting ERP components and EEG power in relation to information that was consistent or inconsistent with the preceding real-world or counterfactual-world context. The results showed that ERPs are sensitive to inconsistencies of RW and CW information. As expected, violations within a RW context lead to an N400 effect at the

critical word, which reflects the fact that readers have detected the anomaly. In contrast, within an appropriate CW context, the N400 effect was reversed so that local- semantic RW violations were processed as acceptable and RW congruent items were processed as anomalous. Clearly, when the use of a word conflicts with what the prior context supposes, this creates an early effect upon reading. Furthermore, the results suggest that an appropriate counterfactual context not only neutralizes the processing difficulties that are normally associated with pragmatic violations, but can actually evoke anomaly detection responses to real-world plausible information when it conflicts with the counterfactual context.

Two important issues have arisen in the ERP results. First, the scalp topography of the consistency effects differs for RW and CW conditions. Specifically, the N400 effect for the RW-inconsistent condition was maximal in frontocentral brain areas, whereas the N400 effect for the CW-inconsistent condition reached a maximum at centroparietal brain regions. Typically, the N400 effect to pragmatic anomalies is larger over posterior electrode sites than over frontal sites (Kutas, 1988), therefore, the frontocentral location of the RW effect was unexpected.

Second, the significantly larger N400 effect for CW compared to RW conditions was unanticipated. Generally, the N400 is thought to be sensitive to semantic integration processes (Brown & Hagoort, 1999; Brown, Hagoort & Kutas, 2000; Kutas & Van Petten, 1994). Accordingly, it had been predicted that the RW-inconsistent condition would lead to the largest N400 effect, as the critical word was unpredictable and did not fit with the readers' world knowledge, and the RW-consistent condition would produce the smallest N400 effect since it was predictable given the context and was appropriate with world knowledge. In comparison, the CW conditions might have initiated a conflict between local and global information as the comprehender had to

represent both factual and counterfactual information, meaning that typical anomaly effects would be reduced.

I suggest three possible explanations for the unexpected topography of the RW consistency effects and the increased amplitude of the N400 effect for RW-consistent items. First, it could be that the presence of eighty counterfactual items has had a detrimental effect on real-world processing. Thus, understanding counterfactual items has made participants 'suspicious' and has changed the way RW passages are interpreted. Another possible explanation relates to the modal verb *could* that introduces the target sentence. As discussed in Chapter 2, *could* expresses a conditional possibility or ability, it may imply that a few options are available to the situation, and therefore lends more to a counterfactual interpretation. For example, if a cat were hungry then we *could* feed it bowl of carrots but it would walk away disdainfully. In line with this, Experiment 3 revealed that replacing *could* with *would* (to express that the event is a repeated or habitual action) resulted in larger and longer-lasting effects of the RW violation for both RW and CW conditions.

A final potential explanation for the effects is that the RW conditions in the current experiment were conditional constructions (e.g. 'If cats are hungry', 'If John wanted to go on holiday', 'If Mum wanted to impress her family and friends'). It is possible that comprehending conditionals in general puts increased demands on cognitive processes. Although recently a few studies have used fMRI or PET to investigate the neural generators of conditional reasoning (Goel, Buchel, Frith, & Dolan, 2000; Goel & Dolan, 2003; Knauff, Mulack, & Greenlee, 2002; Noveck, Goel, & Smith, 2004; Ruff, Knauff, & Spreer, 2003) to date no research has used ERPs to investigate the online comprehension of conditionals and the subsequent spatiotemporal pattern of brain activation. Therefore, the reduced consistency effect might simply be due to more general conditional processing. In contrast, counterfactuals required the

reader to change a large, fundamental part of their RW knowledge (e.g. that cats are vegetarians), which might be more prominent to the reader and thus easier to remember than conditionals that alter one small, sometimes irrelevant, aspect of reality. This interpretation could relate to Urrutia and de Vega's (2007) recent investigations of counterfactual processing. Their study employed ERPs to explore consistency effects in factual (e.g. 'Because Marta found a spade') and counterfactual stories (e.g. 'If Marta had found a spade') followed by a context-consistent or context-inconsistent final sentence (e.g. 'She planted into the hole some roses' versus 'She bought a spade in the market'). They found no effect of consistency at the final word (*roses* versus *market*) in the N400 for the counterfactual conditions. Importantly, the counterfactual items used in Urrutia and de Vega's study were conditionals, and did not 'alter reality' to the same extent as the counterfactuals used here. In fact, the RW conditions used in Experiment 4 may be more similar to the 'counterfactuals' used in Urrutia and de Vega's study. Ultimately, to test these accounts, further experimentation is certainly necessary, for example, blocking the conditions and varying order across participant groups so that some participants saw RW- CW and others saw CW- RW, or comparing the N400 for conditional sentences (e.g. 'If Tom's cat was hungry he could feed it a bowl of carrots/ fish') with the N400 for standard semantic violations (e.g. 'Tom's cat was hungry so he fed it a bowl of carrots/ fish').

The wavelet-based time- frequency analysis revealed that event-related power changes in the theta frequency range were greater for contextually inconsistent conditions (RW-inconsistent and CW-inconsistent) than for contextually appropriate conditions (RW-consistent and CW-consistent). In the gamma frequency band, power appeared to be larger in conditions that included a world knowledge violation (RW-inconsistent and CW-consistent) than in conditions that did not violate world knowledge (RW-consistent and CW-inconsistent). Relative to a baseline, theta oscillations showed

up between 400 and 1000ms post target word onset, with a midfrontal maximum in the scalp distribution, while gamma oscillations emerged later between about 700 and 900ms post target word onset, with a maximum at temporal scalp sites.

Attempts have been made to link oscillations in different frequency ranges to specific cortical structures and cognitive processes. The midfrontal theta increase in the present data was larger after words that did not fit with the wider discourse context (RW-inconsistent and CW-inconsistent) than contextually appropriate words (RW-consistent and CW-consistent). This is consistent with recent research by Hald et al. (2006; see also Hagoort et al., 2004) who revealed a midfrontal theta increase in EEG oscillations, that was only present after a semantic violation. Similarly, Bastiaansen et al. (2002) have shown that syntactic number violations elicited a theta power increase with a left-frontal maximum and syntactic gender violations elicited a theta power increase with a maximum in the right frontal electrodes. Given that each violation type (semantic, syntactic number and syntactic gender) elicits a differential frontal theta increase, one could assume that this reflects specific differences in processing semantic and syntactic information. However, Hald et al., have proposed an alternative interpretation for the results. They argue that the frontal theta following syntactic violations may be due to increased verbal working memory load, reflecting the readers' need to re-analyse the sentence. In a similar way, semantic violations could lead to an increase in verbal working memory load as the comprehender must evaluate on-line whether the incoming word can be integrated into the wider context. This hypothesis fits with the frontal theta effects reported here, where the pragmatic violation in RW-inconsistent condition used more verbal working memory load as participants had to assess the appropriateness of the word in the given context. Interestingly, the CW-inconsistent condition lead to the most increased theta range activity, which can be explained under this hypothesis as participants recruit more visual working memory

load to represent the conflicting factual and counterfactual interpretations of the passage. In contrast, the CW-consistent condition did not reveal such increased frontal theta, as the critical word fits with the wider discourse, thus later checking against the context is not necessary. Further support for this interpretation is gained from similar frontal theta effects reported in the literature on working memory tasks (e.g. Gevins, Smith, McEvoy & Yu, 1997; Jensen & Tesche, 2002; Schack, Vath, Petsche, Geissler & Moller, 2002). Finally, the frontal theta component following both open and closed class words in a sentence, reported by Batiaansen et al. (2005), is compatible with this verbal working memory account of this component.

An alternative interpretation of the increased frontal theta for inconsistent conditions relates to the contextual violation elicited in these conditions. Similarly, the frontal theta increase following syntactic and semantic violations (Hald et al., 2006; Bastiaansen et al., 2002) both constitute an error compared to a correct sentence. Thus, it is also possible that this effect can be explained in terms of the brain registering an error during language comprehension (i.e. error monitoring). However, this explanation is limited as the CW-consistent condition in the current study, containing a world knowledge violation, does not elicit such increased theta power effects. Therefore, an interpretation of this frontal theta effect in terms of error monitoring would have to specifically relate to the fit of the word with constraints from grammar and the preceding context and not to world knowledge violations.

In sum, strong indications are emerging to suggest that the modulations in oscillatory activity in the theta frequency range may be instrumental in performing some of the basic cognitive functions required for language comprehension. However, at this time, one can only speculate as to the specific functions they represent, and ultimately, only further experimentation will allow a distinction between these explanations.

In contrast to effects in the theta frequency band, reports of gamma power changes during on-line sentence processing have been somewhat limited. A few studies have demonstrated gamma power changes, related exclusively to isolated words (Pulvermüller, 1996; 2000) or gamma coherence during sentence comprehension (Weiss, Rappelsberger, Schack & Müller, 2003). In fact, one of the first reports of increased gamma power was reported by Hagoort et al. (2004) who revealed a clear gamma peak for world knowledge violations that was not seen for either correct or semantic violation conditions. Time- frequency investigations on the current data have shown similar, though not significant, effects in the gamma band frequency range. Specifically, conditions containing information that violated the readers' world knowledge (RW-inconsistent and CW-consistent) showed increased gamma effects in temporal scalp sites. This pattern of results is consistent with Hagoort et al.'s suggestion that language comprehension involves two distinct processes: one is to determine the meaning of a sentence and the other is to relate the incoming information to our knowledge about the world. Gamma oscillations have been associated with feature binding within and across language modalities (Tallon-Baudrey & Bertrand, 1999; Miltner, Braun, Arnold, Witte, & Taub, 1999), and as such have been implicated in the integration of activity in both local and distributed networks. Once again, further experiments are necessary to specify the exact nature of this functional role.

It is important to consider why many of the effects that appear in visualizations of the data failed to reach significance in statistical analysis. First, it is likely that the signal-to-noise ratio was high, as only nineteen participants were tested in the study due to time and financial constraints. This number of participants is adequate for ERP analysis, but is somewhat small for time- frequency analysis. Therefore, the signal-to-noise ratio could be improved in future studies by testing ten participants per condition. Second, the number of experimental items may have been too low, with 40 items per

condition, particularly as in reading tasks it is common to reject some trials due to eye-blink and eye-movement artifacts. The standard word-by-word presentation of the target sentence is used to reduce eye-movements. However, future experiments could use auditory language input as participants fixate a central cross, meaning that more items can be included in the analysis. Finally, the lack of significant effects in the gamma frequency range is a common finding as changes observed in the gamma range are relatively broadband (one often sees that gamma reactivity extends over a range of 10-15 Hz). Again this should be improved by lowering the signal-to-noise ratio with increased numbers of participants and experimental items.

In conclusion, the results of this experiment constitute strong evidence that a counterfactual context can overrule a pragmatic violation, and also can elicit brain responses associated with anomaly detection when pragmatically congruent information conflicts with the preceding counterfactual context. As such, they support an interactive dual-processing model of counterfactuals, where the brain retrieves and integrates factual and counterfactual information at the same time, within some 400ms, during on-line discourse processing (e.g. Bates & MacWhinney, 1989; Jackendoff, 2002; Marslen-Wilson & Tyler, 1980). Indeed, the results reported here imply that the counterfactual interpretation of a sentence is accessed much faster than was suggested by the eye-movement studies reported in Chapter 2, which only revealed effects of consistency with the prior context in later measures of reading time. Thus, at the very least, these results concur with a growing number of other observations suggesting that global factors have a very early impact on language comprehension (e.g. Hess, Foss & Carroll, 1995; Altmann & Kamide, 1999; Niewlands & Van Berkum, 2006).

Taken together, the experiment in Chapter 3 demonstrates that an appropriate counterfactual context can reverse typical N400 effects to pragmatic anomalies. Thus, the fact that the N400 effect is reduced in CW-consistent conditions shows that even an

anomaly relating to fundamental knowledge about the world can be integrated into the discourse if the prior counterfactual context depicted a situation in which it would not be unexpected for that event to occur. Furthermore, this experiment illustrates that sometimes it is easier to integrate a semantically anomalous word that fits the counterfactual context (e.g. *carrots*), than it is to process a semantically 'correct' phrase that is implausible with regard to a preceding counterfactual context (e.g. *fish*).

Chapter 4

Negation and Counterfactual Information Processing

Introduction

Chapter four considers the processing consequences for conditional statements where a prior context sentence negates real-world expectations, but does not explicitly set up an alternative scenario, such as in (1).

- (1) If cats were not carnivores...

In this example, participants must cancel real-world knowledge that cats *are* carnivores for a full understanding of the utterance. However, this raises two important processing questions, (i) how quickly is reality negated and, (ii) when is an alternative model created? It creates an interesting comparison with counterfactuals that explicitly state an ‘alternative world’, thus implying that (at least some aspect of) reality is no longer relevant. So, to make sense of a counterfactual utterance, such as, *If cats were vegetarians*, readers must accept the ‘alternative world’ of cats being vegetarians. However, to do this, it is necessary that, at some level, the comprehender suppresses their real-world knowledge that cats are carnivores.

A large amount of research into the processing of negation has been conducted, employing a variety of methods and experimental items. Most of these studies involved participants evaluating a given sentence against background knowledge (e.g. Arroyo, 1982; Eiferman, 1961; Wales & Grieve, 1969; Wason, 1961; Wason & Jones, 1963), as in (2), or against an image presented before or after the target sentence (e.g. Carpenter & Just, 1975; Clark & Chase, 1972; Gough, 1965; 1966; Just & Carpenter, 1971; Trabasso, Rollins & Shaughnessy, 1971), as in (3).

- (2) a. Seven is not an even number.

b. Seven is an odd number.

[Wason, 1961]

(3) a. The circle is not present.

b. The circle is absent.

[Chase & Clark, 1971]

Other studies have measured the impact of negation directly, with sentence completion tasks (e.g. Donaldson, 1970; de Villiers & Tager Flusberg, 1975; Wason, 1961, 1965) or indirectly, for example using tasks that compare the number of inferences drawn for negative and affirmative sentences, measuring how negative instructions are followed or by observing how a negative object description affects choice in an object-selection task (e.g. Just & Clark, 1973; Jones, 1966, 1968; Donaldson, 1970). Despite the variety of different experimental paradigms and negative sentence constructions, all these studies have found evidence for greater difficulty in processing negative than affirmative sentences, as evidenced by longer reading times and higher error rates for negative sentences. Various explanations have been suggested to account for this processing difference between negative and affirmative sentences, including the extra syllable needed for negative sentences (cf. Clark & Chase, 1972). However, this account does not fully explain the observed negation effects as the magnitude of this effect exceeds that explained by these factors. An early syntax-based explanation suggests that negation effects are due to grammatical complications in negative sentences, which require a greater number of grammatical transformations than affirmative sentences (Chomsky, 1957; although this explanation was later found to be flawed for theoretical and empirical reasons, cf. Jackendoff, 1969; Slobin, 1966). To date, the most persuasive justification for difficulty associated with negative sentences relates to contextual pragmatics. Wason (1965) suggested that in everyday language, negative sentences are commonly uttered within an appropriate discourse context. For example, the statement, 'My train was not late this morning' is perfectly acceptable within a context in which the speaker's train is usually late (Wason, 1972). This account is supported by evidence

that negation effects are significantly reduced when negative sentences are presented within an appropriate context (e.g. Wason, 1965; Glenberg, Robertson, Jansen & Johnson-Glenberg, 1999; Giora, Fein, Aschkenazi & Alkabets-Zlozover, 2007). However, even the pragmatic theory only partially accounts for the negation effect as some difficulties often persist for negative sentences in a relevant context.

The *truth value* of a sentence has proved to be an influential factor in the processing of negated sentences, with some studies suggesting that false sentences are generally harder to process than true sentences, independent of any preceding negative context (e.g. Arroyo, 1982; Eiferman, 1961; Gough, 1965). However, a growing amount of research supports an early negation by truth value interaction, where an evaluation of the sentence meaning and the truth value is easier when the two are congruent than when they are incongruent (e.g. Clark & Chase, 1972; Wason & Jones, 1963; Kaup, Lüdtke & Zwaan, 2005). Using examples from my own work, false affirmative sentences such as in (4b) are harder to process than true affirmative sentences (4a). In contrast, for negative sentences such as (5), the opposite holds, as true sentences (b) cause more difficulties than false sentences (a). Kaup, Lüdtke and Zwaan (2005) propose that this negation by truth value interaction is produced shortly after the processing of a negative sentence, when the negated situation is relatively available. However, the actual situation becomes available later, and accordingly, a main effect of truth value emerges.

- (4) a. Cats are carnivores.
 - b. Cats are vegetarians.
- (5) a. Cats are not carnivores.
 - b. Cats are not vegetarians.

Kaup, Zwaan and Lüdtke (in press) have argued that the truth value of a negative statement can influence processing in the following ways. For true affirmative sentences (4a), the predicate in the sentence representation matches the predicate in the reader's knowledge of reality [both: cats (carnivores)], whereas for false affirmatives (4b), the predicates mismatch [sentence: cats (vegetarians); reality: cats (carnivores)]. In contrast, predicates match in false negative sentences (5a) [sentence: not (cats (carnivores)); reality: cats (carnivores)], but mismatch in true negative sentences (5b) [sentence: not (cats (vegetarians)); reality: cats (carnivores)]. Therefore, negative sentences may take longer to verify against the comprehender's real-world knowledge than affirmative sentences because the negation marker reveals a mismatch with the reality predicate.

As described in Chapter 1, growing evidence in the literature supports the notion that non-linguistic representations are important elements of language comprehension. It seems reasonable to assume then that negative information is also represented in this way- even though non-linguistic representations do not allow an explicit representation of negation. Thus, the question of how negated concepts, and their consequences, are represented in a non-linguistic system arises. Kaup and colleagues have carried out a number of investigations to examine this issue (Kaup, Yaxley, Madden, Zwaan & Lüdtke, in press; Lüdtke, Friedrich, De Filippis & Kaup, 2005; Kaup, in press). Specifically, participants read sentences such as, 'There was no eagle in the sky/ nest', and subsequently responded to a related picture. Results showed that responses were faster when the picture matched the negated statement, suggesting that the negated situation has been simulated during language processing.

ERP studies on negation have identified effects of negation in the N400 brainwave (Fischler, Bloom, Childers, Roucos & Perry, 1983; Hald, Kutas, Urbach & Pahrhizkari, 2004). Participants read sentences such as in (6).

- | | |
|----------------------------|---------------------|
| (6) a. Hawaii is tropical. | (True affirmative) |
| b. Hawaii is cold. | (False affirmative) |
| c. Hawaii is not cold. | (True negative) |
| d. Hawaii is not tropical. | (False negative) |

Sentences (6b) and (6c) elicited a large N400 effect, when compared to (6a) and (6d). One interpretation is that participants have not used the negation operator to make sense of negative sentences. Furthermore, these studies show that the semantic meaning of a word and its fit with the preceding context (e.g. Hawaii – tropical) plays a more immediate role in comprehension than the truth value of the sentence as a whole. Thus, semantic plausibility of the sentence as a whole has not influenced initial processing, although it is suggested that the sentence's truth value is computed at a later stage. In fact, a recent study by Lüdtkke, Friedrich, De Filippis and Kaup (2005) demonstrated that when there is a delay in a sentence-picture-verification task (see above for details), a main effect of truth value emerges in the N400 time window. The authors suggest that after this processing delay, comprehenders have finalized the meaning of the negated sentence and have mentally represented this complete meaning. However, these studies have been limited due to confounding priming effects in their experimental items. Also, the passages used in these studies were very short, with the target word immediately following the negation marker 'not' and as such it is possible that participants have not had time to integrate the negative context. It is also important to note that to date no studies have investigated the consequences of negation on later processing (outwith the negated sentence).

One view of how negatives are processed is that they serve to reduce accessibility of information mentioned within its scope during language comprehension, and *nothing more* (see Von Klopp, 1993; Prado & Noveck, 2006). Evans and colleagues

(Evans, Clibbens, & Rood, 1996; Evans & Over, 2004) describe the role of negation as “to deny propositions rather than assert information” (Evans et al., 1996, pp394). Some support for this comes from McDonald and Just (1989) who employed a probe recognition or word-naming task following sentences such as (7) and revealed evidence that readers create a propositional representation where a negative construct (e.g. ‘no’) encapsulates the explicitly negated concept (‘cookies’), thus reducing later accessibility of this information. This account will be referred to as the *narrow-view*.

(7) Almost every weekend Mary bakes some bread but no cookies for the children.

However, contrasting evidence demonstrates that this suppression of negated information is not an obligatory process and instead suggests that negation processing can be viewed as a guide for making the negated object the basis of a wider *search-for-alternatives*. Specifically, McDonald & Just found that when probe words were close associates (e.g. butter), suppression was not evident following *no bread*. In fact, a great number of studies have indicated that although initially, processing is insensitive to negation, effects of negation emerge later in language comprehension (see Giora, 2006 for a review). Kaup, Lüdtke and Zwaan (2006) showed that while negated concepts lost accessibility 750ms after their offset, by 1500ms they were replaced by alternative opposites. Thus, after this long delay, focus shifted from the negated concept (*The door is not open*) to an alternative (‘The door is closed’).

Given this evidence, I now return to the questions posed at the start of this chapter, namely, how quickly reality is negated and when an alternative model is created. Negated statements can be either dichotomous, leading to a single choice of ‘alternative-world’ (e.g. ‘The dog was not dead’ leads readers to assume that the dog must be alive) or can generate multiple choices of ‘alternative-worlds’ (e.g. ‘Susan was

not wearing a black dress' does not specify the actual colour of Susan's dress). In the first of these cases, properties of the negated entity can be inferred with great accuracy although the actual situation is not explicitly specified. However, within the multiple alternatives construct, the reader's representation of the negated entity must contain an unspecified dimension of the negated property. The question then arises as to when readers commit to a specific 'alternative' property. For example, how would the processor deal with sentences such as (8)?

(8) Susan was not wearing a black dress. She had decided to surprise her friends by wearing a dress that was red.

The current studies used scalar and bi-polar concepts (e.g. carnivores/ vegetarians; warm/ cold; dangerous/ harmless) to narrow the number of alternatives available to the comprehender, without being strictly dichotomous.

So far then, research into negation has provided evidence to support a suppression account, which is limited by factors such as the nature and truth value of the negated concept, the processing time allowed and the availability of contextual information. Most research has compared affirmative and negative sentences in isolation, or following a supportive context and as such cannot address the issue of how a negated concept is reflected in later processing of relevant information. The studies reported here provide an investigation of the consequences of negation within a wider discourse, using eye-tracking and ERP methodologies. Specifically, negation was used to cancel real-world expectations within a conditional statement, such as (9). This was then followed by a second sentence with either RW anomalous continuations, where events included a violation of RW knowledge (though consistent with the negated context), or RW congruent continuations, where the events described were congruent

with RW knowledge (inconsistent with negated context). Thus, any differences in reading at sentence 2 must reflect processing in terms of real-world knowledge or the negated-world context.

(9) If cats were not carnivores, they would be cheaper for owners to look after. Families could feed their cat a bowl of carrots/ fish and listen to it purr happily.

This paradigm eliminates many limitations from previous studies. Since negation is depicted in a separate context sentence, the lengthy delay before the consequence in sentence 2 should allow alternative opposites to be activated if necessary. Similarly, by examining effects in the second sentence, difficulties arising directly from the extra syllable in negative sentences are eliminated. Finally, priming effects of simply repeating a previously negated word are avoided here as the negative context negates a category (e.g. carnivores) while later reference is made to a specific example (e.g. fish).

What can be predicted about negated passages in this paradigm, in line with previously detailed research on anomaly detection? If it is true that comprehenders suppress access to the negated concept in their representation, then greater difficulty should emerge for target words that were negated by the context sentence. Thus, if comprehending a sentence such as (9) involves suppression of a carnivore, then this should be reflected in lengthened reading times and increased regressions following *fish*. Also, according to this *narrow-view*, readers should show equal difficulty when the negated context is followed by *carrots*, since this account asserts that a search for alternatives is not initiated as a function of negation. In contrast, the *search-for-alternatives* view would predict that carrots should be easier to process than fish since it is an appropriate alternative to the negated concept, although there may be initial costs

associated with real-world expectations. This is the basic question of the experiments reported here.

In sum, Chapter 4 is a report of two studies in which the materials manipulate propositions that are anomalous with respect to the real-world, but appropriate given a pre-specified negated world. Experiment 5, employed eye-tracking methodology as participants read a prior context depicting a negated-world (NW), or real-world (RW), followed by a second sentence continuation. Events described in these continuations either included a violation of RW knowledge (RW anomalous), or were congruent with RW knowledge (RW congruent). In Experiment 6, ERPs were recorded as participants read NW-inconsistent and NW-consistent passages. The question was whether and at what stage of processing the negative context influences interpretation of the target sentence, making the anomaly acceptable. Also, whether processing of RW congruent information can lead to difficulties when it has been preceded by a negative context.

Experiment 5

Method

Participants

Thirty-six participants were recruited from the undergraduate population of students from the University of Glasgow and were paid to participate in the study. All participants were native speakers of English, who did not have dyslexia and with vision that they reported to be normal or corrected to normal using soft contact lenses. Participants were naïve to the purpose of the study and had not taken part in any previous related experiments.

Materials and Design

Thirty-two experimental items were constructed as in Table 4.1. Two context conditions were crossed with two consistency conditions to create a 2x2 within subjects design. The context condition was split into two levels: a real-world (RW), where the first sentence depicted a realistic circumstance, and a negated-world (NW), where the first sentence cancelled real-world expectations, but did not create an alternative model. The consistency condition also had two levels and was manipulated by changing the noun in the second sentence: inconsistent, such that events described in the second sentence were inconsistent with the prior context; or consistent, whereby the critical noun was consistent with the pre-specified context. This created a fully crossed experiment with four conditions: RW-inconsistent, RW-consistent, NW-inconsistent, and NW-consistent.

RW-inconsistent

If cats are hungry, they usually pester their owners until they get fed.
Families could feed their cat a bowl of carrots and listen to it purr happily.

RW-consistent

If cats are hungry, they usually pester their owners until they get fed.
Families could feed their cat a bowl of fish and listen to it purr happily.

NW-inconsistent

If cats were not carnivores, they would be cheaper for owners to look after.
Families could feed their cat a bowl of fish and listen to it purr happily.

NW-consistent

If cats were not carnivores, they would be cheaper for owners to look after.
Families could feed their cat a bowl of carrots and listen to it purr happily.

Table 4.1: Examples of experimental sentences (Experiment 5).

The length and frequency of the critical nouns was matched across conditions using the British National Corpus. Nouns in the RW-inconsistent and NW-consistent conditions averaged 5.6 (min.= 3, max.= 10) characters, while nouns in the RW-consistent and NW-inconsistent conditions averaged 5.9 (min.= 3, max.= 9) characters.

Mean frequency was 82.1 occurrences per million words for the RW-inconsistent and CW-consistent conditions and 64.5 for the RW-consistent and CW-inconsistent conditions. Thus, we can be confident that any difference in reading times between conditions is not due to discrepancies in length or frequency of the critical nouns.

One version of each item was assigned to one of four presentation lists. The 32 experimental items were assigned to lists so that equal numbers of each condition appeared on each list. One version of each item appeared on each list so that participants did not see more than one version of any given item. The items were displayed alongside one hundred and fifty-two filler sentences of various types to create a single random order. At least one filler item intervened between each experimental item. Nine participants were randomly assigned to read each experimental list and they only saw each target sentence once, in one of the four conditions. A comprehension question was presented after half of the experimental (i.e., 16) and filler (76) items. Participants did not receive feedback for their responses. All participants used in the data analysis scored at or above 90% accuracy on the comprehension questions.

Eye tracking and Procedure

The eye tracking and experimental procedures were identical to those described in Chapter 2.

Results and Discussion

Regions of analysis

The critical second sentence was divided into four regions for the purpose of aggregating reading times and classifying eye-movements, as shown in (10). Note that these regions correspond directly to the regions of analysis used in the eye-tracking studies in Chapter 2, to facilitate close comparison of emerging effects. For each

sentence frame, corresponding regions contained the same number of words in all three versions.

- (10) If cats were not carnivores they would be cheaper for owners to look after.
|Families could₁| feed their cat a bowl of₂| carrots and₃| it would gobble it down
happily.₄|

The first sentence created a RW or NW context for the critical sentence. Region 1 introduced an agent followed by the modal verb *could*. Region 2 (pre-critical) contained material that that led to the critical region. Region 3 (critical) always consisted of the inconsistent or consistent noun, plus the connective *and*, and thus this region was always two words long. Region 4 (post-critical) comprised the critical sentence wrap-up.

First-pass reading time, First-pass regressions out, regression path time, total reading time and regressions in measures were used to analyse tracking patterns. See Chapter 2, Experiment 5 for full details of these measures of analysis. Prior to analysis, fixations were pooled, truncated or removed if necessary (see Chapter 2 for details of this procedure), which accounted for less than 2% of the data.

Table 4.2 displays mean values for each measure in each condition and region.

	Region				
	Context Sentence 1	1 <i>Families could</i>	2 <i>feed their cat a bowl of</i>	3 <i>carrots and</i>	4 <i>it would gobble it down happily.</i>
First-pass reading time (ms)					
RW-inconsistent	2527 (104.2)	454 (25.7)	682 (26.4)	307 (11.3)	865 (44.3)
RW-consistent	2590 (115.2)	481 (28.9)	697 (32.5)	277 (7.9)	880 (45.7)
NW-inconsistent	2480 (115.8)	489 (27.8)	661 (29.9)	281 (9.6)	937 (46.8)
NW-consistent	2504 (125.2)	506 (25.4)	657 (31.0)	286 (8.5)	914 (34.8)
Regression path time (ms)					
RW-inconsistent	2527 (104.2)	514 (33.6)	899 (48.6)	370 (16.9)	1182 (80.2)
RW-consistent	2590 (115.2)	509 (30.1)	875 (42.8)	344 (16.5)	1126 (77.4)
NW-inconsistent	2480 (115.8)	544 (40.2)	830 (37.2)	355 (25.4)	1140 (54.8)
NW-consistent	2504 (125.2)	544 (30.2)	879 (38.8)	352 (16.5)	1065 (49.0)
First-pass regressions out (%)					
RW-inconsistent	-	5.4 (1.7)	16.2 (2.8)	14.6 (2.7)	24.8 (3.5)
RW-consistent	-	4.3 (1.4)	13.8 (2.2)	15.8 (3.1)	18.4 (2.7)
NW-inconsistent	-	4.1 (1.3)	14.5 (2.0)	13.6 (2.1)	19.5 (3.0)
NW-consistent	-	3.7 (1.4)	17.5 (2.4)	12.2 (2.4)	16.6 (2.7)
Total reading time (ms)					
RW-inconsistent	2619 (118.2)	550 (35.2)	902 (40.3)	360 (16.6)	1018 (52.9)
RW-consistent	2651 (117.7)	555 (32.8)	886 (47.0)	313 (11.5)	986 (56.5)
NW-inconsistent	2607 (122.7)	578 (32.7)	819 (33.7)	312 (12.9)	1005 (46.4)
NW-consistent	2577 (128.7)	569 (27.2)	829 (36.3)	322 (10.9)	991 (39.4)
Regressions In (%)					
RW-inconsistent	11.4 (2.1)	21.6 (3.2)	20.8 (3.1)	12.8 (3.1)	0.9 (0.7)
RW-consistent	9.9 (2.0)	16.8 (2.7)	17.8 (3.0)	6.7 (2.1)	1.0 (0.6)
NW-inconsistent	13.4 (2.4)	20.1 (2.9)	15.5 (2.5)	5.9 (1.8)	0.6 (0.4)
NW-consistent	10.7 (2.0)	18.8 (2.5)	15.2 (2.3)	9.5 (1.5)	1.9 (1.1)

Table 4.2: Mean eye- movement measures for regions 1 to 4 (standard errors in parentheses)

First-pass reading times In region 1, following the context sentence, first-pass reading times revealed a main effect of context [$F_1(1, 35) = 2.85, p = 0.1$; $F_2(1, 31) = 4.62, p = 0.04$] that was significant by items and marginal by participants. Specifically, first-pass reading times were longer following a NW context than RW context. This suggests that readers are still processing prior information in NW conditions and that NW statements are more difficult to comprehend.

At the critical region 3, a significant interaction emerged [$F_1(1, 35) = 4.93, p = 0.03$; $F_2(1, 31) = 5.50, p = 0.03$]. Analysis of the simple main effects revealed longer first-pass reading times in the inconsistent than the consistent condition at the level of RW [$F_1(1, 35) = 8.20, p < 0.01$; $F_2(1, 31) = 13.07, p = 0.001$], however this was not

significant at the level of NW [$F_s < 0.3$]. Additionally, RW led to longer first-pass reading times compared to NW for inconsistent conditions [$F_1(1, 35) = 9.06, p < 0.005$; $F_2(1, 31) = 7.84, p < 0.01$] but there was no difference between RW and NW consistent conditions [$F_s < 1.0$]. The increased reading times for the RW-inconsistent condition was expected given previous eye-movement investigations of real-world violations (see Chapter 2). Furthermore, the fact that NW-consistent and NW-inconsistent conditions were not significantly different at this stage suggests that processing is still ongoing within the negated context, and specifically that the NW inconsistency has not been detected at this point. Thus, we provide further evidence that the effects of real-world anomalies can be picked up in measures of very early processing during a reading task. Additionally in this critical region, a main effect of consistency is apparent that was marginal by participants and significant by items [$F_1(1, 35) = 5.28, p = 0.03$; $F_2(1, 31) = 4.63, p = 0.04$]. However, this effect was largely due to greatly increased reading times in the RW-inconsistent condition. There was no main effect of context [$F_s < 1.0$].

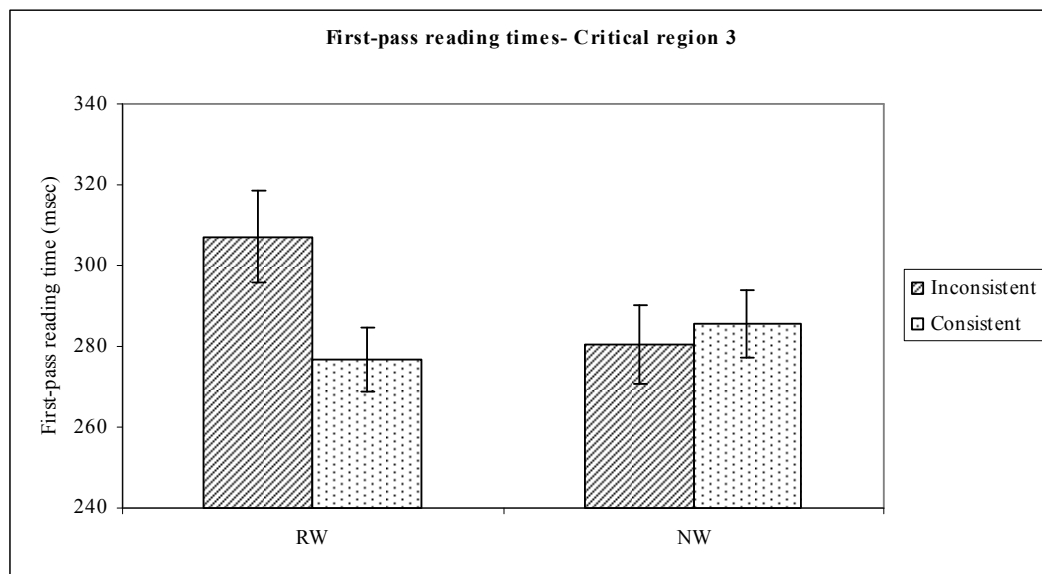


Figure 4.1: Mean first-pass reading times in critical region showing standard error bars.

By the post-critical region 4, a main effect of context emerged [$F_1(1, 35) = 2.86$, $p = 0.1$; $F_2(1, 31) = 4.13$, $p = 0.05$] with longer first-pass reading times following a NW context than a RW context. The fact that readers show decreased first-pass reading time in the critical region followed by more time reading in the post-critical region in the NW-consistent condition suggests differential recovery and integration strategies for RW-inconsistent and NW-consistent conditions following a real-world anomaly. Thus, we suggest that these longer reading times in the post-critical region following a NW context reflects the recruitment of additional processing to relate incoming information to the wider discourse context.

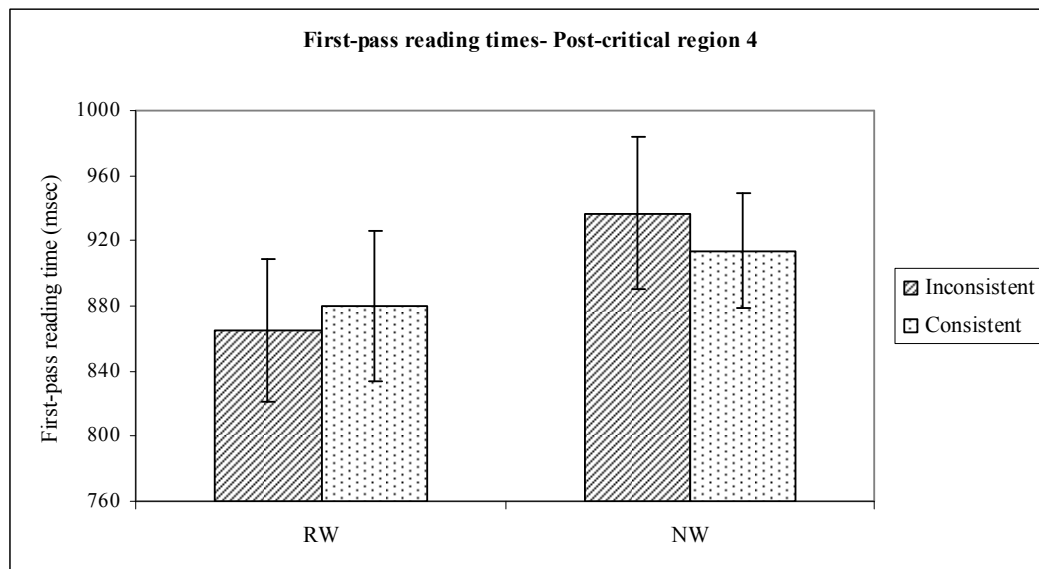


Figure 4.2: Mean first-pass reading times in post-critical region showing standard error bars.

First-pass Regressions Out Figure 4.3 illustrates how each condition affected the mean first-pass regressions out of each region as the sentence progressed.

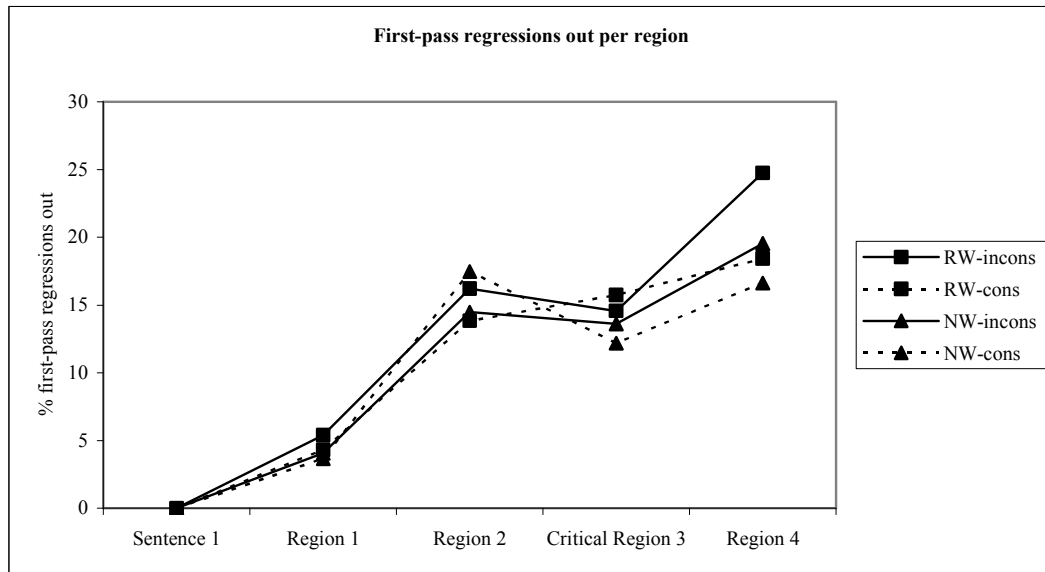


Figure 4.3: Percentage first-pass regressions out per region

In the critical region 3, there was no evidence of any effect of context or consistency, or an interaction on regressions out [$F_s < 1.2$]. However, by the post-critical region 4, a main effect of consistency emerged that was borderline by participants and significant by items [$F_1(1, 35) = 3.02, p = 0.09$; $F_2(1, 31) = 4.77, p = 0.04$]. Thus, by the post-critical region, readers are using the wider discourse to make sense of the passage and regressing back in the text to attempt to make sense of the inconsistency.

Regression path times As with regressions out data, the critical region 3 yielded no main effects or an interaction between factors [all $F_s < 1.4$]. However, by the post-critical region 4, regression path times were longer when the critical word had been inconsistent with the prior context [$F_1(1, 35) = 3.41, p = 0.07$; $F_2(1, 31) = 4.47, p < 0.05$]. This consistency effect suggests that by the post-critical region, participants are using the prior RW or NW context to guide language processing.

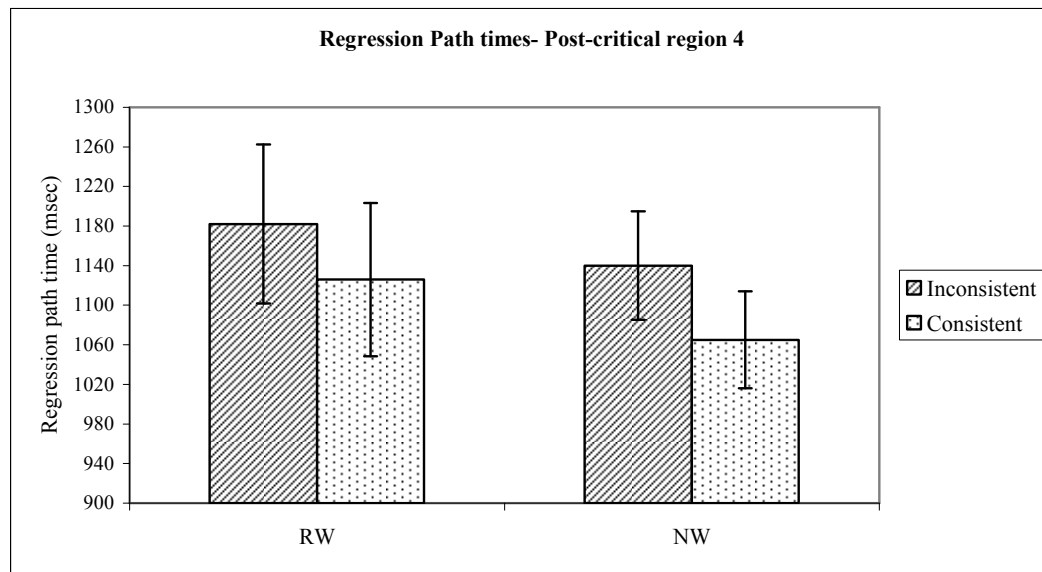


Figure 4.4: Mean regression path reading times in post-critical region, showing standard error bars.

Total reading times The pre-critical region 2 showed a main effect of context [$F_1(1, 35) = 9.43, p = 0.004$; $F_2(1, 31) = 7.33, p = 0.01$] as RW contexts led to longer total reading times than NW contexts in this region. By the critical region 3, a significant interaction [$F_1(1, 35) = 6.68, p = 0.01$; $F_2(1, 31) = 5.34, p = 0.03$], a main effect of context [$F_1(1, 35) = 4.15, p = 0.05$; $F_2(1, 31) = 4.08, p = 0.05$] and a main effect of consistency that was marginal by participants and significant by items [$F_1(1, 35) = 3.37, p = 0.07$; $F_2(1, 31) = 4.08, p = 0.05$] was revealed. Analysis of the simple main effects revealed longer total reading times in the inconsistent than the consistent condition at the level of RW [$F_1(1, 35) = 10.95, p < 0.005$; $F_2(1, 31) = 13.29, p = 0.001$], however this was not significant at the level of NW [$F_s < 0.6$]. Additionally, RW led to longer total reading times compared to NW for inconsistent conditions [$F_1(1, 35) = 12.35, p < 0.001$; $F_2(1, 31) = 11.77, p < 0.002$] but there was no difference

between RW and NW consistent conditions [$F_s < 0.4$]. No main effects or an interaction between context and consistency was evident in the post-critical region 4 [$F_s < 1.0$].⁵

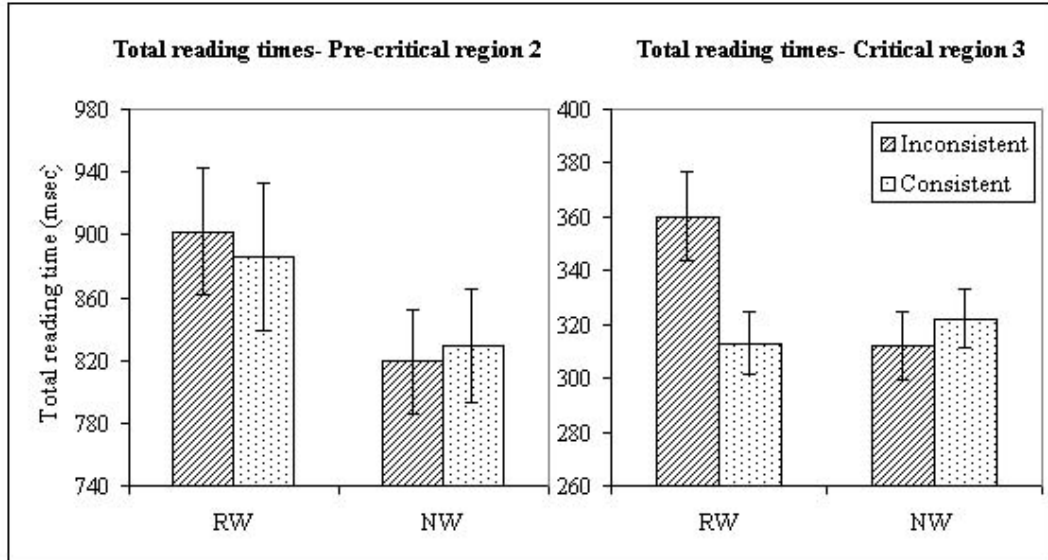


Figure 4.5: Mean total reading times in pre-critical and critical regions, showing standard error bars.

Regressions in

Figure 4.6 shows the mean number of regressions into each region for each condition.

⁵ Number of fixations data reflected total reading times with a main effect of context in the pre-critical region 2 [$F_1(1, 35) = 5.78, p = 0.02$; $F_2(1, 31) = 6.44, p < 0.02$], reflecting more fixations in this region following a RW context than a NW context. Critical region 3 revealed a significant interaction [$F_1(1, 35) = 9.71, p = 0.004$; $F_2(1, 31) = 6.44, p < 0.02$] with increased number of fixations in the region when the critical word violates real-world expectations, regardless of prior context.

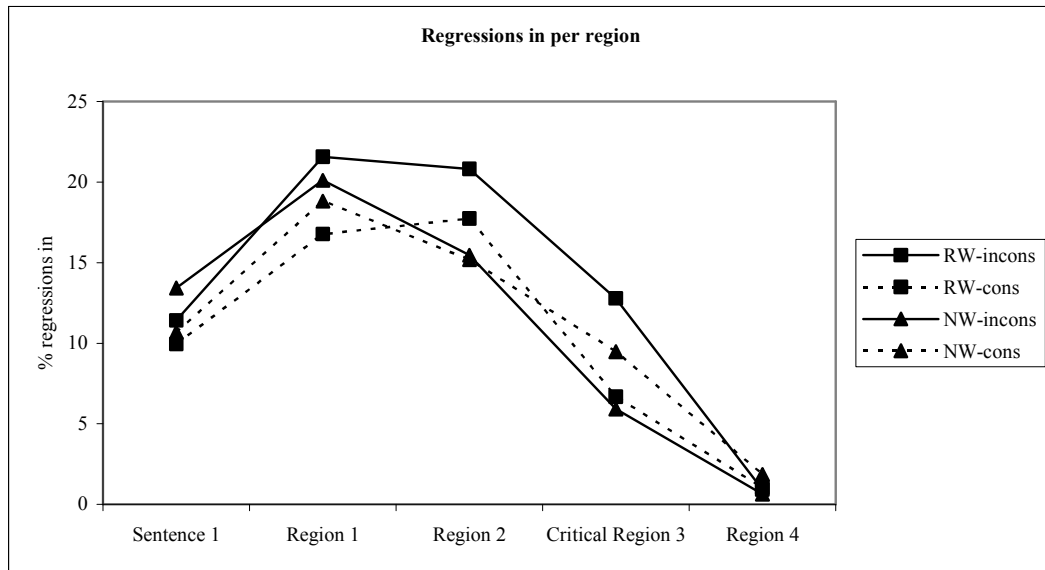


Figure 4.6: Percentage regressions in per region

A significant interaction between context and consistency was found at the critical region 3 [$F_1(1, 35) = 4.70, p = 0.04$; $F_2(1, 31) = 8.52, p = 0.006$], with simple main effects revealing increased incidence of regressions into the region in the inconsistent than the consistent condition at the level of RW [$F_1(1, 35) = 5.14, p < 0.05$; $F_2(1, 31) = 3.80, p = 0.06$], and marginally increased regressions in for inconsistent than consistent conditions at the level of NW [$F_1(1, 35) = 1.74, p < 0.2$; $F_2(1, 31) = 3.27, p = 0.08$]. Furthermore, RW led to more regressions in compared to NW for inconsistent conditions [$F_1(1, 35) = 6.14, p < 0.02$; $F_2(1, 31) = 10.82, p < 0.005$] but there was no difference between RW and CW consistent conditions [$F_s < 2.1$].

In sum, Experiment 5 showed that within a RW context, conditions where the target sentence included a real-world violation led to longer reading times, more fixations and a higher incidence of regressions in at the critical noun than RW-consistent conditions. Thus, information that conflicts with real-world knowledge causes a disturbance in the eye-movement patterns. In contrast, within a NW context, reading patterns around the critical word did not differ significantly between consistent

and inconsistent conditions. This suggests that both global and local integration processes have been delayed, and importantly that a prior negated-world context has not directed comprehension at this stage. However, this effect was later replaced by a delayed disruption in response to critical words that were inconsistent with the preceding NW context. Longer first-pass reading times for NW conditions at the post-critical region, reflecting ongoing evaluation against RW knowledge and increased incidence of regressive eye- movements from this region following NW-inconsistent items confirm that the NW context is eventually incorporated into the representation of the sentence meaning.

In all, the data here supports the results from previous investigations with counterfactual contexts (see Chapter 2), that language comprehension is initially influenced by real-world knowledge, even in the presence of a context allowing an alternative world, and that contextual information influences later discourse resolution. We can also claim that RW inconsistencies were detected earlier, and lead to more robust disruptions in comprehension than NW inconsistencies, as effects of the NW inconsistency were revealed later in the eye- movement record, and only in regressive eye- movement measures.

Experiment 6

The question is whether the introduction of a negated discourse context, such as those used in Experiment 5, can eliminate effects of real-world knowledge in the ERP components. It should not if the integration of a NW context, when present, is delayed as the basis of processing, after the initial use of real-world knowledge (as suggested in Experiment 5). However, increasing evidence using ERP suggests that a strong discourse context *can* overrule local lexical-semantic factors when these two conflict and as such can immediately influence comprehension processes. This has been

demonstrated by the N400 effect, which is highly sensitive to the ease of integration of the meaning of a word into the prior sentence or discourse (Van Berkum et al., 2003; Nieuwlands & Van Berkum, 2006). In Experiment 6 we examined such processing of events that were either congruent or incongruent in terms of a pre-specified negated world, as used in Experiment 5.

The aim was to allow a fuller investigation into the use of NW information, particularly when that information conflicts with existing knowledge about reality. Additionally, we hoped to explore whether NW inconsistencies are processed in the same way as RW inconsistencies, and specifically whether NW inconsistencies reveal a different pattern or time-course of detection as compared to RW inconsistencies (as in Chapter 3). We expected to replicate the findings of Experiment 5, that the representation of the sentence meaning is initially in terms of real-world knowledge (on the critical word), as reflected in increased N400 effects for real violations regardless of prior context, and that the NW context is incorporated into the discourse at some later stage of processing (word downstream of the critical word).

Method

Participants

Eighteen right-handed native English speakers were recruited from the University of Glasgow (9 males) and were paid to take part in this study. Participants ranged in age from 18 to 25 years. Participants did not have dyslexia and had vision which they reported to be normal or corrected to normal with glasses or contact lenses. All participants were naïve to the purpose of the study and had no previous exposure to the test materials.

Materials and Design

Eighty experimental items were constructed for use in this study. A 1-factor within subjects design compared NW-inconsistent and NW-consistent conditions, as shown in Table 4.3.

<p><i>NW-inconsistent</i></p> <p>Cats are popular pets in British households. If cats were not carnivores, they would be cheaper for owners to look after. Families could feed their cat a bowl of fish and listen to it purr happily.</p>
<p><i>NW-consistent</i></p> <p>Cats are popular pets in British households. If cats were not carnivores, they would be cheaper for owners to look after. Families could feed their cat a bowl of carrots and listen to it purr happily.</p>

Table 4.3: Examples of experimental sentences (Experiment 6).

Here, each item consisted of an introduction sentence and a NW context sentence followed by a critical target sentence. The first sentence of each item introduced the topic of the passage, and was identical in both conditions. The purpose of this introductory sentence was to maintain a consistent structure across experimental items and fillers (which were part of a different study). Sentence two depicted a ‘negated-world’ context that cancelled real-world expectations, but did not create an alternative model. The target sentence described an event that could either be inconsistent with the prior context (but congruent with real-world knowledge), or consistent with the prior context (but anomalous according to real-world knowledge). Thus, within the example above, it should be inconsistent for cats to eat *fish* if are they were *not carnivores*, but it should be consistent for cats to eat *carrots* within this context. Apart from this critical word, the remainder of the target sentence was identical across experimental conditions.

The experimental items were organised into two lists, such that each item appeared in one of its two versions in a given list, but appeared in all versions across the two lists. Therefore, each list comprised 40 items in each of the two conditions. The

items were displayed alongside 160 filler sentences of various types, with at least one filler item intervening between each experimental item.

As in Experiment 4, participants were tested in an electrically shielded booth with ambient light kept at a low level. Word stimuli were presented in black 16 point Helvetica font on a white background at the centre of a 15" computer monitor at a viewing distance of 90 cm.

Procedure

Participants were informed about the EEG procedure and experimental task. After electrode application they were seated in a booth where they read the materials from a computer screen. There were six practice trials to familiarize them with the procedure, after which the experimenter answered any questions. As illustrated in Figure 4.7, each trial began with the presentation of a single centrally-located red fixation cross for 500ms to signal the start of a new item. After this time, a white fixation cross appeared for 500ms. Next, sentence 1 (introduction sentence) was presented on the screen. Participants were instructed to read this sentence and press spacebar on a keyboard to continue when ready. A blank screen appeared for 1000ms, before sentence 2 (NW context sentence) was presented, in the same way as sentence 1. Participants were asked to read this so that they understood the context and pressed spacebar to progress at which point, the screen was cleared for 500ms. Finally, a fixation cross (500ms) preceded sentence 3 (critical sentence) that was presented word-by-word, with each word appearing on the centre of the screen for 300ms. A blank-screen interval of 200ms separated words. Sentence-ending words appeared with a full stop. A 2500ms blank-screen interval followed each item. There was no secondary task. Trials appeared in eight blocks of thirty trials. Each block was separated by a break, the duration of which was determined by the participant. Thus, participants were tested in a single session that

lasted approximately one hour, during which they were seated in a comfortable chair located in an isolated room.

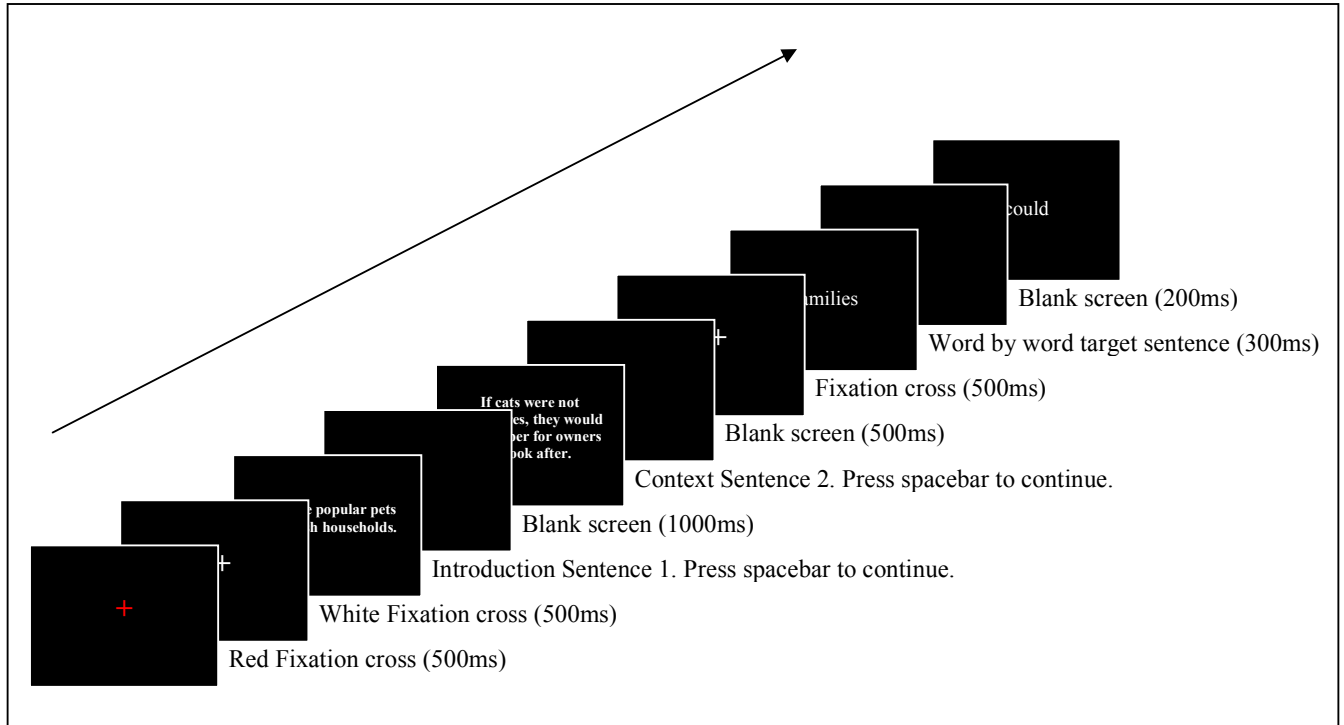


Figure 4.7: Schematic diagram of the experimental procedure.

Data acquisition and analysis

The data acquisition measures and analysis procedures were identical to those described in Chapter 3. For the statistical analysis of ERP amplitude data recorded from midline electrodes, an ANOVA was performed with variables consistency (NW-consistent/ NW-inconsistent) and electrode (AFz, Fz, FCz, Cz, CPz, Pz, POz, Oz). For the analysis of ERP deflections maximal over lateral electrode sites, an ANOVA was performed with variables consistency (NW-consistent/ NW-inconsistent), hemisphere (left, right), ant-pos (anterior, central, posterior), and verticality (ventral, dorsal) using regions of interest that were identical to those defined in Experiment 4.

Results & Discussion

ERP Analysis

Grand average ERP waveforms are presented for the two conditions in Figure 4.8. In the 50-100 ms time interval, the ANOVA did not show any reliable topographic effects [all $F_s < 2.19$, $p_s > 0.13$]. Importantly, during this early time interval the effect of consistency was neither significant as a main effect nor in interaction with any combination of the variables hemisphere, ant-pos, and verticality [all $F_s < 1$]. The initial positivity (P1) was largest over posterior brain areas [$F(2, 34) = 40.3$, $p < 0.001$, $\epsilon = 0.61$], and here larger over ventral than lateral ROIs as indicated by the ant-pos x verticality interaction [$F(2, 34) = 9.8$, $p < 0.01$, $\epsilon = 0.63$]. No main effect of consistency was found for the P1 component, however, a significant consistency x hemisphere x ant-pos x verticality interaction emerged [$F(2, 34) = 5.7$, $p < 0.01$, $\epsilon = 1.0$]. A separate P1 amplitude analysis revealed for posterior ROIs, where this component was maximal, a significant consistency x hemisphere x verticality interaction [$F(1, 17) = 15.8$, $p < 0.001$]. Further testing revealed that consistent as compared to inconsistent conditions lead to a larger P1 amplitude over left ventral sites (2.3 vs. 1.6 μV) but smaller P1 amplitude over right ventral sites (2.7 vs. 3.3 μV) [$F(1, 17) = 9.8$, $p < 0.01$] (cf. Figure 4.9). This difference was not apparent in dorsal regions [$F(1, 17) = 2.2$, $p > 0.15$]. No effects were observed in the midline electrodes [all $F_s < 1$]. In the following N1 time interval the ERP waveform over posterior ROIs was more negative going over left than right sites and over ventral than dorsal sites, as indicated by a hemisphere x ant-pos interaction [$F(2, 34) = 5.4$, $p < 0.05$, $\epsilon = 0.69$] and an ant-pos x verticality interaction [$F(2, 34) = 4.6$, $p < 0.05$, $\epsilon = 0.70$], respectively. Consistency did not influence the N1 amplitude as a main effect [$F(1, 17) = 2.0$, $p > 0.17$] but the consistency x hemisphere x ant-pos interaction was significant [$F(2, 34) = 6.88$, $p < 0.01$, $\epsilon = 0.92$]. A separate N1

amplitude analysis revealed for posterior ROIs a significant consistency x hemisphere interaction [$F(1, 17) = 8.2, p < 0.05$], indicating that consistent as compared to inconsistent conditions lead to a more negative-going N1 amplitude over the right hemisphere (1.3 vs. 2.0 μV) but not over the left hemisphere (1.0 vs. 1.0 μV) (cf. Figure 4.9). Once again, no main effect of consistency or significant effects in the midline region was found [all $F_s < 1$].

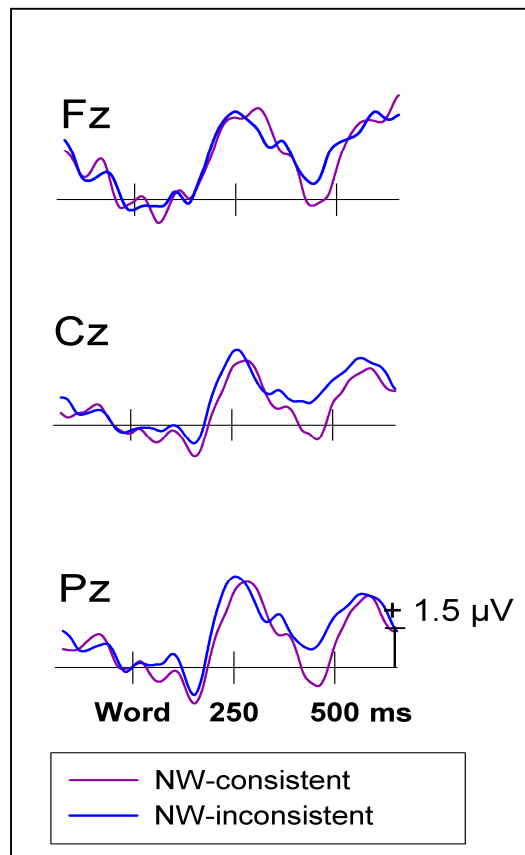


Figure 4.8: Grand average ERPs elicited by critical nouns in sentence three. Note that negativity is plotted downwards.

The positive peak between 200 and 350ms post critical word onset showed the same consistency x hemisphere x ant-pos interaction as in the N1 interval [$F(2, 34) = 5.75, p < 0.01, \epsilon = 0.99$]. Further tests showed that ERP waveforms were more negative-going for consistent than inconsistent conditions over right posterior ROIs (2.4 vs. 2.8

μV ; cf. Figure 4.9), as indicated by the significant Consistency x Hemisphere interaction for posterior ROIs [$F(1, 17) = 5.2, p < 0.05$]. No main effect of consistency was observed in this time window [$F_s < 1$].

The positive wave was followed by a slowly growing negative-going deflection. In the time interval 350-500 ms after target word onset, the widely distributed negative-going ERP waveform was more negative for consistent than inconsistent conditions in the analysis of midline electrode data (0.3 vs. 1.5 μV) [$F(2, 34) = 4.6, p < 0.05$] and marginal in the analysis of lateral electrode data (0.5 vs. 1.2 μV) [$F(2, 34) = 3.6, p = 0.07$]. The latter analysis indicated an interaction between consistency x hemisphere x ant-pos persisted [$F(2, 34) = 6.5, p < 0.01, \epsilon = 0.84$], with the same characteristics as in the earlier 200-350 ms interval, i.e., that is, the ERP waveform was more negative going for consistent than inconsistent conditions over right-posterior sites (cf. Figure 4.9). Finally, the time window between 500 and 700ms post target word onset indicated no residual main effect of consistency or an interaction with electrodes in the midline [all $F_s < 1$]. However, the consistency x hemisphere x ant-pos interaction was still present [$F(2, 34) = 6.0, p < 0.01, \epsilon = 0.86$], although, the nature of this effect changed so that the ERP waveform for consistent as compared to the inconsistent conditions was more positive over left posterior sites and more negative over right posterior sites [$F(1, 17) = 4.9, p < 0.05$].

These effects and their topographical location are illustrated by the maps in Figure 4.9.

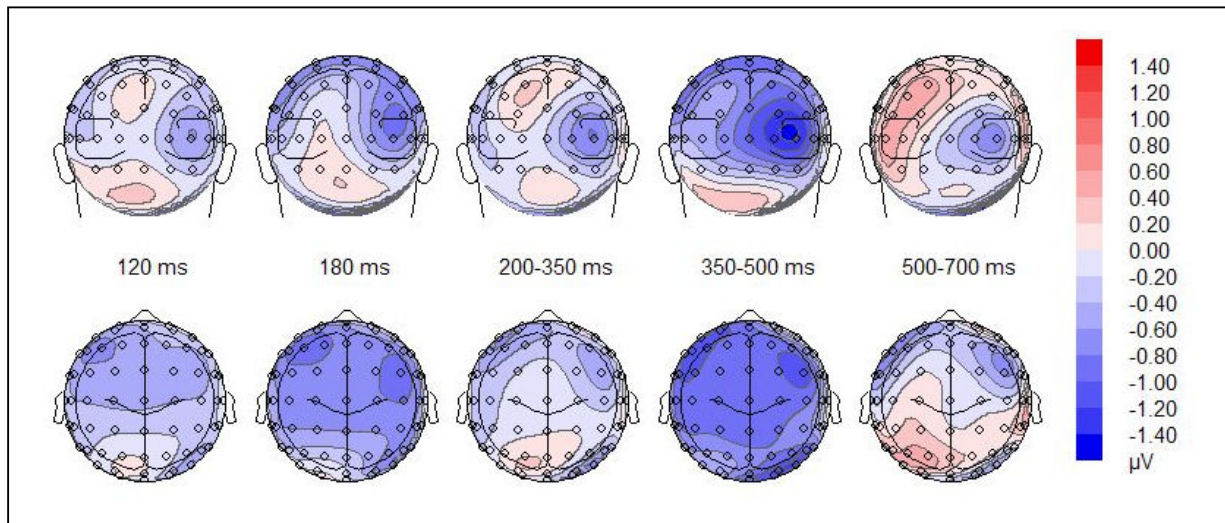


Figure 4.9: Topographic maps of ERP difference waveforms for each time interval of interest relative to critical word onset (inconsistent condition minus consistent condition): P1 (120ms) and N1 (180ms), 200-350ms, 350-500ms (N400) and 500-700ms.

In light of earlier eye-tracking results, showing that consistency effects emerged later in the target sentence, further analyses were carried out to determine whether this N400 effect would be reversed (i.e. larger N400 for context-inconsistent than consistent conditions) later in the ERP waveform. Therefore, analyses examined effects at words $n + 1$ (500- 1000ms after critical word onset) and $n + 2$ (1000- 1500ms after critical word onset). Inspection of later effects was deemed unreliable as accuracy of the time-locking of mental processes related to the critical word is likely to diminish with time from the experimental trigger, which was sent at the critical word onset. Word $n + 1$ was always the connector *and*, while word $n + 2$ initiated some neutral conclusion to the target sentence, and thus was identical across conditions. Therefore, we concluded that ERP differences revealed here might reflect later processing of the critical word. As is visible in Figure 4.10, no reliable effects [all $F_s < 2$] were revealed following the onset of word $n + 1$. Specifically, during this time interval the effect of consistency was neither significant as a main effect nor in interaction with any combination of the variables hemisphere, ant-pos, and verticality [all $F_s < 1$].

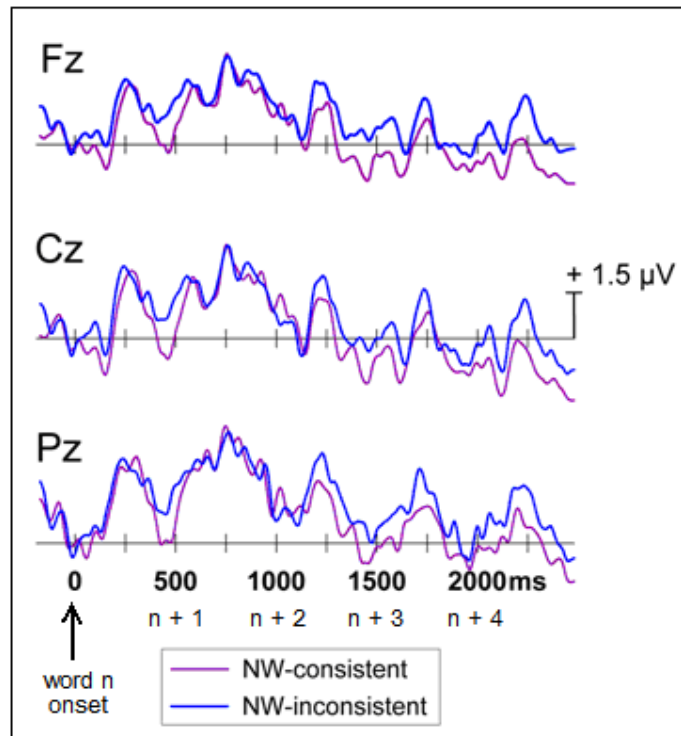


Figure 4.10: Grand average ERPs elicited by critical nouns and subsequent words in sentence two. Note that 0ms indicates the onset of the critical word, and a new word was presented every 500ms following.

However, in the time interval between 250 and 400ms after the onset of target word $n + 2$, a main effect of consistency emerged in the analysis of midline electrode data [$F = 4.52, p < 0.05$], revealing a more negative-going ERP waveform for consistent than inconsistent conditions. Thus, one interpretation of these results is that the consistency effect has not been reversed by word $n + 2$, and processing is still in terms of real-world knowledge.

Discussion

The experiments reported in this chapter examined whether and at what stage of processing a context that negates the readers' knowledge about the world influences interpretation of a target sentence, to overrule local pragmatic violations. Experiment 5 examined eye- movements as participants read passages that included a prior context

depicting a negated-world (NW), or real-world (RW), followed by a second sentence continuation. Events described in these continuations either included a violation of RW knowledge, or were congruent with RW knowledge. The results showed that reading times were longer, with more fixations and a higher incidence of regressive eye movements at the point of anomaly for RW conditions. In contrast, within a NW context, reading patterns around the critical word did not differ significantly between consistent and inconsistent conditions. Thus, it appears that the negated- world framework has not been integrated into the wider sentence meaning at this stage. However, by the post-critical region, reading times and regressions were led by the fit of the critical word with the preceding context, as NW-inconsistent items led to longer first-pass reading times and increased regressive eye- movements compared to NW-consistent. This delayed context effect is taken to reflect ongoing evaluation of the incoming information against knowledge about the world until the NW context can be incorporated into the representation of the sentence meaning.

Further evidence for the delayed influence of a negated context was found in Experiment 6. Here, ERPs were recorded to examine processing of events that were either congruent or incongruent in terms of a pre-specified negated world. Results revealed that introducing a negated-world context was not sufficient to reverse the typical N400 effect to semantic violations at the critical word. Thus, this supports the proposal that following a negated context, the model is not immediately updated and that language input is initially and persistently tested against real-world knowledge.

Taken together, these results support previous reading experiments that have demonstrated that initial processing of a sentence is not influenced by a preceding negation operator (Fischler et al., 1983; Hald et al., 2004; Giora, 2006). Further, the suggestion that a passage's total meaning is computed at a later stage is confirmed here by evidence in the eye- movement data for a delayed reversal of local pragmatic effects

following a negated context. Thus, these results allow us to reject the *narrow-view* suggestion that negatives simply reduce accessibility of a negated concept (e.g. ‘carnivores’), which would predict that information mentioned within the negative’s scope (e.g. ‘fish’) would result in early processing difficulties. Instead, the results reported here support the *search-for-alternatives* view. According to this approach, negation prompts the reader to search for an appropriate alternative to the negated concept, following an initial processing insensitivity to negation (e.g. Giora, Balaban, Fein & Alkabets, 2005; Hasson & Glucksberg, 2006; Kaup et al., 2006). Kaup et al. (2006) suggest that the delayed effects of negation are due to participants mentally simulating the negated situation prior to suppressing this simulation and replacing it with a simulation of the actual situation.

The experimental items used in the current studies allowed novel investigations of the consequences of negation on later processing (outwith the negated sentence), improving on previous experimental confounds such as, priming and distance between the negative operator and the negated concept. Nevertheless, these short passages afforded a limited exploration of the readers’ representation of the negated world. Therefore, future investigations could examine how readers process information over time when the constraints of the negated world are repeatedly supported, such as in (11).

- (11) If cats were not carnivores, they would be much cheaper for owners to look after. Families could feed their cat a bowl of carrots/ fish and listen to it purr happily. Cats could get moody if they don’t eat carrots/ fish regularly. In fact, my cat is so greedy she would pester me until I provide mountains of carrots/ fish!

Using this longer narrative, one would expect the reader to gradually and implicitly set up an alternative world that is at odds with the readers' knowledge about the world, in which it is not uncommon for cats to eat vegetables. Thus, it is anticipated that the first world knowledge violation would elicit standard anomaly detection responses (increased reading times and regressions and an amplified N400 effect) regardless of the preceding NW context. However, this interference from real-world knowledge would diminish and eventually disappear after repeated exposure to NW-consistent information. The build-up of a discourse context has been investigated previously by Niewlands and Van Berkum (2006; Experiment 1). Specifically, they examined the build-up of a cartoon-like context and revealed that while a large N400 effect was initially elicited following animacy violations, this effect disappeared following comparable animacy violations later in the story.

The issue of polarity has also been investigated in relation to natural language quantifiers, demonstrating different patterns of focus induced by various negative (e.g. 'few') and positive (e.g. 'a few') quantifiers. For example, a proposition can convey information about a group of individuals, but differing quantifiers can direct the readers' attention to the good or the bad aspects, as in *Few of the patients were critically ill* (which is good), or *A few of the patients were critically ill* (which is bad). Different patterns of pronominal reference have been revealed for positive and negative quantifiers in continuation tasks (e.g., Moxey & Sanford, 1987; 1993a; Sanford, Moxey & Paterson, 1996). Following a negative quantifier, continuations typically refer to the *Complement Set* (i.e. the patients who were *not* critically ill), while following a positive quantifier, attentional focus is directed to the *Reference Set* (i.e. the patients who *were* critically ill). Therefore, the polarity of the quantifier used clearly affects the inferences made during comprehension.

Accordingly, negation could be influencing the saliency of information in the current studies. Negative contexts could initially focus the readers' attention onto the fact that *cats are not carnivores*, and therefore lead to questions such as why this would be the case and initiate a search for alternatives. In contrast, counterfactual (affirmative) contexts could focus readers' attention onto the explicitly stated alternative world of *cats being vegetarians* and therefore focus attention onto the consequences of such a world.

It is interesting to note that while the N400 effect to pragmatic violations can be reversed by introducing an appropriate counterfactual discourse context, the same is not true following a negated- world context. Thus, an important question arises as to whether the increased N400 effects to RW-inconsistent, CW-inconsistent and NW-consistent conditions are modulated by the same underlying mechanisms. This issue could be examined in future experiments using magneto-encephalography (MEG) techniques to locate the cortical sources underlying the N400 effects. The task of inferring the sites of brain activation is often more straightforward from MEG than from EEG. This is due to the electric and magnetic properties of the tissues in the cranium and also to the fact that MEG is selectively sensitive to currents flowing tangential to the scalp, corresponding to sulcal activations. Thus, the MEG method merges good spatial accuracy with accurate real-time tracking of brain activity, revealing both the sequential structure of neural activation and the frequently observed overlap between time courses of activation in distinct brain areas.

To date, there are several lines of evidence suggesting that the N400 ERP effect evoked by associative semantic violations might reflect neuronal activity within the temporal cortex and the inferior prefrontal cortices. First, the N400 effect is reduced in patients with left temporal and temporo-parietal lesions (Friederici, Hahne & von Cramon, 1998; Hagoort, Brown & Swaab, 1996). Second, intracranial

electrophysiological recordings implicate the left postero-lateral temporal (Halgren, Baudena, Heit, Clarke, Marinkovic & Clarke, 1994), anterior-inferior temporal (McCarthy, Nobre, Bentin & Spencer, 1995; Nobre & McCarthy, 1995) and inferior prefrontal (Halgren, Baudena, Heit, Clarke, Marinkovic, Chauvel, & Clarke, 1994) cortices as sources of the N400. Third, investigations using functional magnetic resonance imaging techniques (fMRI) in the same linguistic paradigms that generate the N400 effect, have revealed that the fMRI hemodynamic signal is modulated within the postero-lateral and inferior temporal cortices, primarily on the left, and that this modulation correlates with the N400 effect (Kuperberg, McGuire, Bullmore, Brammer, Rabe-Hesketh, Wright, Lythgoe, Williams & David, 2000; Kiehl, Laurens & Liddle, 2002; Newman, Pancheva, Ozawa, Neville & Ullman, 2001; Ni, Constable, Mencl, Pugh, Fulbright, Shaywitz, Shaywitz, Gore & Shankweiler, 2000; Kuperberg, Holcomb, Sitnikova, Greve, Dale & Caplan, 2003; Hagoort, Hald, Bastiaansen & Petersson, 2004; Kotz, Cappa, von Cramon & Friederici, 2002; Rossell, Price & Nobre, 2003). Finally, studies using another technique, MEG, in the same linguistic paradigms show modulation of temporal and prefrontal regions within the time epoch of the N400 (Halgren, Dhond, Christensen, Van Petten, Marinkovic, Lewine & Dale, 2002; Simos, Basile & Papanicolaou, 1997; Helenius, Salmelin, Service & Connolly, 1998; Dale, Liu, Fischl, Buckner, Belliveau, Lewine, & Halgren, 2000). Ultimately, only further experimentation will reveal whether the N400 effects found here and in Chapter 3 are derived from the same neural generators.

Chapter 5

The Visual- world Task: Investigating Expectations in Counterfactual and
Theory of Mind Reasoning

Introduction

This chapter starts with an investigation of how early counterfactual- world driven expectations affect processing (Experiment 7). The results from eye- tracking and ERP studies reported in Chapters 2 and 3 demonstrate that comprehenders are rapidly able to represent a counterfactual world and thus accept some appropriate counterfactual event within that framework. In this chapter, we were interested in examining whether and at what point comprehenders can override their real- world expectations following a counterfactual context to anticipate upcoming information in an unfolding sentence. Specifically, are readers able to anticipate a counterfactually appropriate (and reality inappropriate) referent within a counterfactual context or is this anticipation delayed by constraining expectations based on world knowledge?

In order to address this question the experiments reported here have used the ‘visual world’ paradigm to investigate language-mediated eye- movements around a visual scene. Initial studies of this type demonstrated that eye- movements can be directed by auditory input towards appropriate objects in a visual display (Cooper, 1974; Tanenhaus, Spivey-Knowlton, Eberhard & Sedivy, 1995). It is commonly believed that such language-mediated eye- movements reflect the cognitive processes that underlie language comprehension. In fact, growing evidence has shown that the eyes can move towards a corresponding critical object *before* a word referring to that object is available. Altmann and Kamide (1999), for example, demonstrated that when an auditory sentence such as, ‘*the boy will eat the cake*’ is paired with a visual display depicting a boy and a cake (among other objects), participants launch anticipatory eye- movements towards the cake during the verb ‘*eat*’.

Numerous experiments have used the visual- world paradigm to demonstrate that discourse processing is driven by predictive relationships involving syntax (e.g. Kamide, Scheepers & Altmann, 2003; Scheepers & Crocker, 2004; Arai, van Gompel,

& Scheepers, 2007), semantics (e.g. Sedivy, Tanenhaus, Chambers & Carlson, 1999; Kamide, Altmann & Haywood, 2003; Huettig & Altmann, 2005; Yee & Sedivy, 2006; Scheepers, Keller, & Lapata, in press) and real-world expectations (Altmann & Kamide, in press). However, it is not clear whether these fundamental processing strategies can also be influenced by introducing a ‘reality- altering’ context, such as a counterfactual. The visual- world paradigm is ideal to study expectations in this type of reasoning, as counterfactuals can rapidly establish a context that is contradictory to the readers’ real-world or factual knowledge.

The second issue of interest in this chapter relates to theory of mind reasoning and is based on developmental theorists’ proposal that ToM is a special case of counterfactual thinking, and as such may engage a network of consistent specialized cognitive processes (Leslie, 1987; Riggs, Peterson, Robinson & Mitchell, 1998), as discussed in Chapter 1. In fact, ability in counterfactual reasoning has emerged as a necessary, but not sufficient, component of successful performance in false belief tasks (Peterson & Bowler, 2000). However, to date no empirical data are available to investigate this suggestion or to provide any basis for predicting how propositions are processed with respect to ‘reality’, ‘counterfactual’ and ‘beliefs of others’ spaces. Therefore the second experiment discussed in this chapter is a direct attempt to examine the role played by real-world (factual) knowledge, and inferences from the beliefs of others (Experiment 8) during on-line comprehension of simple statements in a ‘visual world’. This will provide the first on-line investigations of theory of mind comprehension and will assist in determining whether related processes are revealed in counterfactual and theory of mind tasks. Similar to counterfactuals, we expect knowledge of the beliefs of others to create strong predictive biases that would interact with real-world knowledge during processing. The issue we examined, therefore, was

whether people can use their knowledge of the wider discourse to over-ride real-world knowledge to predict specific upcoming words as the current sentence is unfolding.

Theory of mind is a case of possibly valid reasoning based on the beliefs of other people that might be false according to our own knowledge of reality. Thus, tasks involving theory of mind (ToM) require an understanding of events according to the intentions, beliefs and desires of other people. In line with models of counterfactual thinking, it appears plausible to assume that ToM tasks engage a dual comprehension process, where the comprehender must create two mental spaces to represent information about both their own reality and reality according to another person's beliefs. To date, much work on ToM has centred around impairments of this ability, such as Autism spectrum disorders (Baron- Cohen, 2000; Tager- Flusberg, Boshart & Baron- Cohen, 1998; Leslie, 1994) and schizophrenia (Frith & Frith, 1988; Frith & Corcoran, 1996) and also on locating a neurological basis for ToM reasoning (Gallagher & Frith, 2003; Happe, Malhi & Checkley, 2001; Rowe, Bullock, Polkey & Morris 2001; Stone, Baron-Cohen & Knight, 1998; Stuss, Gallup & Alexander, 2001). However, this research has been limited by the use of traditional response-based measures used to investigate ToM comprehension.

Recently, some studies have attempted to use on-line measures to investigate the linguistic processing of perspectives, including common ground knowledge and theory of mind issues (Nadig & Sedivy, 2002; Hanna, Tanenhaus & Trueswell, 2003; Keysar, Barr, Balin & Brauner, 2000; Keysar, Lin & Barr, 2003; Epley, Morewedge & Keysar, 2004). Common ground refers to knowledge shared by two or more interlocutors and differs from privileged ground knowledge, which represents knowledge known to only one member of a group. These studies employed a novel research paradigm, monitoring people's eye movements while they followed a confederate's instructions to manipulate objects. Using these methods, evidence was provided that communicators have rapid

access to common ground information but can use perspective cues to accurately infer privileged information from a speaker. Keysar et al. (2003) used this technique to enhance current understanding of theory of mind, reporting a dissociation between peoples' ability to reflect on information from their own versus other peoples' knowledge and the routine ability to apply it in social situations. Their results suggest that while people have no problem assessing another person's knowledge, they do not reliably use this information to predict the intentions of that person. Further, in language production studies, speakers have been shown to adjust the syntactic structure of a sentence to facilitate comprehension in another person, suggesting that information from their own knowledge and the knowledge of others interacts to ease production and comprehension (Haywood, Pickering & Branigan, 2005). Only one of these studies examined the progressive temporal nature of perspective switches (Hanna et al., 2003), although it did not directly test whether knowledge of another person's beliefs can lead to assumptions on predicting others' behaviour. These issues will be specifically addressed in this chapter.

As part of my doctoral research I have made several attempts to investigate the on-line comprehension of theory of mind. Three studies tracked the eye- movements (using a DPI eye- tracker) of participants while they read short stories depicting situations where a character's beliefs may or may not reflect reality and a subsequent event may or may not reflect that belief. For example, an introduction established a context event (*character A left object Z in location X*). A second sentence described *character B moving object Z to location Y*, with or without the knowledge of character A (establishing a basis for false belief in some conditions). The final sentence described *where character A would later search for object Z* and could either be consistent or inconsistent with that character's predefined beliefs (location X or Y). However, these studies have remained limited by a lack of significant effects, even in conditions where

character A explicitly watches character B move object Z to a new location. It is likely that the on-line processes involved in representing the beliefs of others are very rapid and complex and as such may not be sensitive to the constraints of eye-tracking methodology. Therefore, the visual-world paradigm may be an ideal alternative and provide important information on the build up of expectations within a 'beliefs of others' framework. With this method, we hoped to determine where and at what point comprehenders are able to use knowledge of another person's beliefs to influence anticipation towards visually presented referents, regardless of their own knowledge of reality.

Investigations of theory of mind tasks have also initiated theories of a gender bias in cognition. Simon Baron-Cohen (1999) has proposed an extreme male brain theory of autism based on evidence that males and females differ in cognition. Specifically, females are superior to males on tests of social judgement and measures of empathy and cooperation, which are imperative for ToM tasks involving understanding others' intentions, beliefs and desires. Conversely, males excel in practical skills, such as mathematical reasoning, mental rotation, spatial tasks and target-directed motor skills, which do not require ToM abilities. A large body of evidence has been presented to support this proposal (Baron-Cohen & Hammer, 1997; Geary, 1998; Charman, Ruffman & Clements, 2002; Bosacki, 2000; Goldenfeld, Baron-Cohen & Wheelwright, in press). Consequently, an additional aim of the work presented in this chapter is to investigate evidence for a gender bias in ToM processing using a novel on-line task, and to examine the existence of such effects during counterfactual reasoning.

Experiment 7

Experiment 7 was an investigation of the comprehension of counterfactual conditionals such as in (1).

(1) If cats were vegetarians...

Participants heard a real-world (RW) or counterfactual-world (CW) context sentence, followed by a target sentence paired with visually presented referents. Eye movements around the visual scene were monitored and time-locked to related auditory input to examine context effects on the anticipation of forthcoming linguistic RW or CW referents. According to the mental model theory, counterfactual reasoning requires people to keep in mind both the counterfactual and the factual alternatives. This immediately leads to a processing question: can our real-world expectations be 'neutralised' within a pre-specified counterfactual world context, and if so, at what stage of processing does this context-consistent effect emerge? More specifically, can a prior counterfactual context lead to anticipatory eye-movements towards contextually relevant objects in a scene (that are anomalous given RW knowledge) or is this contextual integration process delayed so that it initially leads to a RW preference, and later becomes accommodated by the counterfactual world representation? This is the basic question of Experiment 7.

Method

Participants

Twenty-eight participants (16 female) from the University of Glasgow's undergraduate population were paid to take part in the study. All were native English speakers with normal or corrected to normal vision and had no prior exposure to the experimental

items. Note that all participants also took part in Experiment 8 and the two experiments were run in separate testing blocks in a counterbalanced order (half of participants did Experiment 7-Experiment 8 and half did Experiment 8-Experiment 7), alongside different filler items

Stimuli and Design

Twenty-four experimental pictures were paired with auditory passages in one of four conditions. Table 5.1 and Figure 5.1 provide an example of such experimental sentences and the associated visual displays. Visual displays were created using commercially available clip art collections and were presented on a 21 inch colour monitor running at 85 Hz refresh rate in 1024 x 768 pixels resolution. Each scene contained four objects: Topic (the cat in the given example), RW Referent (fish), CW Referent (carrots), and a Distracter (bus) which was neither RW nor CW congruent. To prevent any systematic viewing strategies, spatial arrangements of these four picture elements differed across items. Sound files consisted of two sentences: Sentence one created a RW or CW context (“If cats are hungry”, versus “If cats were vegetarians”) and Sentence two drew reference to a RW- or CW- relevant referent (“Families could feed their cat a bowl of *fish* versus *carrots*”), resulting in a 2x2 within subjects design. Note that RW-anomalous referents (e.g. *carrots*) are congruent in a CW context, and vice-versa. Experimental sentences varied in syntactic structure, such that the critical word (“fish” or “carrots”) did not always occur in exactly the same position across items. However, we made sure that the position of the critical word always occurred roughly mid-sentence and was identical across conditions for each item. One version of each item was assigned to one of four presentation lists, with each list containing twenty-four experimental items, six in each of the four conditions, blocked to ensure that they were evenly distributed. In addition, twenty-four unrelated filler items were added to each

list. They all consisted of correctly matched picture- sentence pairings and were interspersed randomly among the twenty-four experimental trials to create a single random order. Each subject only saw each target sentence once, in one of the four conditions. At least one filler trial intervened between any two experimental trials.

<i>RW context- CW language input</i> If cats are hungry they usually pester their owners until they get fed. Families could feed their cat a bowl of carrots and it would gobble it down happily.
<i>RW context- RW language input</i> If cats are hungry they usually pester their owners until they get fed. Families could feed their cat a bowl of fish and it would gobble it down happily.
<i>CW context- CW language input</i> If cats were vegetarians they would be cheaper for owners to look after. Families could feed their cat a bowl of carrots and it would gobble it down happily.
<i>CW context- RW language input</i> If cats were vegetarians they would be cheaper for owners to look after. Families could feed their cat a bowl of fish and it would gobble it down happily.

Table 5.1: Examples of experimental sentences (Experiment 7).



Figure 5.1: Example visual stimulus used in Experiment 7. Participants heard the target sentence (see above) whilst viewing this picture.

Sentences were recorded in a single session from a native female British English speaker (regional accent: Scottish) who was instructed to use a neutral intonation. It is standard practise in visual world studies to maintain a neutral intonation for auditory recordings so that prosody does not influence comprehension or focus the listener's attention onto specific information. The auditory files were presented as 16 KHz mono sound clips via a satellite speaker system connected to the eye-tracker PC. The temporal onsets of critical target words in Sentence 2 were hand-coded with millisecond resolution using the GoldWave sound-editing package.

Comprehension questions, relating to either the auditory or visual input, followed half of the experimental and half of the filler trials. Participants did not receive feedback for their responses to these questions. Only participants scoring at or above 90% accuracy on the comprehension questions were used in the data analysis.

Procedure

Participants were seated in front of a 21 inch colour monitor that was connected to an SMI EYELINK II head-mounted eye tracking system running at 500 Hz sampling rate. Viewing was binocular, but only the participants' dominant eye was tracked, as determined via a simple parallax test prior to the experiment. Participants were given the following instruction: "In this experiment you will hear short spoken passages and during the second sentence a picture will also be displayed. We are interested in how the pictures help you understand the spoken passages".

As illustrated in Figure 5.2, each trial began with the presentation of a single centrally-located dot and participants were asked to fixate it so that an automatic drift correction could be performed. While the participant fixated this dot, the experimenter pressed a button to initiate the trial. The dot was replaced by a fixation cross while participants heard Sentence 1 (RW or CW context, no picture presentation). They were

asked to continue looking at the fixation cross during this time. Then a 100ms blank screen was presented, followed by the target picture combined with Sentence 2. The onset of the target picture preceded the onset of the corresponding spoken sentence by 1000ms. The picture stayed on the screen for nine seconds, and the corresponding sentence typically ended 1-2 seconds before the end of the trial.

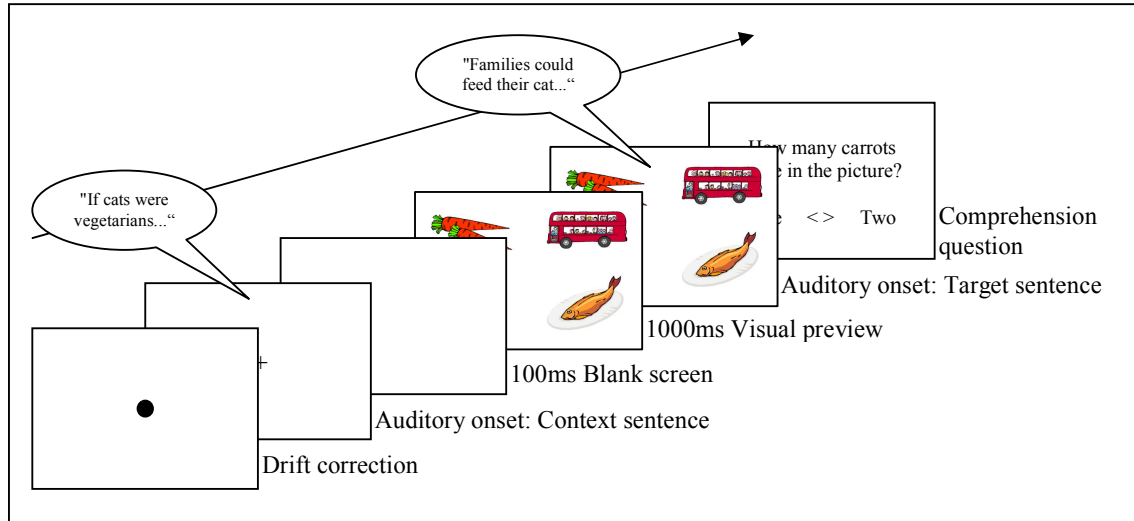


Figure 5.2: Illustration of the experimental procedure in Experiment 7.

At the beginning of the experiment, and once every ten trials thereafter, the eye-tracker was calibrated and validated against nine fixation points. This procedure took about half a minute and an entire session lasted for about half an hour.

Results and Discussion

Data Processing

Eye-movements that were initiated during Sentence 2 were processed according to the relevant picture and sound onsets for the purpose of aggregating fixation locations and durations. Temporal onsets and offsets of the fixations were recalculated relative to the corresponding picture onset by subtracting the picture onset from the relative fixation onsets. An automatic procedure was used to pool short contiguous fixations. Fixations

shorter than 80ms (fewer than 4% of the cases) were integrated with the immediately preceding or following fixation if that fixation lay within half a degree of visual angle, otherwise the fixation was excluded. The rationale for this was that such short fixations usually result from false saccade planning (see Rayner & Pollatsek, 1989) and are unlikely to reflect meaningful information processing. In case a blink occurred, its duration was added to the immediately preceding fixation (processing is unlikely to pause during a blink). The spatial coordinates of the fixations (in pixels) were then mapped onto the appropriate object regions using colour-coded bitmap templates; if a fixation was located within 20 pixels around an object's perimeter, it was coded as belonging to that object, otherwise, it was coded as background. Finally, all consecutive fixations within one object region before the eyes moved to a different region were pooled into a single *gaze*.

Arai, van Gompel and Scheepers (2007) developed an analysis measure that expresses the strength of the visual bias towards one referent relative to another referent. This method means that unlike traditional referent- probability analyses, the referent is not included as a variable in the statistical analysis, which is appropriate because proportions of looks to different referents are not linearly independent of one another. Thus, the absolute score from a log ratio reflects the magnitude, while its sign expresses the direction of the visual bias. Since we were interested in directly comparing the probabilities of gazes to the critical RW and CW referents as a function of time, fixations during the critical sentence were analysed using the following log-ratio measure:

$$\text{(Eq. 1)} \quad \log(\text{RW}/\text{CW}) = \ln(P_{(\text{RW})} / P_{(\text{CW})}),$$

where $P_{(RW)}$ refers to the probability of gazes on the RW referent (fish) and $P_{(CW)}$ to the probability of gazes on the CW referent (carrots); \ln refers to the natural logarithm. The measure is symmetrical around zero such that higher proportions of gazes on the RW referent result in a positive score (e.g. $\ln(.50/.25) = 0.693$) and higher proportions of gazes on the CW referent in a negative score (e.g. $\ln(.25/.50) = -0.693$). Equal proportions of looks between the two referents yields a score of zero ($\ln(1) = 0$).⁶

For our $\log(RW/CW)$ analyses, we chose a time period ranging from 1500 ms *before* the onset of the critical word (“fish” or “carrots”, respectively) until 2000 ms *after* the onset of the critical word. (Note that the critical word duration averaged 925 ms, and ranged from 575 ms to 1220 ms across items). The data were synchronized on a by-trial basis, relative to the onset of the critical word in the appropriate item-condition combination. Figure 5.3 plots the observed average $\log(RW/CW)$ data in each condition, for every 20 ms time-slot within the selected time period. The solid vertical line in the figure ($t = 0$) indicates the critical word onset and the arrow indicates the average verb onset (e.g. *feed*).

⁶ Since this measure only takes proportions of gazes on the RW and CW referent into account, it is important to stress that proportions of gazes on the Topic (cat) and Distracter (bus) referents revealed no significant cross-condition effects whatsoever (See Figure 5.10 in the appendix for a graphical representation of these data).

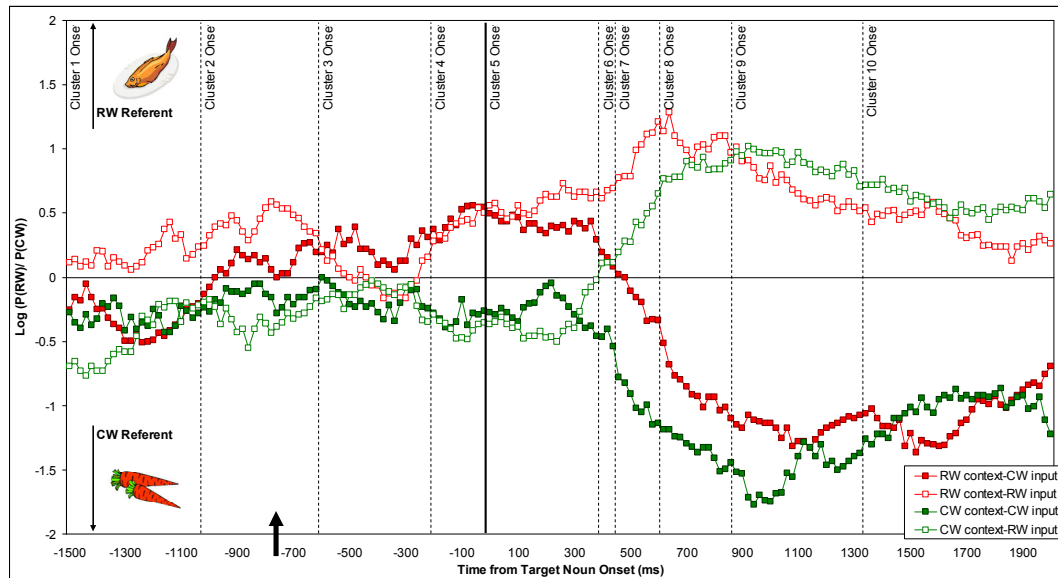


Figure 5.3: The average $\log(\text{RW}/\text{CW})$ as a function of each condition in Experiment 7. Note that the solid black vertical line in the figure ($t = 0$) indicates the critical word onset, dashed lines represent cluster boundaries for statistical analysis and the arrow indicates the average verb onset (e.g. feed).

Data Reduction using Cluster Analysis

A large amount of time series information is provided from visual- world experiments, including detail about how a given experimental manipulation influences the timing and strength of a given visual bias (e.g. whether referent A attracts more fixations than referent B). However, conducting statistical analyses at each individual time step leads to two major errors. First, the *family-wise error rate* is increased with a large number of tests (when $\alpha = 0.05$, one out of twenty tests will falsely reject the null-hypothesis). Second, the nature of a visual world task means that effects typically change gradually over time, meaning that data for any two successive time points are likely to be correlated (*autocorrelation problem*). Thus, in order to reduce the number of statistical tests without masking potentially important detail, the 20ms time-slots in Figure 5.3 were aggregated into larger analysis windows.

In the past, this has been achieved using procedures such as dividing the whole time series into k equally-sized analysis windows and performing inference statistical

analyses for each of these windows after averaging the data across the constituent time slices per window. However, this method often conceals potentially important detail as a visual bias toward one referent could be masked by aggregating data containing an equally sized bias toward a different referent. Another common method is to divide the time slices into k unequally-sized time windows, based on visual inspection of the data. Using this method, the researcher can ensure that important effects are not missed, however, it can be rather arbitrary and subjective. Moreover, it is not necessarily a very precise or replicable procedure, particularly if more than two conditions are involved. Finally, curve fitting divides each time series in terms of a parsimonious mathematical function and parameter estimates are then compared across conditions. This produces an accurate description of the data without reducing the data to be analysed, although the procedure is very time-consuming and it is not always the case that a given time series can be modelled in terms of a simple, computationally tractable function.

The present studies employed an innovative k -means cluster-analysis to define time windows of interest (Hartigan, 1975; Hartigan & Wong, 1979). This procedure identifies an optimal number of k clusters to sort different eye-movement patterns into groups such that the variation between fixations is minimal if they belong to the same cluster and the variance between clusters is maximised. Therefore, the smaller the average distance between individual observations and their relevant cluster centres, the better the fit. The experimenter must specify the number of clusters k a priori, thus providing an optimal compromise between goodness of fit and a minimum number of clusters. Indeed, a large k will always lead to better fit of data into clusters than a small k , with a perfect fit achieved when k is equal to the number of observations. The optimal k value is estimated by plotting the average distance from the cluster centre against increasing values of k and selecting the value where increasing k yields comparatively

minor improvements in fit (i.e. the average distance has levelled off)⁷. In sum, this clustering procedure improves on previous methods of data reduction that are based on arbitrary visual inspection as it offers a more replicable and precise technique to prepare the data for statistical analysis.

Therefore, using this procedure, 9 groups of contiguous time-slots were identified for the current experiment (among the 175 available), which showed maximally similar cross-condition data patterns within each cluster and maximally distinct patterns between clusters. Since one of these groups spanned across the critical word onset (-200 to 400 ms), we divided it into two clusters for analysis. This enabled accurate statistical tests of effects immediately preceding (cf. anticipation) and following the critical word onset. The resulting analysis clusters are indicated by the dashed vertical lines in Figure 5.3.

Main Analyses

In the first set of analyses, we were interested in whether prior context (RW versus CW) affected proportions of gazes on the RW referent (the *fish* in Figure 5.1) relative to the CW referent (the *carrots* in Figure 5.1) in time periods preceding and following the onset of the critical word (“fish” or “carrots”). Another question was whether and how type of context interacted with the RW/CW language input in Sentence 2.

For each participant (respectively item) and condition, a weighted average⁸ log(RW/CW) score was calculated over the 20ms time slots per analysis cluster (dashed vertical lines in Figure 5.3). The weighted averages per cluster were then subjected to 2*2 ANOVAs with context (RW vs. CW) and language input (RW vs. CW) as

⁷ See <http://www.psy.gla.ac.uk/~christop/clusterstuff/cluster.pdf> for further details and worked examples.

⁸ Due to saccades or occasional blinks, numbers of observations differed slightly across 20 ms time slots. The weighted average takes this into account, so that time slots with more observations contribute proportionally more to the average than time slots with fewer observations.

repeated-measures factors. Table 5.2 displays the statistical details of the effects, allowing generalization to participants (F_1) and items (F_2), for each time window of interest. Strength of association is reported in terms of partial eta-squared ($\rho\eta^2$).

Source of Variance	F_1				F_2			
	df	F1 value	p-value	$\rho\eta^2$	df	F2 Value	p-value	$\rho\eta^2$
<i>(-1500) - (-1020) ms</i>								
Context	1, 27	1.31	0.26	0.05	1, 23	6.28	0.02 *	0.21
Language input	1, 27	1.7	0.2	0.06	1, 23	2.66	0.12	0.1
Context x Language input	1, 27	0.91	0.35	0.03	1, 23	1.7	0.21	0.07
<i>(-1020) - (-600) ms</i>								
Context	1, 27	4.2	0.05 *	0.14	1, 23	1.46	0.24	0.06
Language input	1, 27	1.95	0.17	0.07	1, 23	0.12	0.73	0.01
Context x Language input	1, 27	1.64	0.21	0.06	1, 23	0.87	0.36	0.04
<i>(-600) - (-200) ms</i>								
Context	1, 27	6.8	0.01 **	0.19	1, 23	2.41	0.13	0.1
Language input	1, 27	0.68	0.42	0.03	1, 23	0.12	0.73	0.01
Context x Language input	1, 27	0.75	0.39	0.03	1, 23	0	0.99	0
<i>(-200) - 0 ms</i>								
Context	1, 27	21.02	<0.001 ***	0.44	1, 23	6.18	0.02 *	0.21
Language input	1, 27	0.08	0.78	0	1, 23	0.11	0.74	0.01
Context x Language input	1, 27	0.14	0.72	0.01	1, 23	0.91	0.35	0.04
<i>0 - 400 ms</i>								
Context	1, 27	5.9	0.02 *	0.18	1, 23	13.32	<0.001 ***	0.37
Language input	1, 27	0.21	0.65	0.01	1, 23	0.37	0.55	0.02
Context x Language input	1, 27	0.34	0.56	0.01	1, 23	0.67	0.42	0.03
<i>400 - 460 ms</i>								
Context	1, 27	3.47	0.07	0.11	1, 23	6.7	0.02 *	0.23
Language input	1, 27	1.51	0.23	0.05	1, 23	1.73	0.2	0.07
Context x Language input	1, 27	0.11	0.75	0.01	1, 23	0.21	0.65	0.01
<i>460 - 620 ms</i>								
Context	1, 27	7.38	0.01 **	0.22	1, 23	8.56	0.008 **	0.27
Language input	1, 27	16.55	<0.001 ***	0.38	1, 23	31.13	<0.001 ***	0.58
Context x Language input	1, 27	0.5	0.48	0.02	1, 23	0.07	0.79	0
<i>620 - 880 ms</i>								
Context	1, 27	1.77	0.19	0.06	1, 23	2.63	0.12	0.1
Language input	1, 27	45.64	<0.001 ***	0.63	1, 23	67	<0.001 ***	0.74
Context x Language input	1, 27	1.06	0.31	0.04	1, 23	0.06	0.81	0
<i>880 - 1340 ms</i>								
Context	1, 27	0.02	0.9	0	1, 23	0.03	0.86	0
Language input	1, 27	45.6	<0.001 ***	0.63	1, 23	55.43	<0.001 ***	0.71
Context x Language input	1, 27	3.93	0.06	0.13	1, 23	0.99	0.33	0.04
<i>1340 - 2000 ms</i>								
Context	1, 27	0.91	0.35	0.03	1, 23	0.59	0.45	0.03
Language input	1, 27	16.6	<0.001 ***	0.38	1, 23	40.9	<0.001 ***	0.64
Context x Language input	1, 27	3.43	0.07	0.11	1, 23	0.64	0.43	0.03

Table 5.2: Analysis of variance results for each time window of interest (Experiment 7).

The analyses revealed no fully consistent effects within the first three time windows (cluster 1 to 3). However, a reliable main effect of context emerged in cluster 4,

beginning 200ms prior to the critical word onset and ending right at the critical word onset. Fixations were more likely to be made towards contextually relevant referents. That is, a RW context lead to an anticipatory visual bias towards the RW-referent (as indicated in more positive $\log(RW/CW)$ scores in Figure 5.3) and a CW context lead to an anticipatory bias towards the CW-referent (negative $\log(RW/CW)$ scores). The main effect of language input was neither expected nor found during this time period where the critical word is not yet available. The effect of context persisted into cluster 5 (0-400ms post-critical word onset) with the same pattern of gazes as in cluster 4. Again, no main effect of language input emerged in this time window, which suggests that the critical word is still being processed until up to 400ms after critical word onset. Also note that an additional inspection of the *intercept* estimates for the ANOVAs up to and including cluster 5 (testing whether the log-ratio scores are generally different from zero) revealed no evidence for an overall visual bias [all $F_s < 2$]. This suggests that the observed anticipation effects are *solely* driven by context (additional consideration of world knowledge should have manifested itself in reliably more positive log-ratio scores).

The context effect persisted into cluster 7 (460- 620ms post-critical word onset), as more fixations were made towards contextually relevant referents. However, during this time period, a main effect of language input also emerged, indicating that the critical word has been recognised and that the relevant ‘appropriate’ referent is therefore visually favoured. In other words, participants’ attention has shifted from purely contextually constrained expectations to additional bottom-up influences from the available language input. Subsequent analyses revealed a similar main effect of language input in cluster 8 (620- 880ms) cluster 9 (880- 1340ms) and cluster 10 (1340-2000ms). This suggests that from 460ms after the onset of the critical word, participants visually favour the referent that is ‘appropriate’ to the auditory input, regardless of

inconsistencies with prior context.

Interestingly, Figure 5.3 also suggests that after perceivers had recognised the critical word (from cluster 7 onwards), the resulting bias towards RW referents peaked earlier (between cluster 7 and 8, see positive scores) than the bias towards CW referents (peaking within cluster 9, see negative scores) – independently of context (there were no context \times language input interactions for these clusters, cf. Table 5.2).

To address this issue, additional analyses were conducted with language input (RW vs. CW, averaged across the two context conditions) and cluster (7, 8, 9, 10) as repeated-measures factors. The analyses were performed on *cluster ranks*⁹ per language input condition, computed individually for each participant and item, respectively. Since four clusters were considered, the rank scores ranged from 1 to 4. For RW language input, the cluster with the most *positive* log-ratio mean was scored highest (4) and the cluster with the least positive log-ratio mean lowest (1); for CW language input, the cluster with the most *negative* log-ratio mean was scored highest (4) and the cluster with the least negative log-ratio mean lowest (1). In this way, the cluster ranks indicated (on an ordinal scale) how strongly perceivers were biased towards the ‘appropriate’ referent in each time-cluster after recognising the critical word. The mean cluster ranks are shown in Table 5.3, together with 95% confidence limits both for the rank means and for the RW-CW rank differences per cluster.

⁹ Rank scores are robust against extreme values as well as global differences in visual bias.

	Cluster rank (by subjects)	Cluster rank (by items)
<i>Cluster 7 (460-620ms)</i>		
RW input	2.07 ± 0.41	2.21 ± 0.47
CW input	1.61 ± 0.34	1.79 ± 0.48
<i>Difference</i>	+0.46 ± 0.54	+0.42 ± 0.51
<i>Cluster 8 (620-880ms)</i>		
RW input	3.04 ± 0.36	3.21 ± 0.28
CW input	2.54 ± 0.39	2.46 ± 0.37
<i>Difference</i>	+0.50 ± 0.52	+0.75 ± 0.52
<i>Cluster 9 (880-1340ms)</i>		
RW input	2.82 ± 0.37	2.58 ± 0.48
CW input	3.11 ± 0.30	2.92 ± 0.45
<i>Difference</i>	-0.29 ± 0.43	-0.33 ± 0.59
<i>Cluster 10 (1340-2000ms)</i>		
RW input	2.07 ± 0.48	2.00 ± 0.50
CW input	2.75 ± 0.48	2.83 ± 0.46
<i>Difference</i>	-0.68 ± 0.68	-0.83 ± 0.67

Table 5.3: Mean cluster ranks representing ordinal strength of bias towards ‘appropriate’ referents per cluster as a function of language input (RW vs. CW congruent). Ninety-five percent confidence limits (by participants and items) are provided for the cluster ranks themselves as well as for the RW-CW input difference per cluster.

Two-way ANOVAs established a main effect of cluster [$F_1(3, 81) = 9.72, p < 0.001; \eta^2 = 0.26; F_2(3, 69) = 4.12, p < 0.01; \eta^2 = 0.15$], due to differing average ranks across the four clusters. The main effect of language input was not, and could not be, statistically meaningful because the coding implied an average rank of exactly $(1+2+3+4)/4 = 2.5$ in each language input condition. Crucially, there was a reliable cluster \times language input interaction [$F_1(3, 81) = 3.50, p < 0.02; \eta^2 = 0.11; F_2(3, 69) = 4.98; p < 0.004; \eta^2 = 0.18$]; inspection of Table 5.3 indicates that early on (cluster 7 and 8) the ordinal bias towards ‘appropriate’ referents tended to be stronger with RW rather than CW language input; later (cluster 9 and 10) the reverse was true. Hence, the analyses confirm a reliably earlier peak location for the bias towards ‘appropriate’ referents after recognising RW- rather than CW-congruent language input. This is interesting because it represents an analogy to findings from reading showing that real-world consistent information is easier to integrate early on than real-world inconsistent

information, regardless of context (Chapter 2).

No effects of participant gender were observed at any stage of processing counterfactuals.

Preview Region

In order to examine very early anticipatory effects prior to language input, we analysed $\log(\text{RW}/\text{CW})$ distributions during the picture preview. Recall that the onset of the picture preceded the onset of the corresponding target sentence by 1000ms. Specifically, we analysed weighted average $\log(\text{RW}/\text{CW})$ scores from 500ms to 1000ms post-picture onset (prior to that time period, participants were likely to fixate the area around the previously presented fixation cross, meaning insufficient numbers of observations for log-ratio analyses). Note that this time window did not overlap with the main analysis time period in any of the experimental trials. The data were synchronized on a by-trial basis, relative to 500ms post- picture onset in the appropriate item-condition combination. Figure 5.4 shows the relevant descriptive data. There was a main effect of context [$F_1(1, 27) = 4.2, p < 0.05, \eta^2 = 0.12$; $F_2(1, 23) = 9.2, p < 0.01, \eta^2 = 0.29$], characterised by increased looks towards the CW-referent following a CW context (more negative scores). However, following a RW context, no such early anticipation towards the RW referent was evident (scores around zero). This suggests that after a CW context, participants are already forming assumptions as to an appropriate continuation even before the target sentence is available. Effects of language input were not reliable [$F_s < 1.2$]. Figure 5.4 shows the relevant descriptive data.

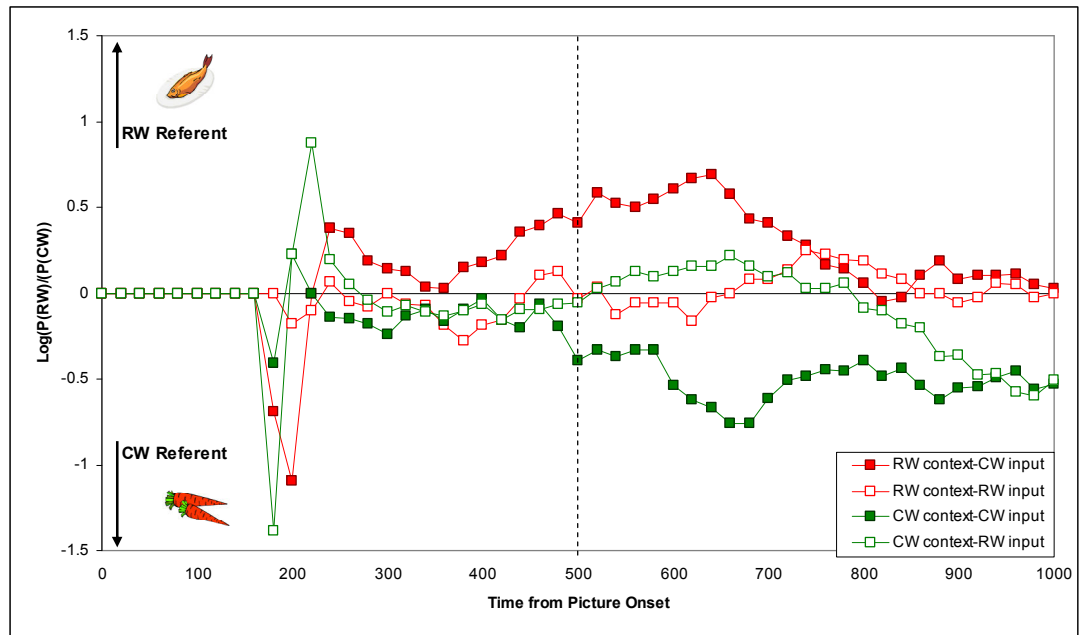


Figure 5.4: Average $\log(\text{RW}/\text{CW})$ scores per condition during picture preview in Experiment 7. Note that ($t = 0$) indicates the picture onset and the dashed line represents the time point from which data were considered for analysis (500ms to 1000ms post picture onset). Prior to this point, numbers of observations were too low to obtain reasonable scores.

To summarise, participants were able to quickly use prior context information to make anticipatory eye-movements towards a relevant referent in the visual display. The corresponding anticipation effects were initiated from at least 200ms prior to critical word onset. Our data indicated that participants expect a context-relevant continuation *regardless* of whether this continuation is consistent with world-knowledge or not. Indeed, additional analyses of the preview region revealed that following a *counterfactual* context, participants were immediately drawn towards the contextually relevant visual object. This suggests that the mental space representing counterfactual information expects a continuation of the form ‘If...then...’, whereas, a real-world context does not seem to trigger immediate expectations towards a specific consequence.

At least for the given example, a potential concern might be that the word ‘vegetarians’ in the CW context conditions could prime access to *carrots* in the visual

scene. However, the following considerations render low-level priming a rather implausible explanation of the anticipatory eye-movement patterns during the preview period. First, CW contexts not only contained words such as ‘vegetarians’ (likely to prime *carrots*) but also words such as ‘cat’ (likely to prime *fish*). Therefore, if early anticipatory effects were solely driven by low-level priming, gazes should be more or less evenly distributed between CW- and RW-referents in the CW context conditions, while showing an early RW-referent bias in the RW context conditions (RW contexts only contained words such as ‘cat’ as potential primes). In fact, the exact opposite pattern of results was found during preview. Second, if participants’ eye-movements were mostly sensitive to such low-level factors, then co-occurrence of the visual referents should also have an impact on the relevant viewing patterns, again predicting an immediate bias towards RW-referents (cats are more likely to be seen in combination with *fish* rather than *carrots*). In contrast to this, only CW contexts were found to elicit a significant bias towards contextually relevant (CW) referents during preview. This supports a model where comprehenders are using the counterfactual discourse to construct a novel ‘alternative world’, thus relying on higher-level comprehension processes rather than just low-level priming. Finally, the priming issue has been explicitly addressed in a previous study using eye-tracking in reading (Chapter 2, Experiment 3); no significant priming effects were established in that study.

Shortly after the critical word onset, the relevant ‘appropriate’ referent was visually favoured. Analyses on how this bias towards language-supported referents developed over time (cf. Table 5.3) suggested that the integration of real-world consistent information (e.g. *Families could feed their cat a bowl of fish ...*) had a temporal advantage over the integration of real-world inconsistent information (e.g. *Families could feed their cat a bowl of carrots ...*). This can be interpreted as a confirmation of findings from reading which show that real-world violations lead to

early processing disruption regardless of context (Chapter 2).

Experiment 8

As intended, in Experiment 8 I investigated whether these context- dependent anticipation effects can be replicated for predicting events according to the beliefs of others. It should if people are able to ‘neutralise’ their knowledge of reality to adopt an alternative ‘reality’, consistent with the beliefs of others, as the basis of processing. An example of a *false* belief statement is shown in (2) where reality and the beliefs of another person are in direct conflict with one another.

(2) John washed the dishes after his breakfast and left his watch on the table. While John was distracted, Victoria moved the watch from the table to the bed. Later, John wanted to find his watch so he looked on the bed and yawned.

In this example, context suggests that John is unlikely to know that the watch has moved from the table to the bed (he was *distracted* while that happened), so his reported actions (*he looked on the bed*) are inconsistent with his beliefs. In Experiment 8 such processing of the beliefs of others (Theory of Mind, ToM) was investigated.

Participants heard a ‘reality’ or ‘belief’ context, followed by a target sentence paired with visually presented referents. Eye movements around the visual scene were monitored and time-locked to related auditory input to examine context effects on anticipation towards forthcoming linguistic reality or belief referents. Following from the mental model theory, it seems plausible to presume that ToM tasks engage a dual-stage comprehension process, similar to what has been proposed for counterfactuals, where mental spaces are created to represent information about both our own reality and ‘reality’ according to another person’s beliefs. The aim was to allow a fuller

investigation into the representation and processing of information within a specified context. Additionally, we hoped to explore whether the beliefs of others are processed in the same way as counterfactuals, and specifically whether there is a different pattern or time-course of prediction for counterfactual and theory of mind reasoning.

Furthermore, Experiment 8 examined evidence for a gender bias in ToM processing using a novel on-line task. Following the large body of research showing that females are superior to men on ToM tasks, it was predicted that some processing advantage for females would be observed on this task.

Method

Participants

The same twenty-eight participants (16 female) as in Experiment 7 took part in this study. Note that the two experiments were run in separate testing blocks in a counterbalanced order, alongside different filler items.

Stimuli and Design

Twenty-four sets of three experimental pictures were paired with an auditory passage in one of four conditions. Table 5.4 and Figure 5.5 provide an example of such experimental sentences and the associated visual scenes.

Reality context- Belief language input

John washed the dishes after his breakfast and left his watch on the table.
 Later, John noticed Victoria move the watch from the table to the bed.
 Later, John wanted to find his watch so he looked on the table and yawned.

Reality context- Reality language input

John washed the dishes after his breakfast and left his watch on the table.
 Later, John noticed Victoria move the watch from the table to the bed.
 Later, John wanted to find his watch so he looked on the bed and yawned.

Belief context- Belief language input

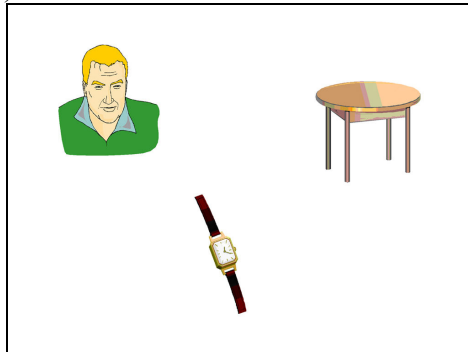
John washed the dishes after his breakfast and left his watch on the table.
 While John was distracted, Victoria moved the watch from the table to the bed.
 Later, John wanted to find his watch so he looked on the table and yawned.

Belief context- Reality language input

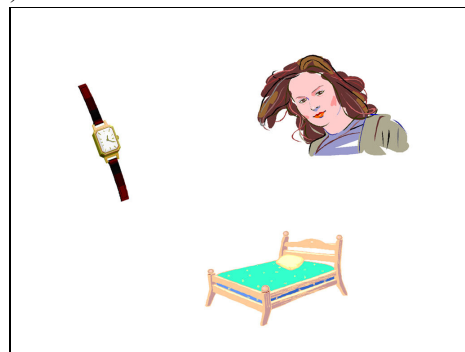
John washed the dishes after his breakfast and left his watch on the table.
 While John was distracted, Victoria moved the watch from the table to the bed.
 Later, John wanted to find his watch so he looked on the bed and yawned.

Table 5.3: Examples of experimental sentences (Experiment 8).

(A)



(B)



(C)

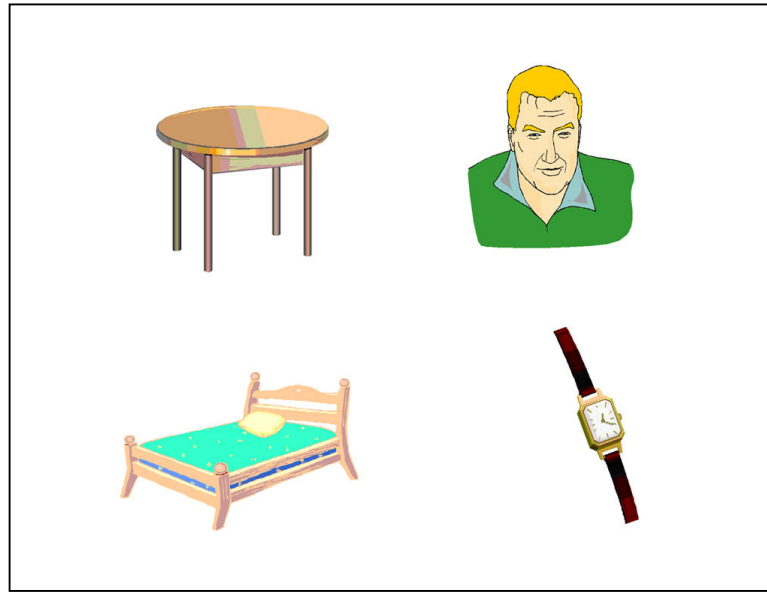


Figure 5.5: Example experimental visual scenes used in Experiment 8. Participants heard sentence 1 with scene (A), context sentence 2 with scene (B). Eye-movements were monitored during the target sentence 3 whilst viewing scene (C). (A) Sentence 1, (B) Context sentence 2, and (C) Target sentence 3.

The design of the Experiment was similar to Experiment 7. Sound files consisted of three sentences: Sentence one introduced a character and described that character putting a target object in a given location. Sentence two then described a second character moving the target object to a new location. This action was either ‘explicitly observed’ or ‘missed’ by the first character, creating a ‘reality’ or a ‘belief’ context (“Later, John noticed Victoria move the”, versus “While John was distracted, Victoria moved the...”). A final third sentence drew reference to a *reality*- or *belief*-relevant location (“Later, John wanted his watch so he looked on the *bed/ table*”), resulting in a 2x2 within subjects design. Note that reality-violating referents are congruent in a belief context, and vice-versa. Three different visual scenes were composed to accompany each auditory sentence. The first scene contained an image of the target object, Character 1 and Location 1. The second scene displayed the target object, Character 2 and Location 2. Finally, the target scene contained four objects: target object, Character 1, reality Referent and belief Referent. One version of each item was assigned to one of

four presentation lists, with each list containing twenty-four experimental items, six in each of the four conditions, blocked to ensure that they were evenly distributed. In addition, twenty-four filler items were added to each list. They all consisted of correctly matched picture- sentence pairings and were interspersed randomly among the twenty-four experimental trials to create a single random order. Each subject only saw each target sentence once, in one of the four conditions. At least one filler trial intervened between any two experimental trials.

Sentences were recorded by the same female native British English speaker as in Experiment 7 and were presented to participants via the same apparatus. As in Experiment 7, comprehension questions followed half of the experimental and half of the filler trials. The questions could either refer to aspects of the previously presented pictures or to the content of the spoken sentences. Participants did not receive feedback for their responses. All participants used in the data analysis scored at or above 90% accuracy on the comprehension questions.

Procedure

The eye tracking procedures were similar to those in Experiment 7. Participants were given the following instruction: “In this experiment you will hear short spoken passages and during each sentence, a picture will be displayed. We are interested in how the pictures help you understand the spoken passages”.

As illustrated in Figure 5.6, each trial began with the presentation of a single centrally- located dot and participants were asked to fixate it so that automatic drift corrections could be performed. Following successful fixation, the experimenter pressed a button to initiate the trial. The dot was then replaced by Scene 1 while participants heard Sentence 1. Then a pause/ blank screen for 100ms. Next, Scene two was presented with Sentence 2 (reality or belief context). Following a short pause/ break for

100ms, the target Scene 3 appeared with Sentence 3. The onset of each picture preceded the onset of the corresponding spoken sentence by 1000ms and participants' eye-movements were only recorded during the final (target) picture/sentence presentation. Each trial was automatically ended after 9 seconds; auditory sentences typically ended around 1-2 seconds before the end of the corresponding picture presentation.

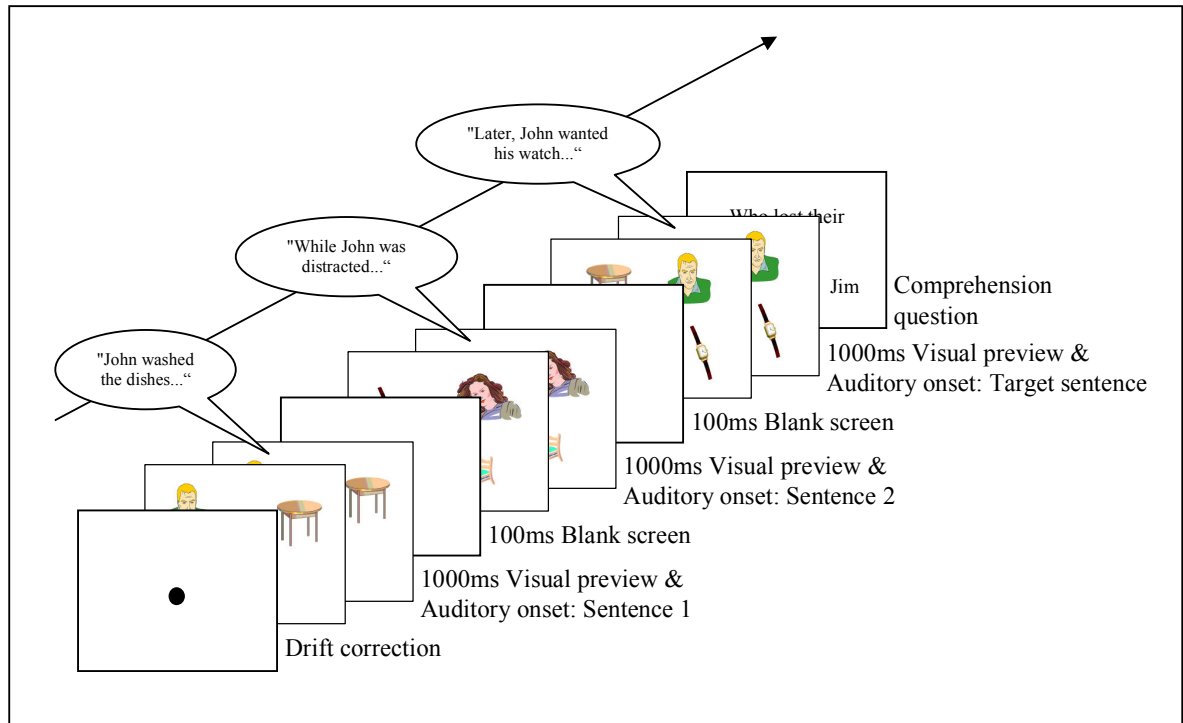


Figure 5.6: Illustration of the experimental procedure in Experiment 8.

As in Experiment 7, the eye-tracker was calibrated and validated at the beginning of each session and once every ten trials thereafter.

Results and Discussion

Data Processing

Analysis procedures were largely the same as in Experiment 7. Eye-tracking data collected during the final (target) picture/sentence presentation were summarised in terms of the following log-ratio measure:

$$(Eq. 2) \quad \log(R/B) = \ln(P_{(R)} / P_{(B)}),$$

where $P_{(R)}$ refers to the probability of gazes on the ‘Reality-referent’ (the *bed* in our example) and $P_{(B)}$ to the probability of gazes on the ‘Belief-referent’ (*table*); positive scores on this measure indicate a visual preference for the Reality-referent and negative scores a visual preference for the Belief-referent.¹⁰

Since the critical word (“bed” or “table”, respectively) was located closer to the end of the sentence than the critical word in Experiment 7, a slightly shorter time period was analysed, this time spanning from 1500ms before critical word onset until 1500ms after the critical word onset. The reason for this shorter time period of analysis, compared to Experiment 7, was that the critical word appeared closer to the sentence conclusion in Experiment 8 than in Experiment 7 (two versus seven words prior to sentence conclusion respectively). (Note that the critical word duration averaged 620 ms, and ranged from 390 ms to 1220 ms). Figure 5.7 shows the corresponding average $\log(R/B)$ data per condition, sampled in 20ms resolution. As in Experiment 7, the solid black vertical line in the figure ($t = 0$) indicates the critical word onset, the dashed lines represent cluster boundaries and the arrow indicates the average verb onset (*looked*). Again, a *k*-means cluster analysis was employed to identify larger time windows for analysis. The procedure identified 12 clusters of contiguous 20ms time slots with similar data patterns across conditions, as shown in Figure 5.7 below. Note that cluster 4 and 5 already happened to border right at the critical word onset. The following inferential analyses were based on weighted average $\log(R/B)$ scores per cluster.

¹⁰ Again, we found no differential effects of experimental condition on proportions of looks to the remaining referents in the pictures (e.g. *John* or the *watch*), justifying our approach of focusing on Reality- and Belief-referents only. (See Figure 5.11 in the appendix for a graphical representation of this data).

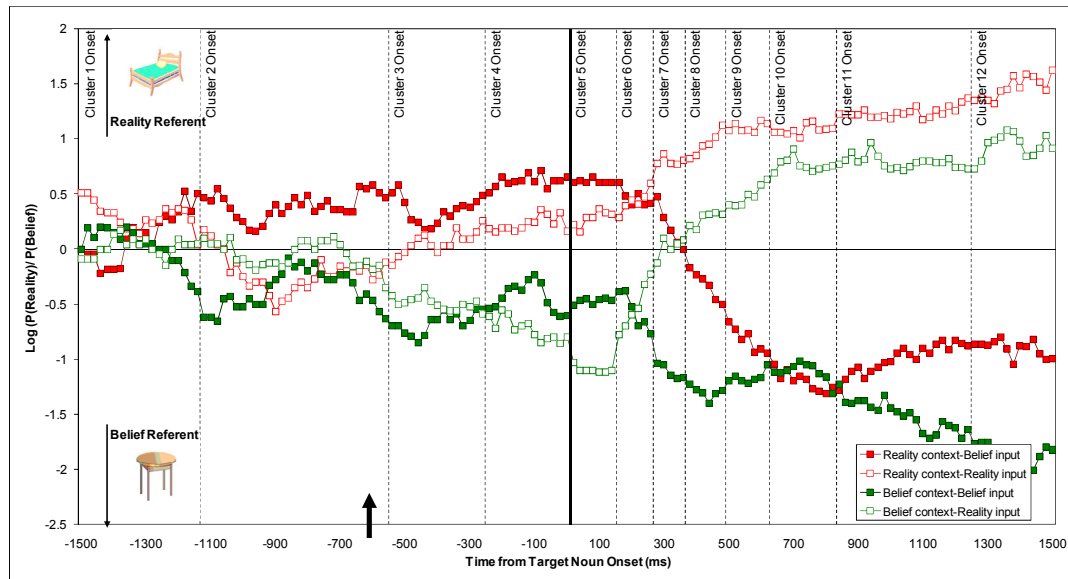


Figure 5.7: The average $\log(R/B)$ as a function of each condition in Experiment 8. Note that the solid black vertical line in the figure ($t = 0$) indicates the critical word onset, dashed lines represent cluster boundaries for statistical analysis and the arrow indicates the average verb onset (e.g. looked).

Main Analyses

For each analysis cluster, we performed a 2×2 ANOVA comprising context (reality versus belief) and language input (reality versus belief) as repeated-measures factors.

Table 5.5 displays the statistical details of the effects, allowing generalization to participants (F_1) and items (F_2), for each time window of interest.

Source of Variance	F ₁				F ₂			
	df	F1 value	p-value	$\rho\eta^2$	df	F2 Value	p-value	$\rho\eta^2$
<i>(-1500) - (-1140) ms</i>								
Context	1, 27	1.7	0.2	0.06	1, 23	0.02	0.9	0.9
Language input	1, 27	0.005	0.94	0	1, 23	0.33	0.57	0.57
Context x Language input	1, 27	0.13	0.72	0.01	1, 23	1.02	0.32	0.32
<i>(-1140) - (-560) ms</i>								
Context	1, 27	1.82	0.19	0.06	1, 23	2.04	0.17	0.17
Language input	1, 27	1.26	0.27	0.05	1, 23	0.14	0.71	0.7
Context x Language input	1, 27	3.8	0.06	0.12	1, 23	4.23	0.16	0.05
<i>(-560) - (-260) ms</i>								
Context	1, 27	11.67	0.002***	0.3	1, 23	17.36	<0.001***	0.43
Language input	1, 27	0.36	0.56	0.01	1, 23	0.35	0.56	0.02
Context x Language input	1, 27	0.23	0.63	0.01	1, 23	1.82	0.19	0.07
<i>(-260) - 0 ms</i>								
Context	1, 27	10.53	0.003***	0.28	1, 23	19.49	<0.001***	0.46
Language input	1, 27	0.52	0.48	0.02	1, 23	2.93	0.1	0.11
Context x Language input	1, 27	0.002	0.96	0	1, 23	2.07	0.16	0.08
<i>0 - 160 ms</i>								
Context	1, 27	15.87	<0.001***	0.37	1, 23	26.95	<0.001***	0.54
Language input	1, 27	1.7	0.2	0.06	1, 23	3.8	0.06	0.14
Context x Language input	1, 27	0.24	0.63	0.01	1, 23	0.04	0.84	0
<i>160 - 280 ms</i>								
Context	1, 27	14.24	0.001***	0.35	1, 23	16.89	<0.001***	0.42
Language input	1, 27	0.14	0.71	0.01	1, 23	0.07	0.79	0
Context x Language input	1, 27	0.03	0.86	0	1, 23	0.01	0.92	0
<i>280 - 380 ms</i>								
Context	1, 27	18.11	<0.001***	0.4	1, 23	22.51	<0.001***	0.5
Language input	1, 27	13.77	0.001***	0.34	1, 23	16.42	<0.001***	0.42
Context x Language input	1, 27	1.03	0.32	0.04	1, 23	0.9	0.35	0.04
<i>380 - 500 ms</i>								
Context	1, 27	9.49	0.005***	0.26	1, 23	17.66	<0.001***	0.43
Language input	1, 27	38.34	<0.001***	0.59	1, 23	43.92	<0.001***	0.66
Context x Language input	1, 27	0.37	0.55	0.01	1, 23	0.01	0.91	0
<i>500 - 640 ms</i>								
Context	1, 27	2.61	0.12	0.09	1, 23	6.16	0.02*	0.21
Language input	1, 27	54.45	<0.001***	0.67	1, 23	51.07	<0.001***	0.69
Context x Language input	1, 27	0.2	0.66	0.01	1, 23	0.89	0.35	0.04
<i>640 - 860 ms</i>								
Context	1, 27	1.18	0.29	0.04	1, 23	1.11	0.3	0.05
Language input	1, 27	72.31	<0.001***	0.72	1, 23	73.63	<0.001***	0.76
Context x Language input	1, 27	1.21	0.28	0.04	1, 23	1.95	0.18	0.08
<i>860 - 1260 ms</i>								
Context	1, 27	7.04	0.01**	0.21	1, 23	5.97	0.02*	0.21
Language input	1, 27	40.28	<0.001***	0.61	1, 23	52.06	<0.001***	0.69
Context x Language input	1, 27	0.04	0.84	0	1, 23	0.23	0.63	0.01
<i>1260 - 1500 ms</i>								
Context	1, 27	8.38	0.007**	0.24	1, 23	8.12	0.008**	0.27
Language input	1, 27	41.76	<0.001***	0.61	1, 23	49.99	<0.001***	0.69
Context x Language input	1, 27	2.13	0.16	0.07	1, 23	0.74	0.4	0.03

Table 5.5: Analysis of variance results for each time window of interest (Experiment 8).

The analyses revealed no significant effects before cluster 3 (560 to 260ms prior to critical word onset) where a reliable main effect of context emerged: comparable to Experiment 7, anticipatory fixations were more likely to be made towards contextually relevant referents. Thus, from 560ms prior to critical word onset, participants were already able to predict events according to the previously induced reality or the beliefs of others. Furthermore, since no interaction emerged, it is assumed that people's knowledge about reality did not interfere with their expectations according to others' beliefs. This effect lasted into cluster 4, from 260ms before to 0ms (critical word onset), cluster 5 (20- 160ms) and cluster 6 (160- 280ms) with no additional effects of, or interactions with, language input. Also, there was no indication of a general bias in the log-ratio scores [$F_s < 1$ for the ANOVA *intercepts* not shown in the table for the sake of space]. Thus, up until cluster 6, it appears that contextually inconsistent critical words are not being recognised, and that context is the sole determinant of participants' anticipatory eye-movement behaviour.

However, from cluster 7 (280- 380ms) a main effect of language input emerged, revealing that from 280ms after critical word onset, participants visually favoured the relevant 'appropriate' referent. This effect appeared alongside a reliable context main effect. Cluster 8 (380- 500ms) showed a similar pattern of results, with reliable effects of language input and context. Clusters 9 (500- 640ms) and 10 (640- 860ms) maintain the significant effect of language input. However, effects of context have largely faded away in these time windows. Clusters 11 (860- 1260ms) and 12 (1260- 1500ms) also showed a reliable main effect of language input, and interestingly, reliable effects of context re-emerge in these time windows. Thus, it appears that prior context regarding reality or the beliefs of others has a very early (anticipatory) and enduring influence on language comprehension in this kind of paradigm.

Finally, note that there was no clear suggestion of language-input dependent differences in how visual biases towards ‘appropriate’ referents developed over time, contrasting with Experiment 7.

Preview Region

As for Experiment 7, anticipation effects were examined in the preview period prior to linguistic input. Specifically, we analysed the time window from 500ms to 1000ms post-picture onset, as before. Once again, this time window did not overlap with the main analysis time window for any experimental items. Statistical analyses were carried out on the probabilities of gazes to the critical Reality and Belief referents as a function of time, using the same log-ratio measure as explained previously (Eq. 2). The data were synchronized on a by-trial basis, relative to 500ms post- picture onset in the appropriate item-condition combination. Inferential analyses revealed no significant main effect of context or language input, and there was also no reliable context by language input interaction [all $F_s < 2.8$]. Figure 5.8 shows the corresponding observed $\log(R/B)$ distributions in the considered time period.



Figure 5.8: The average log(R/B) as a function of each condition in Experiment 8. Note that (t = 0) indicates the picture onset and the dashed line represents the time point at which statistical analysis was initiated (500ms to 1000ms post picture onset).

Gender

Following theories suggesting a gender bias in cognition, the log(R/B) data were further examined to investigate effects of gender on language comprehension in this task (cf. Figure 5.7). For this purpose, we employed 3-way ANOVAs with context and language input as repeated measures factors and gender as an additional between-subjects factor. These analyses were performed using the time windows defined in the main analysis to maintain consistency and to enable direct comparisons of gender effects, should they emerge. The analyses revealed a significant gender x context interaction in cluster 1 (1500- 1140ms prior to critical word onset) [$F_1(1, 27) = 8.9, p = 0.006, \eta^2 = 0.26$] and cluster 2 (1140- 560ms prior to critical word onset) [$F_1(1, 27) = 11.3, p = 0.002, \eta^2 = 0.3$]. Closer inspection of this interaction revealed that while females showed large context-biases in their anticipatory eye- movements towards contextually-relevant

referents in the time windows from -1500ms to -560ms prior to critical word onset (Figure 5.8), males did not show this effect in cluster 1, and instead showed a reversed context effect in the -1140ms to -560ms time window (Figure 5.9)¹¹. Full details of statistical analyses are presented for females and males in Tables 5.6 and 5.7 respectively. We suggest that this reversed context effect reflects a general male difficulty in creating appropriate predictions in this task. It is also important to note that both males and females show a main effect of language input from the same time window. Specifically, males and females fixate on the correct referent (according to language input) from the 280ms to 380ms time window onwards. Thus, it does not appear that gender influences the representation of currently available input-information. No effects of gender were observed in the preview window [all $F_s < 1.3$].

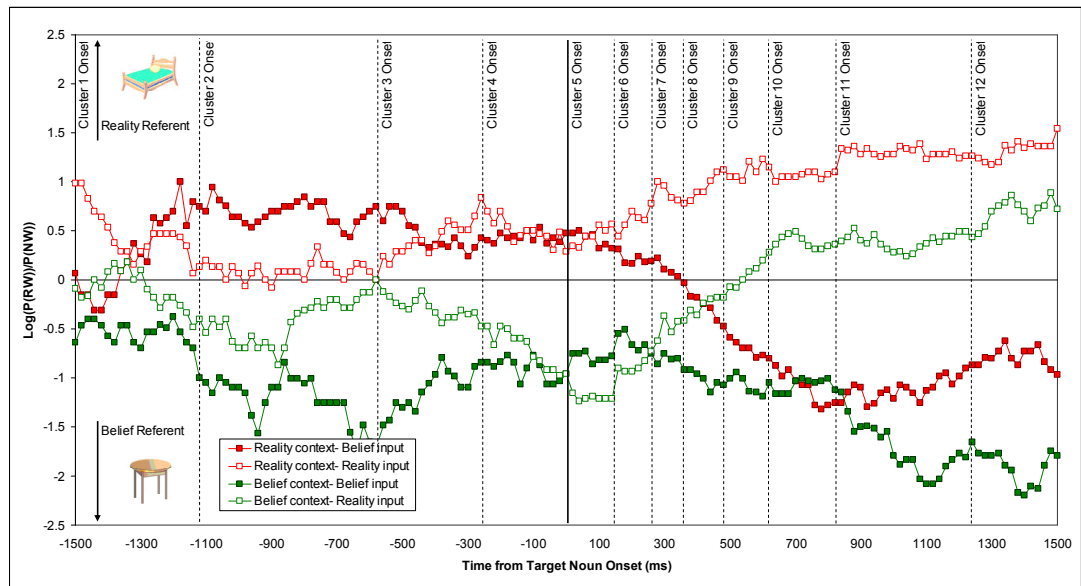


Figure 5.8: The average $\log(R/B)$ for females, as a function of each condition in Experiment 8. Note that the solid black vertical line in the figure ($t = 0$) indicates the critical word onset and dashed lines represent cluster boundaries for statistical analysis.

¹¹ Statistical analysis of male participants' data also revealed an incorrect prediction to language input in the -260ms to 0ms time window and to a lesser extent in the 0ms to 160ms time window. However, since language input has not yet been revealed to participants (and in the later time window, insufficient time has passed to execute an appropriate saccadic eye- movement) these effects might possibly reflect Type I errors.

Source of Variance	F ₁			F ₂				
	df	F1 value	p-value	$\rho\eta^2$	df	F2 Value	p-value	$\rho\eta^2$
<i>(-1500) - (-1140) ms</i>								
Context	1, 15	5.53	0.03*	0.27	1, 23	2.21	0.15	0.09
Language input	1, 15	0.58	0.46	0.04	1, 23	0.82	0.37	0.03
Context x Language input	1, 15	0.13	0.72	0.01	1, 23	0.04	0.84	0
<i>(-1140) - (-560) ms</i>								
Context	1, 15	7.47	0.01**	0.33	1, 23	19.4	<0.001***	0.46
Language input	1, 15	0.01	0.99	0	1, 23	0.1	0.75	0.01
Context x Language input	1, 15	5.51	0.03*	0.27	1, 23	5.21	0.03*	0.18
<i>(-560) - (-260) ms</i>								
Context	1, 15	8.02	0.01**	0.35	1, 23	16.41	<0.001***	0.42
Language input	1, 15	0.81	0.38	0.05	1, 23	1.16	0.29	0.05
Context x Language input	1, 15	0.97	0.34	0.06	1, 23	0.35	0.56	0.01
<i>(-260) - 0 ms</i>								
Context	1, 15	8.64	0.01**	0.37	1, 23	21.35	<0.001***	0.48
Language input	1, 15	0.09	0.77	0.01	1, 23	0.01	0.97	0
Context x Language input	1, 15	0.01	0.94	0	1, 23	0.26	0.61	0.01
<i>0 - 160 ms</i>								
Context	1, 15	9.84	0.007**	0.4	1, 23	23.94	<0.001***	0.51
Language input	1, 15	0.16	0.69	0.01	1, 23	0.02	0.88	0
Context x Language input	1, 15	0.65	0.43	0.04	1, 23	0.55	0.46	0.02
<i>160 - 280 ms</i>								
Context	1, 15	6.92	0.02*	0.32	1, 23	22.07	<0.001***	0.49
Language input	1, 15	0.18	0.68	0.01	1, 23	1.09	0.31	0.04
Context x Language input	1, 15	1.04	0.32	0.06	1, 23	1.25	0.28	0.05
<i>280 - 380 ms</i>								
Context	1, 15	10.44	0.006**	0.41	1, 23	12.9	0.002**	0.36
Language input	1, 15	4.69	0.05*	0.24	1, 23	4.3	0.05*	0.16
Context x Language input	1, 15	0.45	0.51	0.03	1, 23	0.57	0.46	0.02
<i>380 - 500 ms</i>								
Context	1, 15	8.97	0.009**	0.37	1, 23	10.08	0.004**	0.31
Language input	1, 15	15.65	0.001**	0.51	1, 23	19.23	<0.001***	0.45
Context x Language input	1, 15	0.79	0.39	0.05	1, 23	1.06	0.31	0.04
<i>500 - 640 ms</i>								
Context	1, 15	4.54	0.05*	0.23	1, 23	7.23	0.01**	0.24
Language input	1, 15	36.27	<0.001***	0.71	1, 23	31.94	<0.001***	0.58
Context x Language input	1, 15	1.87	0.19	0.11	1, 23	0.75	0.4	0.03
<i>640 - 860 ms</i>								
Context	1, 15	1.28	0.28	0.08	1, 23	2.63	0.12	0.1
Language input	1, 15	36.81	<0.001***	0.71	1, 23	45.27	<0.001***	0.66
Context x Language input	1, 15	1.5	0.24	0.09	1, 23	1.44	0.24	0.06
<i>860 - 1260 ms</i>								
Context	1, 15	9.02	0.009**	0.38	1, 23	11.52	0.002**	0.33
Language input	1, 15	43.77	<0.001***	0.74	1, 23	61.65	<0.001***	0.73
Context x Language input	1, 15	0.95	0.34	0.06	1, 23	0.27	0.61	0.01
<i>1260 - 1500 ms</i>								
Context	1, 15	12.17	0.003**	0.45	1, 23	10.35	0.004**	0.31
Language input	1, 15	50.76	<0.001***	0.77	1, 23	55.83	<0.001***	0.71
Context x Language input	1, 15	0.22	0.65	0.01	1, 23	0.05	0.83	0

Table 5.6: Analysis of variance results for each time window of interest for females (Experiment 8).

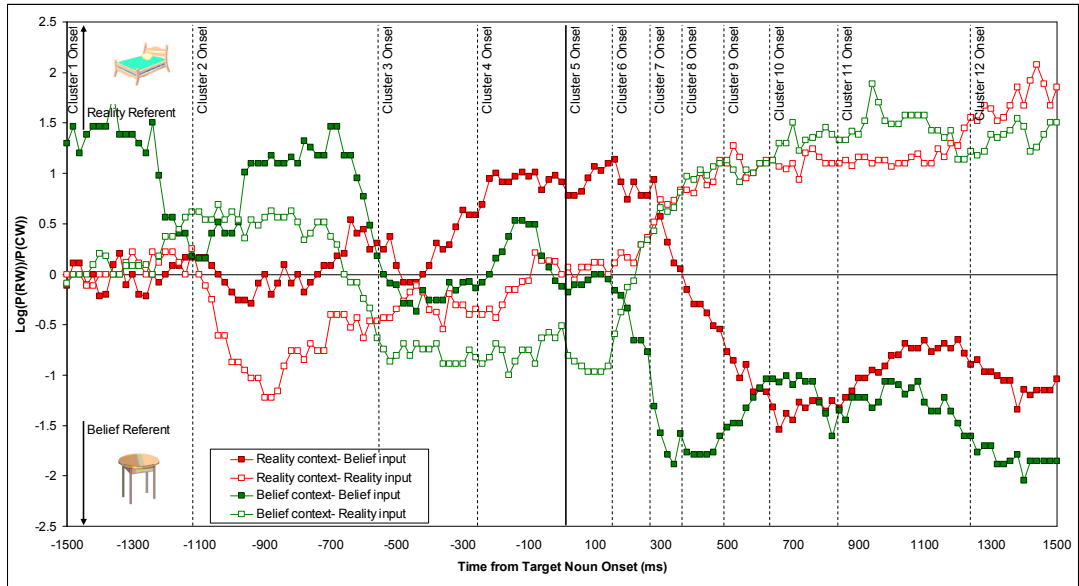


Figure 5.9: The average $\log(R/B)$ for males, as a function of each condition in Experiment 8. Note that the solid black vertical line in the figure ($t = 0$) indicates the critical word onset and dashed lines represent cluster boundaries for statistical analysis.

Source of Variance	F ₁				F ₂			
	df	F1 value	p-value	p η^2	df	F2 Value	p-value	p η^2
<i>(-1500) - (-1140) ms</i>								
Context	1, 13	1.89	0.2	0.15	1, 23	1.16	0.29	0.05
Language input	1, 13	0.41	0.54	0.04	1, 23	0.34	0.56	0.01
Context x Language input	1, 13	0.81	0.39	0.07	1, 23	0.87	0.36	0.04
<i>(-1140) - (-560) ms</i>								
Context	1, 13	5.04	0.05*	0.31	1, 23	6.51	0.02*	0.22
Language input	1, 13	2.48	0.14	0.18	1, 23	3.74	0.07	0.14
Context x Language input	1, 13	0.3	0.6	0.03	1, 23	0.14	0.71	0.01
<i>(-560) - (-260) ms</i>								
Context	1, 13	2.04	0.18	0.16	1, 23	1.89	0.18	0.08
Language input	1, 13	4.02	0.07	0.27	1, 23	2.5	0.13	0.1
Context x Language input	1, 13	0.06	0.81	0.01	1, 23	0.02	0.9	0
<i>(-260) - 0 ms</i>								
Context	1, 13	2.83	0.12	0.21	1, 23	0.86	0.04*	0.17
Language input	1, 13	11.3	0.006**	0.51	1, 23	0.61	0.02*	0.22
Context x Language input	1, 13	0.01	0.92	0	1, 23	0.01	0.93	0
<i>0 - 160 ms</i>								
Context	1, 13	15.32	0.002**	0.58	1, 23	9.19	0.006**	0.29
Language input	1, 13	4.67	0.05*	0.3	1, 23	4.48	0.04*	0.16
Context x Language input	1, 13	0.11	0.75	0.01	1, 23	0.05	0.82	0.01
<i>160 - 280 ms</i>								
Context	1, 13	16.21	0.002**	0.6	1, 23	12.54	0.002**	0.35
Language input	1, 13	0.01	0.93	0	1, 23	1.06	0.31	0.04
Context x Language input	1, 13	1.49	0.25	0.12	1, 23	5.07	0.03*	0.18
<i>280 - 380 ms</i>								
Context	1, 13	18.18	0.001***	0.62	1, 23	9.79	0.005**	0.3
Language input	1, 13	8.01	0.02*	0.42	1, 23	44.4	<0.001***	0.66
Context x Language input	1, 13	4.15	0.07	0.27	1, 23	7.4	0.01**	0.24
<i>380 - 500 ms</i>								
Context	1, 13	2.9	0.12	0.21	1, 23	2.72	0.11	0.11
Language input	1, 13	23.34	0.001***	0.68	1, 23	65.31	<0.001***	0.74
Context x Language input	1, 13	2.58	0.14	0.19	1, 23	2.94	0.1	0.11
<i>500 - 640 ms</i>								
Context	1, 13	0.1	0.75	0.01	1, 23	0.03	0.87	0
Language input	1, 13	23.06	0.001***	0.68	1, 23	55.83	<0.001***	0.71
Context x Language input	1, 13	0.27	0.61	0.02	1, 23	0.04	0.84	0
<i>640 - 860 ms</i>								
Context	1, 13	0.19	0.67	0.02	1, 23	0.15	0.7	0.01
Language input	1, 13	23.41	0.001***	0.68	1, 23	52.74	<0.001***	0.7
Context x Language input	1, 13	0.01	0.91	0	1, 23	0.01	0.98	0
<i>860 - 1260 ms</i>								
Context	1, 13	0.91	0.36	0.08	1, 23	0.35	0.56	0.01
Language input	1, 13	10.69	0.007**	0.49	1, 23	37.25	<0.001***	0.62
Context x Language input	1, 13	3.21	0.1	0.23	1, 23	1.04	0.32	0.04
<i>1260 - 1500 ms</i>								
Context	1, 13	4.31	0.06	0.28	1, 23	2.1	0.16	0.08
Language input	1, 13	14.59	0.003**	0.57	1, 23	67.04	<0.001***	0.74
Context x Language input	1, 13	1.64	0.23	0.13	1, 23	0.57	0.46	0.02

Table 5.7: Analysis of variance results for each time window of interest for males (Experiment 8).

Visual inspection of Figure 5.8 suggests that females were using context (reality or belief) to anticipate the actions of another person from around 1200ms prior to critical word onset. Thorough inspection of the experimental items revealed that this time point reflects the auditory offset of the target object, e.g. 'watch'. Thus, at this point, females demonstrate an ability to predict the characters' actions based on their intentions, beliefs and desires. In contrast, males do not seem to display significant anticipation of context-appropriate referents in the scene.

In sum, Experiment 8 showed that participants were, on average, able to use information from a prior context to update their knowledge about reality and the beliefs of others to anticipate a relevant referent from 560ms prior to the critical word onset. This supports findings from Experiment 7 that prior context is rapidly processed so that participants *expect* a context-relevant continuation. As with counterfactuals, the relevant 'appropriate' referent was visually favoured shortly after the critical (reality or belief-referent) word became available in the sentence. However, contrasting with Experiment 7, there was no clear suggestion of a difference in the dynamics of integrating reality or belief-consistent language input. This makes sense because the establishment of a reality or belief-context in Experiment 8 did not draw upon *pre-stored* world knowledge information, unlike the stereotypical/counterfactual relationships investigated in Experiment 7.

Another contrast to Experiment 7 was that no effects of context were observed in the preview region. This suggests that while people can mentally represent both reality and an alternative 'reality' based on another person's beliefs, they do not build up expectations of forthcoming events according to this knowledge until necessary. In addition, an early processing advantage was revealed for females over males in predicting other peoples' actions based on knowledge about their beliefs. These results together provide some novel evidence of different processes underlying the

comprehension of counterfactuals and the beliefs of others. These issues will be discussed in full below.

Discussion

The primary issue investigated in the present chapter has been whether and to what extent the constraints of real-world knowledge and prior context influence eye-movements directed towards objects in the visual world, demonstrating predictive or anticipatory processes. Previous experiments have shown that discourse processing is driven by predictive relationships involving syntax, semantics and real-world expectations. Chapter 2 initiated the study of counterfactuals using an eye-tracking reading paradigm and showed early difficulties following violations of real-world knowledge and a delayed influence of context, where events were accommodated into the counterfactual framework. However, this chapter explored the construction of *expectations* during language comprehension. Specifically, whether people can use their knowledge of the wider discourse (using either a counterfactual or beliefs of others framework) to override real-world knowledge to predict specific upcoming words as the current sentence is unfolding.

In Experiment 7 we used the visual-world paradigm to investigate whether the typical (anticipatory) visual bias towards real-world consistent objects in this task (cf. *little girls are more likely ride carrouseles than motorbikes* in Kamide et al., 2003 versus *cats are more likely to eat fish than carrots* in the present study) could be eliminated by introducing an appropriate counterfactual context of the form, “If...then...”. The results showed that anticipatory eye-movements were made towards contextually relevant referents from at least 200ms prior to the critical word onset. The fact that participants direct their attention towards real-world relevant objects in a concurrent visual scene following a real-world context is not surprising given previous research suggesting such

anticipation. However, the fact that this real-world bias can be eliminated by a counterfactual context in preference of a counterfactual-world relevant referent provides novel findings, with interesting theoretical implications, which will be discussed shortly.

Experiment 7 also demonstrated evidence of very early prediction based on the discourse context, with increased looks towards the CW referent in the preview region following a CW context. However, following a RW context, no such early anticipation towards the RW referent was evident. This suggests that during the CW context sentence, participants are already forming assumptions as to an appropriate continuation. But why is this not the case following a RW context? It is likely that participants were more susceptible to creating expectations according to the CW context because reality in the RW context was implied, whereas the CW context explicitly stated a hypothetical counterfactual scenario. This would account for the significant anticipation towards the contextually-relevant referent even before target sentence onset. In contrast, following the RW context, participants delay their expectations to seek more information from the upcoming linguistic input.

Further evidence for anticipation according to prior contexts was found in Experiment 8, where a prior context directed comprehenders to make sense of the passage either according to reality or, more interestingly, according to the beliefs of another person. Effects were found similar to Experiment 7, with typical real-world biases, based on information about the Agent and verb, eliminated by an appropriate 'beliefs of others' prior context. Anticipatory eye-movements were made towards contextually relevant referents from 560ms prior to the critical word onset. In other words, context was able to elicit very early expectancy effects that modified the constraints of local semantics. Hence, these studies provide evidence for an incremental language processor that makes immediate use of all information available to construct a

plausible interpretation of the linguistic input, as suggested by Kamide et al. (2003). However, the current studies expand on this suggestion as they demonstrate that linguistic context can overrule experiential knowledge of objects and their interactions to create *novel* relationships between objects in the scene as the sentence unfolds. In short, monitoring eye- movements around a visual scene can reveal expectations established either through real-world knowledge (e.g. Altmann & Kamide, 1999; Kamide et al., 2003) or from some appropriate alternative linguistic input such as counterfactual context (Experiment 7) or theory of mind (Experiment 8).

The results from Experiments 7 and 8 are consistent with a processing model where comprehenders are able to represent information from a counterfactual or beliefs of others perspective and create strong predictive relationships within that ‘alternative world’ framework, even though knowledge of reality is upheld. Here, the models applied to counterfactuals in Chapter 2 can be related to the comprehension of the ‘beliefs of others’, which requires listeners to represent different information for both ‘reality’ and ‘belief’. The ‘reality’ conditions used in Experiment 8 may have also involved a representation of both ‘reality’ and ‘belief’ spaces, although the information was identical in both. This is typical of everyday ToM situations. The fact that participants in these experiments were quickly able to use contextual information, even in cases where doing so conflicted with real-world knowledge or reality, supports the suggestion that some mental representation of both possibilities is set-up in the comprehender’s mental model following a counterfactual or belief context, but that early anticipation is driven by prior context.

It is interesting to note that no interference from real-world knowledge was evident in the anticipatory eye-movement results from Experiments 7 or 8. This is a novel finding suggesting that top-down expectations during processing appear to be solely driven by context. Eye-tracking studies on reading, by contrast, primarily tapped

into the cost of *integrating* RW-consistent or -inconsistent information. For example, the experiments in Chapter 2 demonstrated that RW-inconsistent language input leads to early processing disruption, regardless of context. Interestingly, Experiment 7 in the present paper was able to establish findings that corroborate this conclusion: upon recognising the critical word in the auditory language input, participants' visual biases towards 'appropriate' referents developed faster with RW-consistent rather than RW-inconsistent language input. However, it is important to bear in mind that these effects emerged *after* the critical word has been available to the listener, just as findings from reading were established *after* the critical word has been fixated for the first time. Hence, we propose that it is important to distinguish between bottom-up integration of linguistic input on the one hand and top-down prediction of forthcoming input on the other. While pre-stored world knowledge appears to have an influence on the former, the latter is predominantly context-driven. Top-down predictions can be established through combinations of verb-based information (e.g. *eat*), a pre-verbal argument (Agent) (e.g. *the cat*) and an appropriate discourse context. The visual- world paradigm encourages the formation of predictions since the visual referents prompt the comprehender to incrementally assess the fit of the referents to the current linguistic input. In contrast, no such predictive cues are available in a reading task, meaning that anticipation, though undoubtedly occurring, cannot be measured in the corresponding eye- movement records. In conclusion, it is clear that different tasks complement each other and that combining results across paradigms evidently leads to a fuller understanding of language processes than when used individually.

In reference to the data reported here, two processes became manifest. The first process in the comprehension of counterfactuals is to create expectations about the unfolding discourse according to a contextually updated model of the world. This stage is particularly evident given the very early context-based anticipation in the preview

window in Experiment 7. Second, newly encountered input is briefly checked against pre-stored world knowledge. This stage becomes apparent in effects occurring *after* the critical word in the language input has become available to the reader or listener: both reading and visual-world data demonstrate an early, time-limited conflict arising upon encountering RW-inconsistent input, regardless of context. Hence, it appears that context-consistent (cf. anticipation) and real-world consistent (cf. integration) mental models are represented in parallel during the processing of counterfactuals.

Experiment 8 did not address the role of pre-stored world knowledge (it relied solely on currently established ‘reality’ or ‘belief’ situations) and revealed no suggestion of a temporary conflict in integrating reality- versus belief-consistent language input. However, in Experiment 8, females were found to be more likely to predict events according to the beliefs of others than males. This supports long-standing evidence suggesting an innate female advantage in theory of mind abilities (Baron-Cohen & Hammer, 1997; Skuse, 1998). These accounts draw on data from both normally-developing and clinical groups of adults and children and suggest that an ‘extreme’ male cognitive style may underlie autistic spectrum disorders. However, the data presented here provides the first *on-line* evidence of a gender bias in cognition. The question therefore arises as to why such a female advantage became manifest? Existing literature suggests three possible explanations, although at this stage, I will not commit to a final conclusion on this matter. First, recent research has shown high heritability in theory of mind ability, which is independent of language skill (Hughes & Cutting, 1999). This suggests a genetic predisposition to connect with or make sense of certain aspects of the world around us. However, socialisation accounts of ToM development may also play an important role. Girls appear to be favoured over boys in the amount of supportive and emotion talk that mothers and older siblings engage in during early development (Cervantes & Callanan, 1998; Leaper, Anderson & Sanders, 1998; Brown,

Donelan-McCall & Dunn, 1996). This difference in experience may enhance girls' ability to use ToM skills compared to boys. A third possible explanation for the gender effect is that the ToM advantage for girls is mediated by superior general language ability. Numerous studies show that performance on ToM tasks is related to language ability (see Milligan, Astington & Ain (Dack) (2007) for a summary of this evidence) and several researchers have shown girls to be scoring higher than boys on literacy tests and cognitive tasks (Justice, Invernizzi, Geller, Sullivan & Welsch, 2005; Sammons, Elliot, Sylva, Melhuish, Siraj-Blatchford & Taggart, 2004; Sylva, Sammons, Siraj-Blatchford & Taggart, 2004; Strand, 1999), which continues to be evident throughout the school years (Herbert & Stipek 2005). This final explanation is important for future studies that could examine this issue directly by including extensive tests of language abilities of participants.

It is important to note that the general male difficulty in creating appropriate predictions revealed here may be task-specific. It is possible that the effects in Experiment 8 are simply due to different processing strategies regarding errors or being misled about another persons' beliefs. For example, while females continue to predict other peoples' behaviour, even when that prediction is incorrect on some trials, males could cancel anticipation when the chance of correct expectations is reduced. Alternatively, linguistic experience could account for performance on this task, such that females are generally more inclined than males to read short narratives involving characters and the relations between them. Ultimately, only further experimentation will reveal how the gender effects reported here fit with everyday cognition.

The results from Experiments 7 and 8 demonstrate mixed evidence for the recruitment of related processes during the comprehension of counterfactuals and beliefs of others. Evidence is provided here to support the involvement of similar mental models to achieve a full understanding of the linguistic input. Both tasks require

comprehenders to create two mental spaces to represent the linguistic information provided. In the case of counterfactual conditionals, one is the factual and the other is the counterfactual hypothetical space, whereas theory of mind tasks require reality and the beliefs of others to be represented in separate spaces. However, the relationships between these two mental spaces appear to differ between the two tasks leading to differing levels of availability for each mental space. This claim is supported by the fact that during the one-second ‘preview’ period (where the picture is available to the perceiver but the sentence has not started yet), participants already predict a continuation according to the counterfactual-world context in Experiment 7; beliefs of others (Experiment 8), by contrast, were not able to elicit such early anticipatory eye-movements during preview. This suggests that within a counterfactual discourse of the form ‘If...then...’ participants attach some appropriate consequence of the counterfactual world to their mental model of that context.¹² In contrast, comprehending the beliefs of others does not seem to support such early anticipation. This suggests that while people can mentally represent both reality and an alternative ‘reality’ based on another person’s beliefs (as established in the two preceding context sentences), they do not build up expectations of forthcoming events or predict whose perspective to take according to this knowledge until prompted by later linguistic input. Finally, the gender bias revealed for predicting others’ actions based on their beliefs, but not when predicting events in a counterfactual world, suggests different processes underlying the two tasks. This is particularly evident given that the same participants took part in the two tasks, thus the poor anticipatory performance demonstrated here by males in the beliefs of others task cannot be attributed to general difficulties in

¹² Note that while in the given example, one might worry that ‘vegetarians’ in the CW context might prime access to *a vegetable* in the visual scene, not all the items included in Experiment 7 (see Appendix) allow for a priming explanation. Also, this issue has been directly investigated in a previous reading eye-tracking study (see Experiment 2, Chapter 2) with no significant effects of priming reported.

generating expectations in discourse or using the visual world task. Further investigations into this area are essential to gain a detailed understanding of the overlapping mechanisms employed in these tasks. Consequently, future studies will attempt to bridge the gap between reasoning with counterfactuals and the beliefs of others (ToM) using a variety of methodologies and may shift attention to the processes that underlie *encoding* of counterfactual or theory of mind situations.

To conclude, in this chapter we have demonstrated that comprehenders can immediately anticipate a counterfactually appropriate referent within a counterfactual context. Importantly, the results reported here provide novel evidence that this is true even when that referent is anomalous with real-world expectations that normally determine which referents are appropriate given local semantic constraints. Furthermore, comprehending events according to the beliefs of others also sets up this early predictive bias so that comprehenders anticipate referents that are relevant to a character's beliefs, even in cases where this belief does not reflect reality. However, subtly distinct processes separate the comprehension of counterfactuals and the beliefs of others. Counterfactuals lead to very early anticipation (immediately following the context sentence), whereas within a beliefs of others story, expectations are delayed until further motivational information is provided in the critical sentence. Finally, gender analyses revealed a females advantage for predicting events based on the beliefs of others that was not evident for predicting events in a counterfactual world.

Chapter 6

Summary and General Conclusions

The research carried out in this thesis was an investigation of the on-line processing of counterfactual information, with an emphasis on the interference of real-world knowledge on the integration of counterfactual information. The introduction reviewed previous studies that are of relevance to this topic and identified a number of shortcomings in the current literature. The first pertains to language comprehension accounts for counterfactual information processing. It is commonly agreed that processing counterfactual information requires the comprehender to reason within a model that is false with respect to reality. At the same time, it is necessary to know, or to be able to retrieve easily, the fact that the model does not reflect reality, but is an alternative to it, otherwise reality and fantasy would become confounded (e.g. Fauconnier & Turner, 2003; Byrne & Tasso, 1999). It is commonly understood that information from a text is mentally represented (e.g. Sanford & Garrod, 1981; 1998; Sanford & Moxey, 1995; 1999; Glenberg, Meyer & Lindem, 1987; Glenberg & Kaschak, 2002; Zwaan, 2004; Graesser, Millis & Zwaan, 1997; Zwaan & Radvansky, 1998; Johnson-Laird, 1983; Garnham, 1981; 1999). However, only two such accounts have been directly applied to the comprehension of counterfactuals. On one hand, there is good evidence to suggest that readers mentally represent both factual and counterfactual possibilities as separate mental representations where reality is linked to the counterfactual world unidirectionally (e.g. Johnson-Laird, 1983; Johnson-Laird & Byrne, 1991; Fauconnier, 1985; 1997). On the other, a more recent account has suggested that counterfactuals initiate a minimal change to reality to temporarily accept the counterfactual as the true world (e.g. Evans & Over, 2004; Evans, Over & Handley, 2005). Thus, this account allows for both directional links and an assessment of the probability of the counterfactual premise. However, while both these accounts support the view that a proper appreciation of counterfactuals requires both real and counterfactual world information to be represented in a discourse model associated with

the introduction of a counterfactual situation, it is unclear whether the two would be present simultaneously. Indeed, processing counterfactuals could involve a sequential process, in which the counterfactual was temporarily accepted as the true world, although the consequences of this could be tested against the true world for inference either initially or sometime later.

Another shortcoming is the very limited body of research on how counterfactuals are understood during language comprehension, for instance of what kinds of representations they set up. Most research to date has investigated the role of counterfactuals within diverse cognitive activities, such as creative imagination and reasoning (e.g., Sternberg & Gastel, 1989; Byrne & Tasso, 1999; Johnson-Laird & Byrne, 2002; Byrne, 2002) or has explored the social functions of counterfactuals to express emotions such as regret (e.g. Kahneman & Tversky, 1982; Byrne, 2007; Kahneman, 1995). Thus, even though counterfactuals have been extensively discussed in the literature, surprisingly few researchers have attempted to investigate the mental representations and cognitive processes that are revealed on-line during the comprehension of counterfactuals. On this note, the final shortcoming that was targeted in this thesis concerned the very limited work (two studies to date) that has investigated the on-line processing of counterfactual information (Van de Ven, 2001; de Vega, Urrutia & Rizzo, in press). This lack of research is complicated further as the two existing studies have produced contradictory evidence for updating in counterfactual sentences. While de Vega et al. provide preliminary evidence suggesting that readers do not update their mental model following some counterfactual context, the results from Van de Ven's study suggest that a counterfactual context *is* rapidly integrated into the sentence interpretation. Additionally, these studies were limited by several confounding factors, including the imprecise reading time and probe recognition methodologies and the uncontrolled lexical properties of the target words or sentences.

This thesis offered more extensive and better controlled approaches to these issues over a series of 8 experiments, by employing various on-line methodologies, including eye- movements and ERPs during reading to examine processing costs and the visual- world paradigm to explore expectancies within counterfactual constructions. This allowed an investigation of how and when comprehenders use counterfactual information to make sense of some consequent that might require real-world knowledge to be suppressed for it to be accommodated within the pre-specified counterfactual model. Additionally, complementary experiments investigated the on-line processing of negated information and linguistic situations that require the comprehender to represent information according to the beliefs of another individual (theory of mind). I will now address these issues individually, summarising the experiments presented in this thesis and drawing conclusions about the processing of counterfactuals, negation and theory of mind.

Comprehending Counterfactuals

The experiments in Chapters 2 and 3 were specifically aimed at eye- movement (Experiments 1, 2, and 3) and electrophysiological responses (Experiment 4) to local pragmatic anomalies versus discourse context anomalies, and the subsequent interaction of these linguistic factors. Thus, I examined the processing of information that violates readers' knowledge of the world (*feeding a cat a bowl of carrots*) either in a realistic context (*If cats are hungry*) or in a counterfactual context (*If cats were vegetarians*), making the world knowledge violation acceptable. Additionally, I examined the processing of a statement that was congruent within the readers' world knowledge (*feeding a cat a bowl of fish*) but inconsistent with a preceding counterfactual context.

A great deal of research on anomaly processing has demonstrated that difficulties in processing a text are reflected in the eye- movement patterns (Rayner,

1998). Specifically, semantic and pragmatic anomalies have been shown to produce longer reading times and increased incidence of regressive eye movements around the anomalous word. (e.g., Braze, Shankweiler, Ni & Palumbo 2002; Ni, Fodor, Crain & Shankweiler 1998; Rayner, Warren, Juhasz & Liversedge 2004). The results from the three experiments in Chapter 2 revealed very similar results: following an initial disruption to eye-tracking for words that violated world knowledge, the counterfactual context was rapidly accommodated to make RW violations acceptable and RW congruent information anomalous within a counterfactual context. Additionally, Experiment 2 showed that the early disruption to reading was not affected by priming in the counterfactual conditions. In Experiment 3, I showed that the strength of associations to real-world expectancies can be modulated by language input, with the ‘repeated or habitual’ modal verb *would* leading to longer lasting effects of real-world knowledge than the ‘conditional possibility’ modal verb *could*. Taken together, these results suggest that language input is compared initially against real-world knowledge even in the presence of a CW context. Thus, within the limits of this paradigm, it appears that discourse context effects have been delayed by lexical-semantic constraints.

In Chapter 3 I exploited the established sensitivity of the N400 effect in the ERP signal to local semantic requirements (Kutas & Hillyard, 1980; Brown & Hagoort, 1999; Brown, Hagoort & Kutas, 2000; Kutas & Van Petten, 1994) and discourse-level context (Van Berkum, Hagoort and Brown, 1999; Van Berkum, Zwitterlood, Hagoort & Brown, 2003; Nieuwland & Van Berkum, 2006). Increased amplitude of the N400 component has been related to processing local semantic anomalies and discourse-dependent context anomalies, making it ideal to examine the interplay between semantics and discourse within a counterfactual statement. When presented within a RW context, world knowledge violations elicited an N400 effect at the critical word,

reflecting the fact that readers have detected the anomaly. However, when these anomalies were presented within a CW context, this N400 effect was reversed so that local- semantic RW violations were processed as acceptable and RW congruent items were processed as anomalous. Interestingly, no interference from real-world knowledge was revealed in the ERP waveforms for CW conditions. Thus, the increased N400 may reflect evaluation against the dominant or predicted situation following from the counterfactual construction, as revealed in later visual- world experiments.

Clearly there is a tension between the later effects of context, coupled with early real-world checking effects, found in the eye- movements in reading studies and the very early effects of context reported in the ERP study. The reason for these inconsistent results could be partly explained by limitations of each methodology. Eye-tracking in reading offers a natural environment for participants to read each experimental item at their usual pace, allowing regressions back to important parts of the text. In contrast, participants in the ERP study read the context sentence in isolation then read the critical sentence in a word by word manner, which did not allow parts of the text to be revisited for clarification. Thus it is possible that the slower presentation of language input to participants in the ERP study allowed more time to fully integrate the CW context and thus make predictions about upcoming language input in the critical sentence. In order to check this, future ERP experiments could use auditory language input which would present participants with the experimental passages at a natural pace and thus provide a close comparison with the eye- movements in reading studies.

Using data from Experiment 4 I also attempted an investigation of the oscillatory brain dynamics underlying the EEG data. Unfortunately, many effects that appeared in visualizations of the data failed to reach significance in statistical analysis (see Chapter 3 for a full discussion of this). However, contextually inconsistent conditions (RW-inconsistent and CW-inconsistent) appeared to elicit greater power

changes in the theta frequency (2 to 8 Hz) range than contextually appropriate conditions (RW-consistent and CW-consistent). In contrast, power in the gamma frequency band (~30Hz and upwards) appeared to be larger following a world knowledge violation (RW-inconsistent and CW-consistent) than a world knowledge congruent continuation (RW-consistent and CW-inconsistent). Attempts have been made in Chapter 3 to link these effects to specific cognitive processes, such as increased verbal working memory load or error monitoring for theta range changes and integration processes for gamma range changes. However, due to the limited applications of this technique in psycholinguistics, these suggestions are purely speculative for now, and ultimately, only further experimentation will allow a distinction between these explanations.

Chapter 5 (Experiment 7) was an investigation of the build-up of expectations within a counterfactual utterance, using the visual- world paradigm. Evidence has shown that participants are able to anticipate towards a relevant object before it is mentioned in the auditory input, thus reflecting the cognitive processes that underlie language comprehension (Cooper, 1974; Altmann & Kamide; 1999). To date, the visual- world paradigm has provided evidence that language comprehension is driven by predictive relationships between syntax, semantics and world knowledge (e.g. Kamide, Scheepers & Altmann, 2003; Kamide, Altmann & Haywood, 2003; Scheepers, Keller, & Lapata, in press; Altmann & Kamide, in press). Therefore, the specific aim of this study was to explore whether the introduction of a counterfactual context could override knowledge about the real world to predict specific upcoming words as the current sentence is unfolding.

The results showed that anticipatory eye- movements were made towards contextually relevant referents from 200ms prior to the critical word onset. In fact, analysis of the pre-language input preview window revealed that participants were able

to use information from the counterfactual discourse context to predict contextually appropriate upcoming words very early in language processing. Therefore, it can be asserted that during the CW context sentence, participants are already forming assumptions as to an appropriate continuation. Further, Experiment 7 supports the findings from reading (Chapter 2), showing that real-world violations lead to early processing disruption regardless of context. These results lend support to an incremental model of language processing that makes immediate use of all information available to construct a plausible interpretation of the linguistic input. This model allows for the rapid integration of discourse context and experiential knowledge, thus enabling the creation of *novel* relationships between objects, however, RW- congruent information leads to faster integration with the readers' world knowledge.

It should be noted that the effect of the minor infelicities of expression in some of the RW passages has been considered for all these experiments. Specifically, we are aware that tense and modal verb combinations across the RW sentences, as compared to the CW passages, do not always follow naturally. However, we felt it was important to maintain identical critical sentence constructions in RW and CW conditions, and as such it was imperative for CW passages that the critical sentence used a modal verb to introduce an event. We do not believe that this has affected language processing in the RW conditions, particularly since the anticipated anomaly detection responses were found for RW-inconsistent conditions across all experiments and thus we do not consider this issue to have compromised any of the conclusions drawn here.

Discussion

In the reasoning literature, Markovits (1995) pointed out that an initial problem for people presented with counterfactual premises is that these have to be represented without interference from knowledge of the real-world. In normal comprehension,

world knowledge is rapidly and automatically recruited to aid interpretation at levels ranging from the lexical (e.g., Rayner, 1998; Rayner & Frazier, 1989; Sereno, Brewer, & O'Donnell, 2003) to the level of situations (e.g. Bower, Black & Turner, 1979; Cook & Myers, 2004; Garnham, 1979; Garrod & Terras, 2000; Rizzella & O'Brien, 2002; see also Sanford & Garrod, 1981, 1998). Classic work has shown that many errors of memory for passages are due to the enrichment of a mental representation of the text by normally appropriate world- knowledge (e.g., Bartlett, 1932; Bower, Black & Turner, 1979). Sanford and Garrod (1981; 1998; Sanford, 1983; Sanford & Moxey, 1999) have proposed that the mapping of incoming discourse onto existing world knowledge is indeed an automatic, central process, and that without such mapping, rudimentary understanding is impossible. According to their view, it is relating a necessarily fragmentary language input to our understanding of situations that constitutes interpretation, and the richer the mapping, the better the understanding. Frith (1989) termed the tendency to bring real world knowledge to bear on any language input Strong Central Coherence, and has considered the lack of such a capacity to enrich language input a potential problem for persons with autistic spectrum disorder (Frith, 1989; Happé, 1997). It has been argued that an autistic failure to imaginatively elaborate on how counterfactual statements fit with reality may underlie the autistic person's ability to deal with certain types of counterfactual premises (Scott, Baron-Cohen & Leslie, 1999). In sum, there is much evidence to suggest that language input is automatically related to relevant world- knowledge, and that this may well apply to statements that come into the scope of a counterfactual.

Furthermore, in many stories, it can readily be argued that keeping contact with real-world knowledge is essential. For instance, stories often contrast what a protagonist believes with what are the "real" facts. A story set in Holland during the tulip fever period concerned an individual who believed a valuable tulip bulb to be an onion, and

sliced it up for his lunch (Moggach, 2000, pp 209-211). The whole point of the story is that while in the character's counterfactual world it was reasonable to eat the 'onion', the tension in the story arises from the ongoing recognition that he is devouring a fortune in the form of a valuable bulb. While there is much to be explored on this front, it is generally the case that even in counterfactual worlds, certain constraints of reality have to hold. This has been argued by philosophers of language (e.g., Lewis, 1981, McCall, 1984; von Fintel, 2001). The plausibility of this is easy to see at an intuitive level for the case of the peanut falling in love in Niewland & Van Berkum's 2006 study discussed previously. When we hear that a peanut falls in love, the normal range of expected behaviours, feelings, and actions should follow. There has to be an object of that love (a real-world fact). And even though the peanut may be able to move about, at least some of the real-world rules of physics will constrain possible movements. Indeed, within a literary framework, Ryan (1991) has provided a thorough analysis of what constraints from the real-world have to hold in fictional worlds as a function of genres of writing. In short, mappings from the real world to the counterfactual world are inevitable if reasoning is to be generally possible. Studies reported here show that real-world knowledge is in fact utilised early during comprehension, even following the build-up of a counterfactual scenario.

In sum a theory of counterfactual processing would need to account for several aspects of on-line comprehension shown here. Specifically, for counterfactual situations that alter some aspect of reality, a representation of both reality and the counterfactual alternative appear to be available to the comprehender at the point of disambiguation. It is possible that the proportional availability of each representation is influenced by the magnitude of change to reality that the comprehender must make in order to make sense of the counterfactual statement. Thus, when considering whether to accept a given counterfactual scenario, the suggestion made by Evans and colleagues, that people

evaluate a counterfactual premise with respect to suppositional possibilities in which the antecedents of the conditionals holds, seems a valid stage during comprehension. It is likely that some counterfactuals are easier to process than others, particularly in cases that require a minimal change to reality- compared to cases that require a major change to reality. Further investigation is required to examine the extent of this influence and to compare the processing strategies employed for counterfactuals that require a minimal change to reality versus those that involve a major change.

Furthermore, an important stage involved in counterfactual comprehension, as demonstrated in Experiment 7, is to create expectations about the unfolding discourse according to a contextually updated model of the world. Current models of counterfactual processing do not consider the role of altered expectations prior to some disambiguating linguistic input. Therefore, a relevant theory of counterfactuals would need to accommodate this stage, which once again, may or may not be influenced by the closeness of the appropriate possibility.

Comprehending Negation

Experiments 5 and 6 extended the question the comprehension of negated concepts, where a prior context sentence negated some fundamental aspect of world knowledge, but did not explicitly set up an alternative scenario (e.g. *If cats were not carnivores*). I reviewed a large corpus of research on negation that has found evidence for greater difficulty in processing negative than affirmative sentences, as evidenced by longer reading times and higher error rates for negative sentences (e.g. Arroyo, 1982; Wason, 1961; Carpenter & Just, 1975; Clark & Chase, 1972; de Villiers & Tager Flusberg, 1975; Just & Clark, 1973). Various explanations have been suggested to account for this processing difference between negative and affirmative sentences (e.g. Clark & Chase,

1972; Chomsky, 1957; Wason, 1965), however, none has provided an account that fully explains the persistent difficulties experienced for negative sentences.

Recently, experiments have attempted to examine how negated concepts, and their consequences, are represented in a non-linguistic system. Specifically, a great deal of research into negation has provided evidence to support a suppression account, which is limited by factors such as the nature and truth value of the negated concept, the processing time allowed and the availability of contextual information. According to this view, a negation operator serves to reduce accessibility of information mentioned within its scope during language comprehension, and *nothing more* (e.g. Von Klopp, 1993; Prado & Noveck, 2006; Evans et al., 1996; Evans & Over, 2004; McDonald & Just, 1989). However, newly emerging evidence suggests that this suppression of negated information is not an obligatory process and instead suggests that negatives offer a guide for making the negated object the basis of a wider *search-for-alternatives*. Research supporting this account demonstrates that a negation operator does not influence processing initially, however, the effects of negation are evident later in language comprehension as the total sentence meaning is computed including some alternative to the negated entity (e.g. Giora, 2006; Kaup, Lüdtke & Zwaan; 2006).

Thus, the specific aim of Experiments 5 and 6 was to determine whether and at what stage of processing a negative context influences interpretation of a target sentence, for example, making a world- knowledge violation acceptable or world- knowledge congruent information anomalous. To this end, Experiment 5 used eye-tracking methodology. Participants read a prior context depicting a negated-world (NW), or real-world (RW), followed by a second sentence continuation. Events described in these continuations either included a violation of RW knowledge, or were congruent with RW knowledge. Subsequently, Experiment 6 investigated whether the introduction of a negated discourse context could eliminate effects of real-world

knowledge in the ERP components, as was demonstrated by counterfactual contexts in Experiment 4. As in the case of Experiment 4, I was particularly interested in amplitude modulations of the N400 effect, while participants read about events that were either congruent or incongruent in terms of a pre-specified negated world. These studies were carefully prepared to eliminate many confounding limitations from previous studies, including priming, processing time and the extra syllable in negative sentences.

The results of Experiment 5 showed that initially there was no processing disruption following a target word that violated either world-knowledge or a preceding NW discourse context. This shows that the negated-world context has not immediately influenced comprehension, and suggests that readers are checking incoming information against their knowledge of reality. However, shortly after the critical word, we see evidence that the negated-world context has been incorporated into the representation of the sentence meaning, as effects of contextual consistency emerged in the eye-movement patterns. Similarly, the ERP results from Experiment 6 revealed that the typical N400 effect to semantic violations has not been reversed by introducing a negated-world context. Subsequent analyses of the preceding words showed that this effect was still not reversed by 1500ms after the critical word onset.

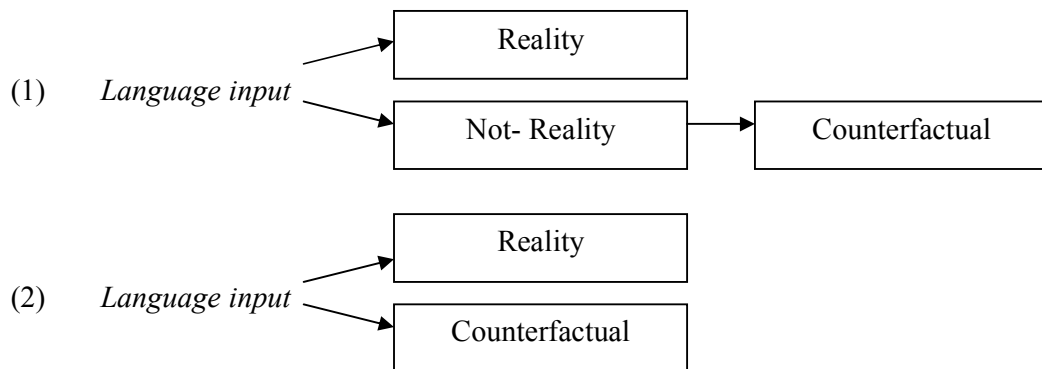
Discussion

The relationship between negation and counterfactuals has been considered by philosophers and researchers for many years. Specifically, it has been proposed that a counterfactual statement implies a negation of some sort. Thus, a counterfactual can imply either that the antecedent is false, or that the class designated by the antecedent has no members (Diggs, 1952). Similarly, negation can be used to set up some counterfactual world, for example negating some event in the past (e.g. 'If Germany had not lost the war'). Here, the negative prompts the reader to cancel their knowledge of

history and imagine a counterfactual world where the negated concept is true.

Fauconnier (2003) has suggested that negatives set up corresponding counterfactual spaces in which the positive version of a sentence is satisfied.

As has already been discussed in this chapter, relating language input to world knowledge is a vital process during language comprehension. However, it seems that processing negated information affords a longer comparison process to reality than counterfactuals. The experiments on negation reported in this thesis provide evidence that when processing negated information, comprehenders first simulate the negated situation and then suppress this model in favour of a simulation of the actual situation. This initial consideration of the negated situation prompts a comparison to reality to assess that reality no longer holds, thus delaying access to the actual situation. Therefore, it appears that to comprehend a negated concept, readers must represent information about reality, *not-* reality and an alternative ‘counterfactual’ reality, although the alternative reality only becomes available after *not-* reality has been accepted, as in (1). In contrast, comprehending a counterfactual appears to involve a shorter, parallel process of generating expectations according to the counterfactual model and relating incoming information to knowledge about reality, as in (2).



Therefore, the investigations on counterfactuals and negation reported here demonstrate similar processes during comprehension. Taken together, the results from these studies illustrate that global factors can override local aspects in shaping text representation following a counterfactual or negated discourse context; however, these effects are delayed within a negated context.

Comprehending Theory of Mind

It has been suggested that theory of mind (ToM) performance is a special case of counterfactual thinking (Leslie, 1987; Riggs, Peterson, Robinson & Mitchell, 1998). This is particularly apparent in counterfactual statements that refer to some event in the past that had a negative outcome. For example, a counterfactual utterance such as, ‘If I had been on time I wouldn’t have missed my appointment’ may initiate inferences relating to regret, disappointment or anger during processing. Therefore, it is plausible that the comprehension of counterfactuals and ToM might engage a network of consistent specialized cognitive processes.

In Experiment 8 I used a visual- world paradigm to investigate the processing of events according to the beliefs of other people. Similar to Experiment 7, the results showed that participants were able to anticipate a contextually relevant referent prior to the onset of the critical word, from 560ms before target word onset. However, in contrast to Experiment 7, no effects of context were observed in the preview region. This indicates that although people can mentally represent both reality and an alternative ‘reality’ based on another person’s beliefs, they do not build up expectations of forthcoming events according to this knowledge until prompted by later linguistic input. Finally, Experiment 8 revealed an early processing advantage for females over males in predicting other peoples’ actions based on knowledge about their beliefs.

Discussion

As has been suggested by developmental researchers, counterfactual thinking and ToM might involve similar mental representations requiring multiple possibilities to be available to the comprehender (*factual* versus *counterfactual*, and *reality* versus *belief*). Indeed, it seems plausible that the human ability to consider the current state of the world as well as how it could be different is a necessary component of theory of mind understanding. Therefore, readers' ability to answer a false belief question, such as, 'Where will [Character 1] look for the [Target object]?' correlates highly with their ability to answer the counterfactual conditional, such as, 'If [Character 2] hadn't moved [Target object], where would the [Target object] be now?'. A growing amount of evidence supports this claim, with researchers showing that children who fail ToM tasks also fail other counterfactual reasoning tasks (Guajardo & Turley-Ames, 2001; Peterson & Bowler, 2000; Riggs, Peterson, Robinson & Mitchell, 1998) even when those tasks do not involve ToM (e.g., photograph task; Zaitchik, 1990). Further evidence for a correlation between counterfactual thinking and theory of mind understanding comes from studies showing that individuals with autism, whose problems with false belief tasks are well established (Baron-Cohen, Leslie, & Frith, 1985; Frith, 2003), are poor at counterfactual reasoning (Peterson & Bowler, 2000; Grant, Riggs, & Boucher, 2000; Hadwin & Bruins, 1997; Scott, Baron-Cohen, & Leslie, 1999).

This link between understanding belief and counterfactual conditionals has been considered in terms of the underlying theory. One suggestion is that understanding of belief is based on *simulation*, where understanding another person's belief is analogous to imagining the world counterfactually, as it looks from the believer's view (Peterson & Riggs, 1999; Riggs et al., 1998). Specifically, Peterson & Riggs (1999) suggest that false belief tasks involve reasoning; the false belief stories used in this thesis required deduction because they never explicitly mentioned where the first character thinks the

target object is (i.e. it's not a recall task). Thus, the comprehender has to reason where a character would look for a target object on the basis of preceding information about whether that character did or did not see the target object move location. An alternative explanation for the relationship between counterfactual and false belief problems has been suggested more recently by Perner, Sprung and Steinkogler (2004). According to their view, simulations of the false belief are not necessarily based on a counterfactual reasoning process that the mistaken believer goes through factually. Instead they propose that the need to relate the derivation process to actual events makes counterfactual reasoning problems akin to the false belief problem, where one has to reason from a belief in a counterfactual state of the world to an action aimed at achieving something in the real world.

Finally, the data presented in Chapter 5, where a gender difference in processing is evident on a ToM task, but not on a similar counterfactual task, suggests two important things. First, that predictions based on the beliefs of others, and not some counterfactual scenario, can be influenced by gender. Second, this difference implies that general difficulties with ToM are not solely based on problems with counterfactual reasoning. In sum, the relationship between the ability to reason with counterfactual conditionals and understanding false belief still needs further investigation.

Conclusions and future work

In this thesis I have applied a range of psycholinguistic paradigms in an attempt to investigate some of the properties of how counterfactuality is processed on-line. Most importantly, the research carried out here provides evidence that the language processor can be immediately directed according to the discourse context to prevent pragmatic violations from disrupting the comprehension process or to elicit anomaly detection responses to pragmatically congruent information. Specifically, the comprehension of

counterfactuals involves a dominant process to create expectations about the unfolding discourse according to the updated model of the world. However, at the point of disambiguation between the real and counterfactual world, events in a counterfactual-world context are rapidly checked against knowledge based on real-world plausibility. In contrast, following a negated context, the dominant process is to relate the described events to real-world expectations. Thus initially, the readers' model of the world has *not* been updated by the preceding negated-world context. However, at some later stage of processing events that are consistent with the negated discourse context are accommodated into the representation of the sentence meaning. Finally, initial investigations on the comprehension of theory of mind have demonstrated that visual attention can be immediately directed according to expectations based on another person's beliefs about the world. This is true even if they are inconsistent with the comprehenders' own knowledge about reality. I have provided evidence that this ability may be subject to a gender bias, with females showing a significant advantage on ToM reasoning compared to males.

Although the present experiments demonstrate novel and highly interesting findings in the field of language comprehension, they also raise several theoretical issues that warrant future research. Many of these issues have been discussed in the relevant chapters, however, some additional suggestions are presented here. For instance, it may be that the current rapid integration of a counterfactual context does not extend to counterfactuals that do not alter such a fundamental part of world knowledge (e.g. 'If it had rained this morning my hair would be wet/ dry by the time I arrived at work'). It would also be interesting to find out whether a gender difference in processing (as in Experiment 8) would be observed for counterfactuals that specifically prompt the reader to infer some emotional state of a character (e.g. 'If Markus had been late again this morning he would have been fired'). Finally, on a more integrative level,

one way to extend this research could be to explore the possible overlap between counterfactual and theory of mind processing. It is conceivable, for example, that theory of mind and counterfactual thinking engage a consistent network of specialized neuronal networks. Future studies could use functional Magnetic Resonance Imaging methods, which provide excellent spatial resolution, to pinpoint active brain areas for each process with a precision of several millimeters.

At the outset of this doctoral work, it was my intention to investigate the correlations between comprehending counterfactuals and the beliefs of others. However, it very quickly became apparent that research on counterfactuals had been largely neglected, particularly with respect to the on-line processes underlying comprehension. This major issue, coupled with persistent difficulties in producing reliable effects in investigations of ToM (see Chapter 5 for a full discussion) led me to direct my questions more specifically to the comprehension of counterfactuals. Thus, this thesis provides exciting advances to our understanding of the processes involved and opens many possibilities for future work to establish the neural basis of counterfactual processing. Ultimately, this will address important questions about comprehending counterfactuals such as, (i) whether it involves recruitment of brain regions associated with ToM, including the medial-temporal structures and prefrontal cortex, and (ii) whether it leads to increased activation in the hippocampus (long-term factual memory) and frontal cortex (working memory) areas, to represent both world knowledge and the novel counterfactual alternative.

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Appendix

Figure 5.11: Probabilities of fixating on either the distracter item or topic (e.g. 'cat') for each condition in Experiment 7, where C1 is CW context- CW input, C2 is CW context- RW input, C3 is RW context- RW input and C4 is RW context- CW input.

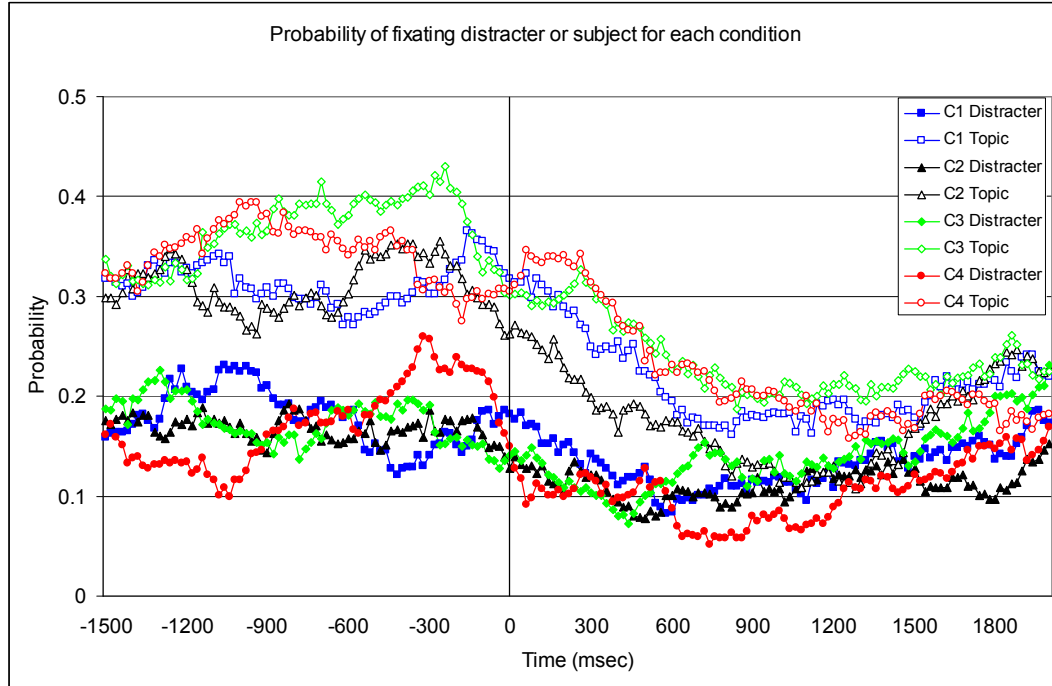
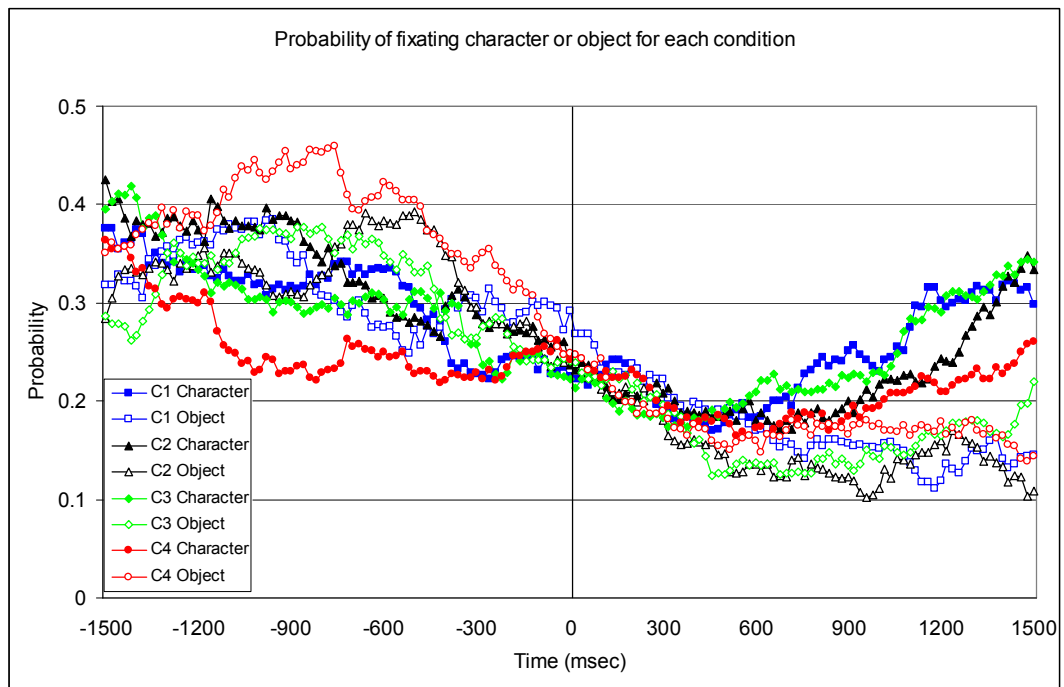


Figure 5.12: Probabilities of fixating on either the character or target object (e.g. 'watch') for each condition in Experiment 8, where C1 is Belief context- Belief input, C2 is Belief context- Reality input, C3 is Reality context- Reality input and C4 is Reality context- Belief input.



Experimental Items used in Experiment 1

1.
If someone was interested in learning new things there is a selection of courses available. A student could take a foreign language course to improve his painting/ French and make his parents proud. They offer foreign language courses at most universities in Scotland.

If part of a foreign language course consisted of painting it would be a popular course. A student could take a foreign language course to improve his painting and make his parents proud. They offer foreign language courses at most universities in Scotland.

2.
If Jenny wanted to make her house very clean there are a lot of jobs that she would need to do. Jenny could wash her laminate floor with a spade/ mop and make it sparkling clean. For hygiene reasons, it would be useful to do this regularly.

If a spade had long and thick bristles like a sweeping brush it would have a lot of uses in the house. Jenny could wash her laminate floor with a spade and make it sparkling clean. For hygiene reasons, it would be useful to do this regularly.

3.
If the children were getting rowdy at weekends there is a lot to keep them amused in Glasgow. Mary could take her children to the Asda superstore to swim/ shop and get some peace. Weekends are always hard work for parents.

If all supermarkets had a swimming pool for the children they would be very busy at weekends. Mary could take her children to the Asda superstore to swim and get some peace. Weekends are always hard work for parents.

4.
If a family couldn't choose where to go on holiday I would suggest somewhere exotic. People could visit Cairo to see the Louvre/ pyramids and take photos for their album. A lot of people are interested in foreign monuments.

If Cairo were in France it would be a popular sightseeing destination with tourists. People could visit Cairo to see the Louvre and take photos for their album. A lot of people are interested in foreign monuments.

5.
If husbands wanted to surprise their wives with a gift there are lots of ideas available on the internet. Husbands could go to a shoe shop to buy some roses/ trainers and their wives would be happy. There are lots of big shoe shops in Edinburgh.

If it were possible to buy flowers in every kind of shop it would make it a lot easier to buy last-minute gifts. Husbands could go to a shoe shop to buy some roses and their wives would be happy. There are lots of big shoe shops in Edinburgh.

6.
If a plumber had the appropriate tools he could do his job a lot faster. Sarah could call a plumber to fix her broken ankle/ toilet and she would be out of her misery. Of course, the bill would be very expensive for the work.

If a plumber were trained in medicine he would be very useful indeed. Sarah could call a plumber to fix her broken ankle and she would be out of her misery. Of course, the bill would be very expensive for the work.

7.
If you wanted to change your appearance completely your friends would be very impressed. You could have your hair cut by a dentist/ hairdresser and show it off at a party. It's always nice to have a change for summer.

If you wanted your hairstyle completely ruined your friends would think it was funny. You could have your hair cut by a dentist and show it off at a party. It's always nice to have a change for summer.

8.

If fish were a rare species they would attract a lot of attention from wildlife lovers. Tourists could watch Scottish salmon walk/ swim and enjoy the countryside. Hopefully no one would try to eat them!

If fish were able to grow legs when they were out of the water it would be a miracle. Tourists could watch Scottish salmon walk and enjoy the countryside. Hopefully no one would try to eat them!

9.

If we had enough money travel agents would be keen to help us find a suitable holiday. We could go to Greenland in November to sunbathe/ sledge and escape from work for a week. Most people enjoy a holiday abroad in winter.

If Greenland had really hot winters like Dubai it would be popular with sun-worshippers. We could go to Greenland in November to sunbathe and escape from work for a week. Most people enjoy a holiday abroad in winter.

10.

If someone had a high enough IQ they would be allowed to study almost anything at university. A student could become a solicitor by studying medicine/ Law and impress his family and friends. Solicitors can make a lot of money if they are clever.

If a medical course taught students about the law there would be a long list of books to read during the course. A student could become a solicitor by studying medicine and impress his family and friends. Solicitors can make a lot of money if they are clever.

11.

If young couples want to enjoy a good night out there's a lot to choose from in a city like Glasgow. John could invite Mary to the cinema for a dance/ movie and they would have a great time. The cinema is always a nice place to go to at weekends.

If all cinemas had a disco and dancefloor inside they would be a popular place with lively young people. John could invite Mary to the cinema for a dance and they would have a great time. The cinema is always a nice place to go to at weekends.

12.

If cats are hungry they usually pester their owners until they get fed. Families could feed their cat a bowl of carrots/ fish and it would gobble it down happily. Cats are loving pets when you look after them well.

If cats were vegetarians they would be cheaper for owners to look after. Families could feed their cat a bowl of carrots and it would gobble it down happily. Cats are loving pets when you look after them well.

13.

If someone were organising a party they would need to organise entertainment and refreshments. Young children could drink bottles of vodka/ cola and dance all night long. Children always eat and drink a lot at parties.

If vodka were non-alcoholic it would have wider market of people who could enjoy drinking it. Young children could drink bottles of vodka and dance all night long. Children always eat and drink a lot at parties.

14.

If newspaper reporters wanted to impress the boss they would have to discover a big story that the public would enjoy. Reporters could carry out an interview with Elvis/ Prince and ask what inspired his music. We can hear a lot of gossip about celebrities from reading the news.

If it were possible to travel back in time and meet famous people, our newspapers would be full of exciting stories. Reporters could carry out an interview with Elvis and ask what inspired his music. We can hear a lot of gossip about celebrities from reading the news.

15.

If Shakespeare had wanted to make his plays longer he shouldn't have killed off the main characters. Romeo and Juliet could have communicated by text/ letter and their families would never have known. Most people think that Shakespeare was a great writer.

If mobile phones had been invented in the 1500's, the content of English literature would be very different. Romeo and Juliet could have communicated by text and their families would never have known. Most people think that Shakespeare was a great writer.

16.

If ants feel threatened on the ground they would have to move fast to escape. A colony of ants could escape from predators by flying/ climbing and building their nests in trees. Survival of the fittest is a big issue in the wild.

If ants had wings they would feel safer from the predators that hunt them. A colony of ants could escape from predators by flying and building their nests in trees. Survival of the fittest is a big issue in the wild.

17.

If you wanted to go somewhere interesting in your spare time it's good to hear what people recommend. Groups of friends could go to the zoo to see kittens/ lions and maybe get a chance to feed them. The zoo is popular place to go at weekends.

If all kittens lived in zoos they would be popular with visitors as they are very cute and enjoy attention. Groups of friends could go to the zoo to see kittens and maybe get a chance to feed them. The zoo is popular place to go at weekends.

18.

If Steve wanted to take a week off work to be more cultural I would recommend he travel around Europe. Steve could see the Eiffel Tower in Germany/ France and show off to his friends at home. The Eiffel Tower is a beautiful iron construction with fantastic views.

If the French gave the Eiffel Tower to Berlin as a present it would be gratefully received by the community. Steve could see the Eiffel Tower in Germany and show off to his friends at home. The Eiffel Tower is a beautiful iron construction with fantastic views.

19.

If it was raining outside there are lots of indoor venues that are able to host events for the public. Crowds of people could watch Tony Blair lead an opera/ campaign and hopefully they would enjoy it. Tony Blair is known for being enthusiastic about everything he does.

If Tony Blair were a fantastic opera singer he would put on a spectacular show for his audiences. Crowds of people could watch Tony Blair lead an opera and hopefully they would enjoy it. Tony Blair is known for being enthusiastic about everything he does.

20.

If you are hungry while out of the house, supermarkets have a lot of choice available. You could eat yoghurt by the slice/ spoonful and have energy till dinnertime. Children are usually very messy eaters.

If yoghurt were frozen to ice cream it would be popular with people of all ages. You could eat yoghurt by the slice and have energy till dinnertime. Children are usually very messy eaters.

21.

If Kevin had problems with his senses a doctor could give him something to help. Kevin could wear a hearing aid to help him see/ hear and his friends would be relieved. Many people have problems with one of their senses.

If a hearing aid restored a person's vision it would be common among the elderly. Kevin could wear a hearing aid to help him see and his friends would be relieved. Many people have problems with one of their senses.

22.

If Gillian were preparing for a big night out she would spend a whole day pampering herself. Gillian could paint sparkly pink nail varnish onto her eyelids/ nails and look beautiful all night. Most girls love to make a big effort for a party.

If nail varnish were for use on the eyes there would be lots of bright colours to choose from. Gillian could paint sparkly pink nail varnish onto her eyelids and look beautiful all night. Most girls love to make a big effort for a party.

23.

If Peter were looking for a cheap holiday, travel agents would have lots of suggestions. Peter could fly to New York City in a spaceship/ aeroplane and enjoy the picturesque scenery. New York is well-known as an exciting place to visit.

If New York City were a city on the moon it would take a long time to get there. Peter could fly to New York City in a spaceship and enjoy the picturesque scenery. New York is well-known as an exciting place to visit.

24.

If Mum were going on a special night out I recommend that she look her best. Mum could wash her hair using margarine/ shampoo and impress her friends and family. People always admire glamorous women.

If margarine contained detergent it would have many domestic uses. Mum could wash her hair using margarine and impress her friends and family. People always admire glamorous women.

Experimental items used in Experiment 2

1.

A foreign language course consists of linguistics and an art course teaches painting. A student could take a foreign language course to improve his painting/ French and make his parents proud.

If all foreign language courses consisted of painting it would be a popular course for all ages. A student could take a foreign language course to improve his painting/ French and make his parents proud.

2.

It is clear to see that a toothbrush is the size of a pen and a broom is the size of a spade. Jenny could use a toothbrush to brush her floors/ teeth and make them sparkling clean.

If a toothbrush were as big as a broom it would be a popular device to improve sanitation in homes. Jenny could use a toothbrush to brush her floors/ teeth and make them sparkling clean.

3.

Parents and their children often go to a supermarket or a leisure centre with a swimming pool to keep busy at weekends. Mary could take her children to the Asda superstore to swim/ shop and battle the crowds.

If all supermarkets were leisure centres with a swimming pool for the children they would be very busy at weekends. Mary could take her children to the Asda superstore to swim/ shop and battle the crowds.

4.

An Atlas can teach us that Cairo is a city in Egypt and Paris is a city in France. People could visit Cairo to see the Louvre/ pyramids and take photos for their album.

If Cairo were a city in France it would be a popular sightseeing destination with tourists. People could visit Cairo to see the Louvre/ pyramids and take photos for their album.

5.

Shopping centres house many shops including shoe shops and florists displaying beautiful flowers. Husbands could go to a shoe shop to buy some roses/ trainers and their wives would be happy.

If shoe shops sold only flowers there would be a great deal of choice for buying gifts for loved ones. Husbands could go to a shoe shop to buy some roses/ trainers and their wives would be happy.

6.

Plumbers are trained to repair faulty water pipes while doctors are qualified in medical care. Sarah could call a plumber to fix her broken ankle/ toilet and she would be out of her misery.

If a plumber were trained in medicine he would be very useful indeed. Sarah could call a plumber to fix her broken ankle/ toilet and she would be out of her misery.

7.

A hair cut is an important event for a girl so it is important to get a professional. You could have your hair cut by a dentist/ hairdresser and show it off at a party.

If you wanted your hair cut by an amateur your friends might think it was funny. You could have your hair cut by a dentist/ hairdresser and show it off at a party.

8.

In the wild, birds enjoy the open air while fish thrive from living underwater. School pupils could go to the countryside to study birds swimming/ flying and enjoy the fresh air.

If all birds lived underwater like fish it would be fascinating to observe their existence. School pupils could go to the countryside to study birds swimming/ flying and enjoy the fresh air.

9.

Studying weather patterns tells us that Greenland has really cold winters and Dubai has very hot winters. We could go to Greenland in November to sunbathe/ sledge and escape from work for a week.

If Greenland had really hot winters like Dubai it would be popular with tourists of all ages. We could go to Greenland in November to sunbathe/ sledge and escape from work for a week.

10.

Choosing between a course that covers aspects of the law and a medical course is a tough decision. A student could become a solicitor by studying medicine/ law and impress his family and friends.

If aspects of the law were only taught in a medical course there would be lots of books to read during the syllabus. A student could become a solicitor by studying medicine/ law and impress his family and friends.

11.

At the weekend, many young people go to the cinema or to a nightclub with a dance floor to unwind. John could invite Mary to the cinema for a dance/ movie and they would have a great time.

If all cinemas were a nightclub with a dance floor inside they would be a popular place with lively young people. John could invite Mary to the cinema for a dance/ movie and they would have a great time.

12.

Evolution dictates that cats are carnivores and cows are vegetarians. Families could feed their cat a bowl of carrots/ fish and it would gobble it down happily.

If cats were vegetarians they would be cheaper for owners to look after. Families could feed their cat a bowl of carrots/ fish and it would gobble it down happily.

13.

At parties, children are only allowed to drink soft drinks while adults often choose to have alcohol. Young children could drink bottles of vodka/ juice and dance all night long.

If children were only allowed to drink alcoholic drinks they would be likely to get over-excited. Young children could drink bottles of vodka/ juice and dance all night long.

14.

Mobile phones are a very popular way to communicate today, but in the 1500's this was not the case. Romeo and Juliet could have communicated by text/ letter and their families would never have known.

If mobile phones were the only way to communicate in the 1500's, the content of literature would be very different. Romeo and Juliet could have communicated by text/ letter and their families would never have known.

15.

People who enjoy visiting a zoo to see the wild animals are often keen on domestic animals like kittens too. Groups of friends could see kittens in a zoo/ farm and maybe get a chance to feed them.

If all kittens lived in zoos they would be popular with visitors as they are very cute and enjoy attention. Groups of friends could see kittens in a zoo/ farm and maybe get a chance to feed them.

16.

Elephants are one of the world's largest mammals, while a mouse is one of the smallest. Children could learn that an elephant weighs about five ounces/ tonnes and draw a picture of its trunk.

If an elephant were the size of a mouse there would be a lot to discover about how their body works. Children could learn that an elephant weighs about five ounces/ tonnes and draw a picture of its trunk.

17.

A few types of shark are man-eaters but many other fish in the sea only eat plants. Parents could consider swimming with great white sharks as harmless/ dangerous and tell their children.

If sharks only ate plants they would be less of a threat to humans and other animals. Parents could consider swimming with great white sharks as harmless/ dangerous and tell their children.

18.

French people are very proud of the Eiffel Tower and Germans promote the cosmopolitan feel of Berlin. Steve could see the Eiffel Tower in Germany/ France and show off to his friends at home.

If the French moved the Eiffel Tower to Berlin as a present it would be gratefully received by the community. Steve could see the Eiffel Tower in Germany/ France and show off to his friends at home.

19.

Tony Blair is a famous politician while Charlotte Church found fame as an opera singer. Crowds of people could watch Tony Blair lead a opera/ campaign and hopefully they would enjoy it.

If Tony Blair were famous for being an opera singer he would put on a spectacular show for his audiences. Crowds of people could watch Tony Blair lead a opera/ campaign and hopefully they would enjoy it.

20.

The calcium in milkshakes and ice cream is very good for people of all ages. You could enjoy a milkshake by the slice/ glass and have energy till dinnertime.

If milkshakes were frozen to ice cream it would be popular with people of all ages. You could enjoy a milkshake by the slice/ glass and have energy till dinnertime.

21.

Many old people wear glasses to restore their vision and a hearing aid for listening. Kevin could wear a hearing aid to help him see/ hear and his friends would be relieved.

If the function of a hearing aid was to restore a person's vision it would be common among the elderly. Kevin could wear a hearing aid to help him see/ hear and his friends would be relieved.

22.

When preparing for a night out, girls often paint their nails with nail varnish and put make-up on their eyes. Gillian could paint sparkly pink nail varnish onto her eyelids/ nails and look beautiful all night.

If nail varnish were for use on the eyes there would be lots of bright colours to choose from. Gillian could paint sparkly pink nail varnish onto her eyelids/ nails and look beautiful all night.

23.

New York City is a popular destination now but tickets are already being sold to fly to the moon. Peter could fly to New York City in a spaceship/ aeroplane and enjoy the picturesque scenery.

If New York City were a city on the moon it would be very expensive to get there. Peter could fly to New York City in a spaceship/ aeroplane and enjoy the picturesque scenery.

24.

Margarine contains oils and cleaning products contain detergents. Mum could use margarine in her hair/ baking and impress her friends and family.

If margarine contained a detergent it would have many domestic uses. Mum could use margarine in her hair/ baking and impress her friends and family.

25.

Most people love to see the sun in summer and enjoy cooling down during the night. People could sunbathe on the beach at midnight/ midday and wear lots of sunscreen.

If the sun only came out during the night it would change the way we spend our holidays. People could sunbathe on the beach at midnight/ midday and wear lots of sunscreen.

26.

When planning a holiday to Spain or America, it is important to find out the local currency. Tourists could go to Spain to spend Euros/ dollars and buy lots of souvenirs for friends.

If Spain used the same currency as America it would make travel between the two countries easier for tourists. Tourists could go to Spain to spend Euros/ dollars and buy lots of souvenirs for friends.

27.

Elvis was a great believer in Christmas and always threw a big party to celebrate. Children could stay awake on Christmas Eve to look for Elvis/ Santa and find out what their presents are.

If it were Elvis who gives presents at Christmas he would be very popular with children. Children could stay awake on Christmas Eve to look for Elvis/ Santa and find out what their presents are.

28.

Many people from Northern Ireland make the magical trip to Australia once in their lives. People could drive the length of Australia in a day/ month and view all the picturesque scenery.

If Australia were the same size as Northern Ireland travel would be much easier for tourists. People could drive the length of Australia in a day/ month and view all the picturesque scenery.

29.

Holidaymakers must decide whether they would rather travel to their destination by ferry or aeroplane. A ferry could travel across the Atlantic Ocean in the air/ sea and arrive in America in record time.

If a ferry were converted into a flying vessel it might save some travelling time for holidaymakers. A ferry could travel across the Atlantic Ocean in the air/ sea and arrive in America in record time.

30.

The food chain shows us that sheep are herbivores and wolves are carnivores. Farmers could leave their sheep in the field to eat rabbits/ grass and concentrate on the other farm work.

If sheep were carnivorous like wolves they would be a lot less work to be looked after. Farmers could leave their sheep in the field to eat rabbits/ grass and concentrate on the other farm work.

31.

Humans have developed language skills while cats must communicate using other ways. Judith could listen to her cat talk/ meow and throw balls of wool for it to play with.

If cats had developed language skills like humans it would be interesting to hear what they have to say. Judith could listen to her cat talk/ meow and throw balls of wool for it to play with.

32.

The rules of football dictate that footballers must not use their hands to touch the ball during play. Footballers could avoid a tackle by passing the ball using their hands/ feet and running into a clear space.

If footballers were only allowed to touch the ball with their hands it would be an easier game to play. Footballers could avoid a tackle by passing the ball using their hands/ feet and running into a clear space.

Experimental items from Experiment 3

1.

If someone was interested in learning a foreign language there is a selection of courses available. A student would take a foreign language course to improve his painting/ French and make his parents proud.

If all foreign language courses consisted of painting it would be a popular course for all ages. A student would take a foreign language course to improve his painting/ French and make his parents proud.

2.

If a couple fancied some Indian cuisine, there are lots of meal choices on offer. Lovers would go to an Indian restaurant to eat some pasta/ curry and feel very full all night.

If Indian cuisine were the same as Italian, we would buy cookbooks for the recipes. Lovers would go to an Indian restaurant to eat some pasta/ curry and feel very full all night.

3.

If the children were getting rowdy at weekends there is a lot that parents can do to keep them occupied in Glasgow. Mary would take her children to the Asda superstore to swim/ shop and battle the crowds.

If all supermarkets were leisure centres with a swimming pool for the children they would be very busy at weekends. Mary would take her children to the Asda superstore to swim/ shop and battle the crowds.

4.

If husbands wanted to surprise their wives with a gift there are lots of ideas available on the internet. Husbands would go to a shoe shop to buy some roses/ trainers and their wives would be happy.

If shoe shops sold only flowers there would be a great deal of choice for buying gifts for loved ones. Husbands would go to a shoe shop to buy some roses/ trainers and their wives would be happy.

5.

If a plumber had the appropriate tools he would do his job a lot faster. Sarah would call a plumber to fix her broken ankle/ toilet and she would be out of her misery.

If a plumber were trained in medicine he would be very useful indeed. Sarah would call a plumber to fix her broken ankle/ toilet and she would be out of her misery.

6.

If you wanted to change your appearance completely your friends would be very impressed. You would have your hair cut by a dentist/ hairdresser and show it off at a party.

If you wanted your hair cut by an amateur your friends might think it was funny. You would have your hair cut by a dentist/ hairdresser and show it off at a party.

7.

If birds were a rare species they would attract a lot of attention from wildlife lovers. School pupils would

go to the countryside to study birds swimming/ flying and enjoy the fresh air.

If all birds lived underwater like fish it would be fascinating to observe their existence. School pupils would go to the countryside to study birds swimming/ flying and enjoy the fresh air.

8.

If a golfer were keen to win the tournament, he would need to sharpen up his technique. A golfer would hurt his shoulder from swinging his racket/ club and visit a physio for treatment.

If golf used the same equipment as tennis, players would work hard to improve their technique. A golfer would hurt his shoulder from swinging his racket/ club and visit a physio for treatment.

9.

If someone were interested in the law they would be encouraged to study at one of the great universities. A student would become a solicitor by studying medicine/ law and impress his family and friends.

If aspects of the law were only taught in a medical course there would be lots of books to read during the syllabus. A student would become a solicitor by studying medicine/ law and impress his family and friends.

10.

If young couples want to enjoy a good night out there's lots to choose from in a city like Glasgow. John would invite Mary to the cinema for a dance/ movie and they would have a great time.

If all cinemas were a nightclub with a dancefloor inside they would be popular places with lively young people. John would invite Mary to the cinema for a dance/ movie and they would have a great time.

11.

If a train is about to make a long journey, there is a lot of activity from the people on board. A train driver would be in charge of the mainsail/ engine and staff would look after passengers.

If trains were powered by wind like tall ships, they would be cheap to operate all year round. A train driver would be in charge of the mainsail/ engine and staff would look after passengers.

12.

If a caterpillar had eaten enough leaves, it would be ready to transform into its next stage. A caterpillar would mature into a sparrow/ butterfly and enjoy testing its new wings.

If caterpillars turned into birds in the chrysalis, it would be an amazing transformation to study. A caterpillar would mature into a sparrow/ butterfly and enjoy testing its new wings.

13.

If newspaper reporters wanted to impress the boss they would have to discover a big story that the public would enjoy. Reporters would carry out an interview with Elvis/ Prince and ask what inspired his music.

If it were possible to travel back in time to meet famous dead people, our newspapers would be full of exciting stories. Reporters would carry out an interview with Elvis/ Prince and ask what inspired his music.

14.

If ants feel threatened on the ground they would have to move fast to escape the danger. A colony of ants would escape from predators by flying/ climbing and building their nests in trees.

If ants had wings instead of legs they would feel safer from the predators that hunt them. A colony of ants would escape from predators by flying/ climbing and building their nests in trees.

15.

If you had planned to visit America, it is recommended that you watch a local sporting event. Visitors would go to Chicago to watch bullfights/ baseball and join the crowds of spectators.

If America had the same national sport as Spain, it would be a popular destination for enthusiasts.

Visitors would go to Chicago to watch bullfights/ baseball and join the crowds of spectators.

16.

If Steve wanted to take a week off work to be more cultural I would recommend he travel around Europe. Steve would see the Eiffel Tower in Germany/ France and show off to his friends at home.

If the French moved the Eiffel Tower to Berlin as a present it would be gratefully received by the community. Steve would see the Eiffel Tower in Germany/ France and show off to his friends at home.

17.

If Tony Blair wanted to attract a big audience he would need to host events for the public. Crowds of people would watch Tony Blair lead an opera/ campaign and hopefully they would enjoy it.

If Tony Blair were famous for being an opera singer he would put on a spectacular show for his audiences. Crowds of people would watch Tony Blair lead an opera/ campaign and hopefully they would enjoy it.

18.

If researchers were interested in chickens, their reproduction would be fascinating. Environmentalists would watch chickens give birth to chicks/ eggs and check they are kept safe.

If chickens were mammals, their behaviour would be interesting to examine. Environmentalists would watch chickens give birth to chicks/ eggs and check they are kept safe.

19.

If Gillian were preparing for a big night out she would spend a whole day pampering herself. Gillian would paint sparkly pink nail varnish onto her eyelids/ nails and look beautiful all night.

If nail varnish were for use on the eyes there would be lots of bright colours to choose from. Gillian would paint sparkly pink nail varnish onto her eyelids/ nails and look beautiful all night.

20.

If you monitored a spider's daily activities, you would be fascinated by their accomplishments. A spider would spend all day producing honey/ webs and admire its hard work later.

If spiders had the same biological systems as bees, we would see evidence of their hard work. A spider would spend all day producing honey/ webs and admire its hard work later.

21.

If a football match were very important, the fans would get very involved with the scoring. Football fans would cheer when a player scores a try/ goal and wave their flags with excitement.

If football used the same scoring terminology as rugby, it would save spectators' confusion. Football fans would cheer when a player scores a try/ goal and wave their flags with excitement.

22.

If holidaymakers wanted to get a great tan they would need to leave lots of time for sunbathing. People would sunbathe on the beach at midnight/ midday and wear lots of sunscreen.

If the sun only came out during the night it would change the way we spend our holidays. People would sunbathe on the beach at midnight/ midday and wear lots of sunscreen.

23.

If parents were in a good mood at Christmas they might let their children play till late. Children would stay awake on Christmas Eve to look for Elvis/ Santa and find out what their presents are.

If it were Elvis who gives presents at Christmas he would be very popular with children. Children would stay awake on Christmas Eve to look for Elvis/ Santa and find out what their presents are.

24.

If Darwin had made more time for his research, he would have given us much more to learn from.

Darwin would have published a book about the evolution of aspirin/ animals and sold lots of copies.

If Charles Darwin had been famous for his pharmaceutical work, we would learn about it in school.
Darwin would have published a book about the evolution of aspirin/ animals and sold lots of copies.

25.

If a ferry wanted to set a new world record the crew would need to be very efficient at their jobs. A ferry would travel across the Atlantic Ocean in the air/ sea and arrive in America in record time.

If a ferry were converted into a flying vessel it might save some travelling time for holidaymakers. A ferry would travel across the Atlantic Ocean in the air/ sea and arrive in America in record time.

26.

If Isaac Newton had wanted to become more influential he would have had to spend more time recording his findings. Isaac Newton would have documented his research on a laptop/ typewriter and we would all learn from it.

If Isaac Newton had had the benefit of modern technology it would have been easier to publicize his investigations. Isaac Newton would have documented his research on a laptop/ typewriter and we would all learn from it.

27.

If we had enough money for a holiday to Switzerland, books would advise us where to visit. Gary would go to Switzerland to climb the sanddunes/ mountains and get suntan to his face.

If Switzerland had the same landscape as Egypt, it would be a beautiful country to visit. Gary would go to Switzerland to climb the sanddunes/ mountains and get suntan to his face.

28.

If cats are bored and want something to do they are usually very good at letting their owners know. Judith would listen to her cat talk/ meow and throw balls of wool for it to play with.

If cats had developed language skills like humans it would be interesting to hear what they have to say. Judith would listen to her cat talk/ meow and throw balls of wool for it to play with.

29.

If footballers wanted to win an important match they would need to be skilful and work as a team. Footballers would avoid a tackle by passing the ball using their hands/ feet and running into a clear space.

If footballers were only allowed to touch the ball with their hands it would be an easier game to play. Footballers would avoid a tackle by passing the ball using their hands/ feet and running into a clear space.

30.

If birds were flying in a confined space, they require a good awareness of their surroundings. A bird would avoid collisions at night using sonar/ sight and identify locations of possible mates.

If birds were equipped with the same sensory abilities as bats, they would find them useful. A bird would avoid collisions at night using sonar/ sight and identify locations of possible mates.

31.

If the Queen died soon, the Royal family would need to appoint a new King to take her place. The next King of England would be chosen by ballot/ heredity and the coronation broadcast on TV.

If the Royal Family were selected by a public vote, everyone would be happy with the choice. The next King of England would be chosen by ballot/ heredity and the coronation broadcast on TV.

32.

If penguins want to survive, they must understand the risks in their home environment. Penguins would learn to outrun cheetah/ bears and find food for their young.

If all penguins lived in the African desert, they would have to adapt to the environment. Penguins would

learn to outrun cheetah/ bears and find food for their young.

Experimental items from Experiment 4

1.

If Eminem organised a charity event, it would be likely to be very popular with young people. Students could line up to watch Eminem teach/ sing and learn from his poignant words.

If Eminem changed professions to become a maths teacher, his fans would be disappointed. Students could line up to watch Eminem teach/ sing and learn from his poignant words.

2.

If a couple wanted a special night out, they would need to make sure they had enough money. People could collect money from a tree/ bank and spend it in one night.

If all money grew on trees, the world would be a happier place and we'd enjoy splashing out. People could collect money from a tree/ bank and spend it in one night.

3.

If travellers wanted to visit cities around the world they would need to save up before they went. Travellers could spend Euros in Delhi/ Rome and enjoy the culture around them.

If Euros were accepted in every country it would be easier for travellers when they visit new cities. Travellers could spend Euros in Delhi/ Rome and enjoy the culture around them.

4.

If dentists were invited into schools to talk to children they would offer good advice. Dentists could warn children about the dangers of eating carrots/ cakes and hopefully they would take note.

If tooth cavities were only caused by eating carrots, children would need to alter their diet. Dentists could warn children about the dangers of eating carrots/ cakes and hopefully they would take note.

5.

If students wanted to impress their teacher they would have to work hard on school projects. Students could write an essay using their feet/ hands and hopefully get a good grade.

If humans always used their feet to write they would be able to do several tasks at once. Students could write an essay using their feet/ hands and hopefully get a good grade.

6.

If farmers wanted to make lots of money, they have to take good care of their animals. Farmers could feed their pigs a bucket of sausages/ turnips and check on other animals too.

If pigs were carnivores they would be more expensive for farmers to look after. Farmers could feed their pigs a bucket of sausages/ turnips and check on other animals too.

7.

If people were interested in learning how gorillas live, they would find it interesting. People could admire gorillas in the garden/ jungle and carefully feed them special food.

If gorillas were domesticated animals like dogs they would be popular to keep as pets. People could admire gorillas in the garden/ jungle and carefully feed them special food.

8.

If you wanted to make a kind gesture, I would suggest offering a gift of flowers. Students could pick flowers from the library/ garden and give them to their mothers.

If all flowers grew out of books we would be able to make lots of daisy chains. Students could pick flowers from the library/ garden and give them to their mothers.

9.

If a tramp felt tired, he would have to look out for somewhere to rest for a while. The tramp could afford to live in a palace/ shack and share it with cheerful friends.

If a tramp won the lottery, he would be able to use the money to change his life. The tramp could afford to live in a palace/ shack and share it with cheerful friends.

10.

If Morocco were cheaper to fly to, it would be a more popular destination for family holidays. We could go to Morocco in December to ski/ sunbathe and talk to the local people.

If Morocco had the same climate as Switzerland, it would be a popular destination to visit. We could go to Morocco in December to ski/ sunbathe and talk to the local people.

11.

If someone wanted to try food and drink from around the world, it would be an exciting journey. Tourists could drink a local malt whisky in India/ Scotland and try some of the local food.

If all the famous whisky distilleries were in India, drink lovers would visit to sample the brands. Tourists could drink a local malt whisky in India/ Scotland and try some of the local food.

12.

If travellers were interested in tasting local delicacies, they would have to be adventurous. They could go to Japan to eat snails/ noodles and recreate the recipes at home.

If Japan had the same cuisine as France, it would be popular with gastronomic enthusiasts. They could go to Japan to eat snails/ noodles and recreate the recipes at home.

13.

If hunters wanted to plan an event in the countryside, there would be lots of preparation involved. Hunters could go to Wales to hunt elephants/ foxes and keep their activities a secret.

If Wales had the same wildlife as Kenya, it would lead to lots of interest in the animals. Hunters could go to Wales to hunt elephants/ foxes and keep their activities a secret.

14.

If we wanted to appreciate the history of music, it would be an exciting learning experience. We could visit New Orleans to listen to authentic reggae/ jazz and dance along with the crowds.

If New Orleans had the same music culture as Jamaica, it would be popular with musicians. We could visit New Orleans to listen to authentic reggae/ jazz and dance along with the crowds.

15.

If Sarah wanted to master traditional dances from around the world, she would have to practise hard. Sarah could travel to New Zealand to learn the salsa/ Haka and brag to friends at home.

If New Zealand had all the same customs as Cuba, it would be a good destination to learn new things. Sarah could travel to New Zealand to learn the salsa/ Haka and brag to friends at home.

16.

If you want an honest opinion about the way of life in Peru, the local people are very informative. Tourists could go to Peru to meet Maoris/ Incas and learn about their cultural style.

If Peru were populated by the same native people as New Zealand, it would be a lively place to visit. Tourists could go to Peru to meet Maoris/ Incas and learn about their cultural style.

17.

If someone wanted a relaxing holiday abroad, I would recommend an Island paradise like Hawaii. Holidaymakers could visit Hawaii to stay in an igloo/ villa and admire views from their window.

If Hawaii had the same weather as the Arctic, the locals would need to keep warm in winter. Holidaymakers could visit Hawaii to stay in an igloo/ villa and admire views from their window.

18.

If someone were doing a project on Scotland's weather, they would need to ask residents for information. People living in Scotland could experience monsoons/ snow and beware of the temperamental weather.

If Scotland had the same climate patterns as Africa, locals would complain noisily about the conditions. People living in Scotland could experience monsoons/ snow and beware of the temperamental weather.

19.

If a stag group wanted celebrate in style with drinks, there are many vibrant cities to choose from. Stag groups could drink authentic sangria in Dublin/ Madrid and enjoy the city's lively atmosphere.

If sangria were the national drink of Ireland, it would be readily available to visitors and locals. Stag groups could drink authentic sangria in Dublin/ Madrid and enjoy the city's lively atmosphere.

20.

If vets updated their training every few years, there would be lots of new techniques to learn. Vets could learn how to treat injured unicorns/ puppies and write books to teach others.

If vets were only trained to treat mythical animals, it would be a complicated course to complete. Vets could learn how to treat injured unicorns/ puppies and write books to teach others.

21.

If someone wanted to buy authentic cigars, I would advise they save them for a special occasion. People could buy hand-rolled cigars in London/ Havana and smoke them to celebrate birthdays.

If all authentic cigars were made in the UK, it would be possible to buy hand rolled cigars locally. People could buy hand-rolled cigars in London/ Havana and smoke them to celebrate birthdays.

22.

If Christians have enough time, they enjoy celebrating their religious holidays with others. Christian revellers could celebrate Passover/ Christmas and spend time with their families.

If Christians celebrated the same religious holidays as Jews, it would be a busy time of year. Christian revellers could celebrate Passover/ Christmas and spend time with their families.

23.

If you were interested in visiting the Scottish Isles, trips can be arranged through travel agents. Visitors could travel between the Islands by subway/ ferry and avoid the usual dirty pollution.

If the Scottish Isles used the same transport system as New York, it would make travel easier. Visitors could travel between the Islands by subway/ ferry and avoid the usual dirty pollution.

24.

If you had expensive wine in the house, it would be nice to share it. Gangsters could happily give a bottle of wine to their enemies/ friends and tell others in the gang.

If wine were deadly like poison, it would be a popular weapon with criminals. Gangsters could happily give a bottle of wine to their enemies/ friends and tell others in the gang.

25.

If policemen worked hard at their training, they would become very good at their jobs. Policemen could mastermind an assault/ arrest and tell the story to journalists.

If policemen caused crime rather than preventing it, they would lose a lot of public respect. Policemen could mastermind an assault/ arrest and tell the story to journalists.

26.

If tourists were interested in seeing the Golden Gate Bridge, I would suggest they cycle across it. People could visit the Golden Gate Bridge in America/ England and have a professional photo taken.

If the Golden Gate Bridge were moved to London, joggers would enjoy running across it. People could visit the Golden Gate Bridge in America/ England and have a professional photo taken.

27.

If you wanted to add flavour to food, including sugar can help make the dish more appetizing. Cooks could use sugar to make food spicy/ sweet and make a deliciously filling meal.

If sugar were hot like curry powder, people would need to change the way it is used in recipes. Cooks could use sugar to make food spicy/ sweet and make a deliciously filling meal.

28.

If a chef wanted to make some traditional food with vinegar, he would look for a recipe. Chefs could use vinegar to make a cake/ dressing and charge high prices in restaurants.

If vinegar were sweet like syrup, children would enjoy having a lot more of it in food. Chefs could use vinegar to make a cake/ dressing and charge high prices in restaurants.

29.

If we were interested in the behaviours of fish, it is valuable to see them in the wild. We could observe tuna fish resting on the grass/ riverbed and wish we could eat one.

If fish could only survive out of the water, they would be able to see more of the world. We could observe tuna fish resting on the grass/ riverbed and wish we could eat one.

30.

If Prince Charles organizes an event when he becomes King, many British citizens would attend. Crowds of people could watch Prince Charles' funeral/ coronation and wave big Union Jack flags.

If Prince Charles died suddenly in an accident, there would be a period of public mourning. Crowds of people could watch Prince Charles' funeral/ coronation and wave big Union Jack flags.

31.

If couples were becoming irritated with each other, it helps to live apart for a while. A wife could travel to see her husband in a rocket/ train and leave when he became annoying.

If all men lived on Mars, there would be fewer arguments between the sexes. A wife could travel to see her husband in a rocket/ train and leave when he became annoying.

32.

If meat were in short supply, workers would need to work hard to keep up with public demand. Pork meat could be produced in a lab/ farm and we'd enjoy a good dinner.

If all meat were grown in test tubes, no animals would need to be killed to make sausages. Pork meat could be produced in a lab/ farm and we'd enjoy a good dinner.

33.

If an athlete trained relentlessly, they would do their best to beat the effects of gravity. Athletes could high jump about two miles/ metres and set soaring new world records.

If gravity on earth were like on the moon, we would be able to do amazing acrobatics. Athletes could high jump about two miles/ metres and set soaring new world records.

34.

If you were feeling under the weather with flu, a doctor can help alleviate the symptoms. Doctors could cure a headache with an operation/ aspirin and expect a quick recovery time.

If all flu symptoms needed surgery to be alleviated, it would cost the NHS a lot of money. Doctors could cure a headache with an operation/ aspirin and expect a quick recovery time.

35.

If Londoners wanted to visit Manchester for a day-trip, they would buy tickets in advance. People could travel from London to Manchester by boat/ bus and buy postcards for their friends.

If Manchester were an island like the Arran, it would be more popular with day-trippers. People could travel from London to Manchester by boat/ bus and buy postcards for their friends.

36.

If Sarah worked hard at her degree work, it would pay off when she finally graduated. Sarah could gain her medicine degree from a restaurant/ university and her parent would be proud.

If all degrees were gained from the hospitality industry, the courses would be very busy. Sarah could gain her medicine degree from a restaurant/ university and her parent would be proud.

37.

If Mum had just bought a new fridge for the kitchen, she would look forward to trying it out. Mum could put chicken in the fridge to keep warm/ cool and serve it for Sunday lunch.

If a fridge were used to heat food like an oven, it would be a useful appliance in a family home. Mum could put chicken in the fridge to keep warm/ cool and serve it for Sunday lunch.

38.

If a mother were very enthusiastic about her baby, she would be very happy to watch its progress. A baby could make his mum proud by graduating/ crawling and show photos to her friends.

If a baby were born with the intelligence of an adult, they would be easier for mums to look after. A baby could make his mum proud by graduating/ crawling and show photos to her friends.

39.

If a jeweller's were known for selling diamonds, it would be very busy at Christmas time. Jewellers could sell huge diamonds for very cheap/ expensive and they would look impressive on.

If diamonds were made from simply burning paper, they would be common among women. Jewellers could sell huge diamonds for very cheap/ expensive and they would look impressive on.

40.

If school children wanted to know more about Hitler, there are lots of books available on him. Children could learn that Hitler was renowned for his smile/ severity and students would learn about him.

If Hitler had been a kind and friendly man, he would have been a popular leader of Germany. Children could learn that Hitler was renowned for his smile/ severity and students would learn about him.

41.

If Markus wanted to climb some European mountain ranges, he would need to be prepared. Markus could go on a mountaineering holiday in Holland/ Italy and wear his new hiking boots.

If all European mountain ranges were in the North, it would be popular tourist area. Markus could go on a mountaineering holiday in Holland/ Italy and wear his new hiking boots.

42.

If seagulls want their young to survive, they must teach them skills they will need later on. Seagulls could teach their young how to swim/ fly and pinch chips from the paper.

If seagulls had evolved with fins instead of wings, it would be harder for them to steal our food. Seagulls could teach their young how to swim/ fly and pinch chips from the paper.

43.

If penguins want to survive, they must understand the risks in their home environment. Penguins could learn to outrun cheetah/ bears and find food for their young.

If all penguins lived in the African desert, they would have to adapt to the environment. Penguins could learn to outrun cheetah/ bears and find food for their young.

44.

If your ears were bothering you, our other senses are very good at making up for the problem. You could block your ears to stop you being able to smell/ hear and the flu wouldn't be bad.

If we had evolved to smell through our ears, it would probably change our other senses as well. You could block your ears to stop you being able to smell/ hear and the flu wouldn't be bad.

45.

If building bricks in a house caught fire, it can cause substantial damage to a home. A house fire could cause the bricks to melt/ burn and many firemen would be called.

If all building bricks were made from ice, safety would be an issue in their maintenance. A house fire could cause the bricks to melt/ burn and many firemen would be called.

46.

If you were interested in Australia's wildlife, a holiday 'down under' is well worth the money. Tourists could go to Australia to observe Triceratops/ kangaroos and to buy special Aussie souvenirs.

If Australia were inhabited solely by dinosaurs, expensive holiday tours would be popular. Tourists could go to Australia to observe Triceratops/ kangaroos and to buy special Aussie souvenirs.

47.

If an astronaut were preparing for a trip to the moon, we would follow the journey on the TV. A trip to the moon could take one hour/ month and we would see fantastic views.

If there existed an express shuttle between Earth and the Moon, it would be an exciting journey. A trip to the moon could take one hour/ month and we would see fantastic views.

48.

If the police had a crack-down on illegal drugs in the UK, many offenders would be caught. Ryan could be arrested by the police for possession of coffee/ heroin and maybe get sent to prison.

If caffeine were made the only illegal drug in the UK, a black market would be sure to develop. Ryan could be arrested by the police for possession of coffee/ heroin and maybe get sent to prison.

49.

If a couple wanted to have a child, they would need to be well prepared for the birth. Human babies could be born to males/ females and the parents would be happy.

If humans reproduced like seahorses, scientists would be interested in studying them. Human babies could be born to males/ females and the parents would be happy.

50.

If we wanted to get into a normal sleeping pattern, it is important to be committed. Everybody could sleep all through the day/ night and struggle wake up quickly.

If humans were nocturnal animals, the pattern of our lives would change dramatically. Everybody could sleep all through the day/ night and struggle to wake up quickly.

51.

If a horse were determined to win a rosette in a show, they would need to impress the crowd. A horse could clear a cross-country course by flying/ jumping and dazzle the judges with skills.

If horses had evolved with wings rather than legs, they would be very elegant animals to watch. A horse could clear a cross-country course by flying/ jumping and dazzle the judges with skills.

52.

If you have lots of onions in your garden, they would be useful in many recipes. People could use fresh onions to make a pudding/ casserole and offer it to dinner guests.

If onions tasted really sweet, they would be more popular at meal-times. People could use fresh onions to make a pudding/ casserole and offer it to dinner guests.

53.

If you want to do well at school, books contain interesting information on most topics. Students could get information from books by listening/ reading and pass exams with high marks.

If books provided information orally when opened, they would be useful in schools. Students could get information from books by listening/ reading and pass exams with high marks.

54.

If you wanted a cultural holiday, there is plenty to see and do in the USA. Tourists could go to the USA to meet their Queen/ President and watch big colourful street parades.

If the USA were run by a monarchy, it would attract more cultural visitors. Tourists could go to the USA to meet their Queen/ President and watch big colourful street parades.

55.

If a dressmaker's were running short of new materials, they would need to order a bulk lot. The dressmaker's could be cluttered with expensive bricks/ fabric and the owner would be stressed.

If a dressmaker's were transformed into a building site, it would be very busy place indeed. The dressmaker's could be cluttered with expensive bricks/ fabric and the owner would be stressed.

56.

If students were having difficulty with algebra, a tutor would be able to assist. All pupils could become expert in algebra at age three/ sixteen and work hard at other subjects.

If algebra were very easy to learn, students wouldn't complain about it so much. All pupils could become expert in algebra at age three/ sixteen and work hard at other subjects.

57.

If a broken bone were painful, a doctor would provide some useful advice on the condition. Timmy's broken leg could be mended in two hours/ months and his Mum wouldn't be worried.

If broken bones were healed immediately with an injection, patients would be relieved. Timmy's broken leg could be mended in two hours/ months and his Mum wouldn't be worried.

58.

If young children were interested in seeing a giraffe, parents would organise a trip to see some. Parents could find a giraffe at the airport/ zoo and children would get very excited.

If all giraffes were used by the police to sniff out drugs, they would be common in the UK. Parents could find a giraffe at the airport/ zoo and children would get very excited.

59.

If Joanne had some roast beef to spare, she would find many recipes to include it in. Joanne could put roast beef into a cake/ curry and teach the family to cook.

If roast beef tasted like strawberries, people would find many recipes to include it in. Joanne could put roast beef into a cake/ curry and teach the family to cook.

60.

If someone were going on a long car journey, they would need to ensure they were prepared. Drivers could fill their car with cola/ petrol and buy sandwiches for their lunch.

If all vehicles ran on fizzy drinks, supermarkets would make huge profits from the sales. Drivers could fill their car with cola/ petrol and buy sandwiches for their lunch.

61.

If scientists studied dolphins' behaviour, they would need to observe them in the wild. Dolphins could communicate with scientists using speech/ squeaks and give insights to their lives.

If dolphins were able to talk, biologists would be able to understand more about them. Dolphins could communicate with scientists using speech/ squeaks and give insights to their lives.

62.

If the Queen died soon, the Royal family would need to appoint a new King to take her place. The next King of England could be chosen by ballot/ heredity and the coronation broadcast on TV.

If the Royal Family were selected by a public vote, everyone would be happy with the choice. The next King of England could be chosen by ballot/ heredity and the coronation broadcast on TV.

63.

If Europeans wanted to improve communication, it would help to learn each other's backgrounds. Scottish people could converse easily with Germans/ Americans and discuss their different cultural qualities.

If everyone in Europe spoke the same new language, it would change relations between countries. Scottish people could converse easily with Germans/ Americans and discuss their different cultural qualities.

64.

If David Beckham were on TV showing off his skills, he would excite his large female following. David Beckham could impress women at the pool/ pitch and get offered good sponsorship deals.

If David Beckham were famous for his swimming skills, he would have a large female following. David Beckham could impress women at the pool/ pitch and get offered good sponsorship deals.

65.

If a fishmonger were well known for excellent products, it would be busy all day. Sam could go to the fishmonger to buy goldfish/ scampi and his family would be happy.

If a fishmonger sold live fish as pets, it would be busy with inquisitive people. Sam could go to the fishmonger to buy goldfish/ scampi and his family would be happy.

66.

If all the acts in the Eurovision song contest were superb, it would be tough to choose a winner. Eurovision could be won by an act from China/ Spain and the crowds would cheer loudly.

If the Eurovision song contest were only open to Asian countries, it would be a popular event. Eurovision could be won by an act from China/ Spain and the crowds would cheer loudly.

67.

If you had time, it would be useful to research the Antarctic's natural world before going. Visitors to the Antarctic could take a trip to see alligators/ penguins and take photos to show friends.

If the Antarctic were as warm as Florida, it would be a popular destination all year round. Visitors to the Antarctic could take a trip to see alligators/ penguins and take photos to show friends.

68.

If you were shopping for a holiday to Dubai, it would be good to know what weather to expect. Visitors to Dubai could wake up in January to see snow/ sun and dress suitably for the weather.

If Dubai had the same weather as Scotland, it would affect the local tourist industry. Visitors to Dubai could wake up in January to see snow/ sun and dress suitably for the weather.

69.

If you were visiting New Zealand, it would be interesting to watch local sportsmen at their best. Sports fans could visit New Zealand to watch a game of baseball/ rugby and support the highest scoring team.

If New Zealand adopted America's national sport as their own, it would take practise to perfect. Sports fans could visit New Zealand to watch a game of baseball/ rugby and support the highest scoring team.

70.

If a big European football match were taking place, sports enthusiasts would get excited. The Marseillaise could be sung by football fans from England/ France and everyone would feel very patriotic.

If France and England swapped national anthems, sports enthusiasts would get excited. The Marseillaise could be sung by football fans from England/ France and everyone would feel very patriotic.

71.

If trade relied on communication between countries, some interactions would be easier than others. American people could understand Russians/ Australians and swap stories about their countries.

If all Northern hemisphere countries only spoke Spanish, it would revolutionize communication. American people could understand Russians/ Australians and swap stories about their countries.

72.

If Tom were in a bad mood, he would be likely to take his frustrations out on things around him. Tom could stamp on a sheet of glass to make it bend/ shatter and throw it around his room.

If glass were made of a flexible material like rubber, it would be safe to use around children. Tom could stamp on a sheet of glass to make it bend/ shatter and throw it around his room.

73.

If Elton John were feeling romantic, he would act on impulse to get married. Elton John could be photographed marrying a woman/ man and tabloids would cover the story.

If Elton John were heterosexual, his fans would be quite surprised by the news. Elton John could be photographed marrying a woman/ man and tabloids would cover the story.

74.

If birds were flying in a confined space, they require a good awareness of their surroundings. A bird could avoid collisions at night using sonar/ sight and identify locations of possible mates.

If birds were equipped with the same sensory abilities as bats, they would find them useful. A bird could avoid collisions at night using sonar/ sight and identify locations of possible mates.

75.

If you were determined to cure a fear of jumbo jets, taking a short trip in one would be helpful. A jumbo jet could travel across the English Channel in the water/ air and transport passengers across water safely.

If a jumbo jet were converted into a floating seaplane, it would be a popular mode of transport. A jumbo jet could travel across the English Channel in the water/ air and transport passengers across water safely.

76.

If the Pope allowed himself more time for social occasions, he would enjoy the experience. The Pope could hold a private celebration for his wedding/ celibacy and many friends would join him.

If the Catholic Church insisted that the Pope get married, he would enjoy the experience. The Pope could hold a private celebration for his wedding/ celibacy and many friends would join him.

77.

If we had enough money for a holiday to Switzerland, books would advise us where to visit. Gary could go to Switzerland to climb the sanddunes/ mountains and get suntan to his face.

If Switzerland had the same landscape as Egypt, it would be a beautiful country to visit. Gary could go to Switzerland to climb the sanddunes/ mountains and get suntan to his face.

78.

If you had some spare time in the evenings, following an IT course would teach useful skills. Ian could take an IT course to improve his fitness/ computing and his colleagues would be impressed.

If an IT course consisted of aerobic exercise, you should sign up early to avoid disappointment. Ian could take an IT course to improve his fitness/ computing and his colleagues would be impressed.

79.

If you were interested in Florida's wildlife, tour guides would offer to show you around. We could go Florida to see wild penguins/ pelicans and ask questions about their diet.

If Florida were part of the North Pole, visitors would be interested in seeing the wildlife. We could go Florida to see wild penguins/ pelicans and ask questions about their diet.

80.

If mosquitoes want to breed, they must make sure they congregate in their optimum environment. Mosquitoes could be in abundance in Iceland/ Thailand and frustrate all the local residents.

If mosquitoes thrived in cold and dry climates, precautions would be taken to avoid nasty bites. Mosquitoes could be in abundance in Iceland/ Thailand and frustrate all the local residents.

81.

If parents knew more about the causes of tooth decay, they would tailor the family's diet accordingly. Children could get tooth decay from eating too many carrots/ sweets and cry about visiting the dentist.

If eating vegetables were the sole cause of tooth decay, parents would tailor the family's diet accordingly. Children could get tooth decay from eating too many carrots/ sweets and cry about visiting the dentist.

82.

If school children were being particularly naughty, teachers have ways to punish them. Teachers could threaten bad pupils with handguns/ detention and students would work much harder.

If teachers were legally allowed to kill, children would be too frightened to misbehave. Teachers could threaten bad pupils with handguns/ detention and students would work much harder.

83.

If children are bored, parents often suggest that they play games with their friends. Children could spend weekends playing tag in a motorway/ field and burn up a good appetite.

If cars were only allowed to drive on grass, pedestrians would need to adjust. Children could spend weekends playing tag in a motorway/ field and burn up a good appetite.

84.

If Victoria were going a holiday to Bangkok, it would help to plan an itinerary for travel. Victoria could get from Newcastle to Bangkok in a second/ day and visit the beautiful local attractions.

If it were possible to teleport from one place to another, foreign travel would be easy. Victoria could get from Newcastle to Bangkok in a second/ day and visit the beautiful local attractions.

85.

If a train were making a long journey, it would be necessary to refuel on route. Railway stations could refuel their trains with milk/ diesel and send them on long journeys.

If all trains ran on dairy products, pollution would be a much smaller problem. Railway stations could refuel their trains with milk/ diesel and send them on long journeys.

86.

If a retirement home were very large and modern, it would earn a lot of money from residents. Retirement homes could be full of students/ pensioners and charge high rates for entry.

If all retirement homes were turned into nightclubs, they would make a lot more money. Retirement homes could be full of students/ pensioners and charge high rates for entry.

87.

If a bedroom needed to be refurbished for Christmas, it is important to get organised early. Russell could redecorate his bedroom with a new toilet/ wardrobe and make sure colours matched well.

If bedrooms contained only bathroom furniture, they would need regular cleaning. Russell could redecorate his bedroom with a new toilet/ wardrobe and make sure colours matched well.

88.

If you learn the colourings of common birds, Robins are easily identifiable. Birdwatchers could associate Robins with the colour blue/ red and note their sightings in books.

If Robins had evolved to have a blue breast, they would be easily identifiable. Birdwatchers could associate Robins with the colour blue/ red and note their sightings in books.

89.

If Victoria Beckham agreed to be weighed in public, fans would be intrigued to know her weight. Victoria Beckham could weigh the same as Pavarotti/ Kylie and spend a fortune on clothes.

If Victoria Beckham put on a lot of weight, the British public would be very surprised. Victoria Beckham could weigh the same as Pavarotti/ Kylie and spend a fortune on clothes.

90.

If George Bush discovered an important political issue, he would be quick to do make his views known. George Bush could introduce new laws in Portugal/ America and the public would probably comply.

If George Bush were reassigned as president of all European countries, it would upset some residents. George Bush could introduce new laws in Portugal/ America and the public would probably comply.

91.

If Darwin had made more time for his research, he would have given us much more to learn from. Darwin could have published a book about the evolution of aspirin/ animals and sold lots of copies.

If Charles Darwin had been famous for his pharmaceutical work, we would learn about it in school. Darwin could have published a book about the evolution of aspirin/ animals and sold lots of copies.

92.

If George Best wanted to get the crowds excited, he would show off his impressive ball skills. George Best could have amazed fans with his bowling/ tackling and signed autographs after the game.

If George Best had been a legendary cricket player, he would have made the sport more exciting. George Best could have amazed fans with his bowling/ tackling and signed autographs after the game.

93.

If a football match were very important, the fans would get very involved with the scoring. Football fans could cheer when a player scores a try/ goal and wave their flags with excitement.

If football used the same scoring terminology as rugby, it would save spectators' confusion. Football fans could cheer when a player scores a try/ goal and wave their flags with excitement.

94.

If it is dark outside, birds have clever ways to locate and interact with each other. Birds could communicate to each other with croaks/ tweets and use it as a mating call.

If birds had the same vocal system as frogs, they would annoy people with the noise. Birds could communicate to each other with croaks/ tweets and use it as a mating call.

95.

If you monitored a spider's daily activities, you would be fascinated by their accomplishments. A spider could spend all day producing honey/ webs and admire its hard work later.

If spiders had the same biological systems as bees, we would see evidence of their hard work. A spider could spend all day producing honey/ webs and admire its hard work later.

96.

If you wanted to see polar bears in the wild, you would need to go to their natural environment. We could see polar bears roaming the Rainforest/ Antarctic and observe their relations with other species.

If polar bears had evolved to favour hot climates, we would be interested in their behaviour. We could see polar bears roaming the Rainforest/ Antarctic and observe their relations with other species.

97.

If Magaluf offered cheaper holiday deals, it would be bustling with people from all over the world. People could travel to Magaluf for the research/ clubbing and take souvenirs for friends at home.

If Magaluf were converted into an ancient archaeological site, it would be bustling with excited people. People could travel to Magaluf for the research/ clubbing and take souvenirs for friends at home.

98.

If a child were keen to be taught new things, school is the best place for varied information. Pupils could go to school to learn spells/ maths and practise at home with their parents.

If schools only taught wizard skills like at Hogwarts, you would learn new things every day. Pupils could go to school to learn spells/ maths and practise at home with their parents.

99.

If we bought a Barbie doll that performs actions, we would need to find out how to power it. Barbie dolls could get energy from food/ batteries and remain active throughout the day.

If all toys were living things like humans, they would be good companions for children. Barbie dolls could get energy from food/ batteries and remain active throughout the day.

100.

If you had building blocks remaining from a build, it would be tempting to fiddle with them. We could hit a building block to make it wobble/ shatter and re-use the blocks elsewhere.

If all building blocks were made of jelly, it would be entertaining to play with them. We could hit a building block to make it wobble/ shatter and re-use the blocks elsewhere.

101.

If students were debating what owls look like, a good teacher would clear it up quickly. Owls could be described as feeling slippery/ downy and their claws would be sharp.

If owls had evolved with scales all over their bodies, they would be fascinating to look at. Owls could be described as feeling slippery/ downy and their claws would be sharp.

102.

If researchers were interested in chickens, their reproduction would be fascinating. Environmentalists could watch chickens give birth to chicks/ eggs and check they are kept safe.

If chickens were mammals, their behaviour would be interesting to examine. Environmentalists could watch chickens give birth to chicks/ eggs and check they are kept safe.

103.

If you had planned to visit America, it is recommended that you watch a local sporting event. Visitors could go to Chicago to watch bullfights/ baseball and join the crowds of spectators.

If America had the same national sport as Spain, it would be a popular destination for enthusiasts. Visitors could go to Chicago to watch bullfights/ baseball and join the crowds of spectators.

104.

If Santa had enough time, he would work hard to deliver presents like in the storybooks. Santa could give presents to children who'd been bad/ good and they would be very excited.

If Santa Claus only gave presents to naughty children, he would be a very busy person. Santa could give presents to children who'd been bad/ good and they would be very excited.

105.

If a caterpillar had eaten enough leaves, it would be ready to transform into its next stage. A caterpillar could mature into a sparrow/ butterfly and enjoy testing its new wings.

If caterpillars turned into birds in the chrysalis, it would be an amazing transformation to study. A caterpillar could mature into a sparrow/ butterfly and enjoy testing its new wings.

106.

If you were feeling a bit down, sweets usually make you feel happier and more relaxed. We could pick up lollypops from the woods/ shops and eat them as a treat.

If all sweets grew on trees they would look very pretty when out walking in the country. We could pick up lollypops from the woods/ shops and eat them as a treat.

107.

If they had enough training, spacemen would go to the moon to study the environment. Spacemen could fly to the moon to collect cheese/ rocks and scientists would analyse the specimen.

If the moon really were made of cheese, it would be an interesting place to study. Spacemen could fly to the moon to collect cheese/ rocks and scientists would analyse the specimen.

108.

If a train is about to make a long journey, there is a lot of activity from the people on board. A train driver could be in charge of the mainsail/ engine and staff would look after passengers.

If trains were powered by wind like tall ships, they would be cheap to operate all year round. A train driver could be in charge of the mainsail/ engine and staff would look after passengers.

109.

If someone took up a martial arts class, they would find it really hard work to become good. A martial arts teacher could demonstrate expertise in cookery/ fighting and students would be in awe.

If a martial arts class taught students catering skills, people would compete to be the best. A martial arts teacher could demonstrate expertise in cookery/ fighting and students would be in awe.

110.

If a golfer were keen to win the tournament, he would need to sharpen up his technique. A golfer could hurt his shoulder from swinging his racket/ club and visit a physio for treatment.

If golf used the same equipment as tennis, players would work hard to improve their technique. A golfer could hurt his shoulder from swinging his racket/ club and visit a physio for treatment.

111.

If the library was very busy at weekends, I would suggest going early in the morning. Mrs. Jones could go to the library for some salami/ books and enjoy relaxing all afternoon long.

If all libraries were converted into a delicatessen, shopping trips would be peaceful. Mrs. Jones could go to the library for some salami/ books and enjoy relaxing all afternoon long.

112.

If a video rental store were busy at weekends, we would have to go early to beat the rush. Helen could go to the video rental store to borrow a book/ film and enjoy it with her friends.

If a video rental store were converted into a library, it would be a busy place at weekends. Helen could go to the video rental store to borrow a book/ film and enjoy it with her friends.

113.

If students at a flower arranging class were keen to learn new things, they would have to concentrate. A student at a flower arranging class could break a keyboard/ vase and have to pay a fine.

If flower arranging classes were taught entirely on computers, students would have to concentrate. A student at a flower arranging class could break a keyboard/ vase and have to pay a fine.

114.

If a flower show had lots of things to see, the public would need to be selective about what to see. Pensioners could visit a flower show to see the tigers/ tulips and ask staff about their job.

If a flowers show only exhibited wild animals, the public would be interested to visit the displays. Pensioners could visit a flower show to see the tigers/ tulips and ask staff about their job.

115.

If a fast food joint were very quiet at lunchtimes, it would rely on customers' endorsements. John could go to the fast food joint to buy some birdseed/ chips and recommend it to many friends.

If a fast food joint only sold animal supplies, it would rely on customers' endorsements. John could go to the fast food joint to buy some birdseed/ chips and recommend it to many friends.

116.

If there were a slow moving queue at the greengrocers, customers would find it frustrating. John could go to the greengrocers to buy tickets/ potatoes and meet friends in the pub after.

If all greengrocers were converted into a theatre box office, they would need to advertise well. John could go to the greengrocers to buy tickets/ potatoes and meet friends in the pub after.

117.

If the US embassy were not busy, the public would be intrigued to look around during their visit. People could go to the US embassy to collect a painting/ passport and enjoy friendly chat with staff.

If the US embassy were turned into an art gallery, the public would be intrigued to look around. People could go to the US embassy to collect a painting/ passport and enjoy friendly chat with staff.

118.

If hairdressers wanted to ensure customer satisfaction, they would need to keep up with demand. Mrs Jones could go to the hairdressers to buy a dress/ shampoo and save it for special occasions.

If hairdressers specialised in selling items of clothing, it would be a profitable business to run. Mrs Jones could go to the hairdressers to buy a dress/ shampoo and save it for special occasions.

119.

If you had a lot of money to spare, I would recommend splashing out on new clothes. Mrs Bruce could buy a new jacket from Harrods to eat/ wear and her friends would be jealous.

If all clothes were edible, we would spend a lot of money buying them each month. Mrs Bruce could buy a new jacket from Harrods to eat/ wear and her friends would be jealous.

120.

If a couple fancied some Indian cuisine, there are lots of meal choices on offer. Lovers could go to an Indian restaurant to eat some pasta/ curry and feel very full all night.

If Indian cuisine were the same as Italian, we would buy cookbooks for the recipes. Lovers could go to an Indian restaurant to eat some pasta/ curry and feel very full all night.

121.

If a fancy dress shop had a lot of new stock, the staff would need to display it well. Claire could go to the fancy dress shop to buy a computer/ costume and admire it back at home.

If a fancy dress shop sold only IT products, the staff would be very knowledgeable. Claire could go to the fancy dress shop to buy a computer/ costume and admire it back at home.

122.

If a ballet competition were coming up, dancers would ensure they prepared well in advance. Stuart could go to a ballet class to practise his tackling/ pirouette and warm up his muscles beforehand.

If ballet were an aggressive sport like rugby, risk of injuries would make it a dangerous sport. Stuart could go to a ballet class to practise his tackling/ pirouette and warm up his muscles beforehand.

123.

If an electrical store were very busy, the staff would need to be efficient at serving customers. Mrs Smith could go to an electrical store to buy a melon/ kettle and rush home to try it.

If an electrical store only sold fresh fruit and vegetables, the staff would need to be efficient. Mrs Smith could go to an electrical store to buy a melon/ kettle and rush home to try it.

124.

If an appliance showroom were messy, it would need cleaned so customers find what they want. Harry could go to the appliance showroom to buy a beer/ plug and his wife would be glad.

If all appliance showrooms were converted into pubs, they would very busy on Saturdays. Harry could go to the appliance showroom to buy a beer/ plug and his wife would be glad.

125.

If someone were interested in learning a foreign language, a selection of courses is available. A student could take a foreign language course to improve his painting/ French and make his parents very proud.

If a foreign language course only taught artistic skills, it would be a popular course for all ages. A student could take a foreign language course to improve his painting/ French and make his parents very proud.

126.

If Jenny wanted to make her house very clean, there would be lots of preparation involved. Jenny could use a toothbrush to brush her floors/ teeth and make them look sparkling clean.

If a toothbrush were as big as a broom, it would be useful for improving sanitation in homes. Jenny could use a toothbrush to brush her floors/ teeth and make them look sparkling clean.

127.

If the children were getting rowdy, supermarkets are busy places that should keep them occupied. Mary could take her children to the supermarket to swim/ shop and battle the crowds of families.

If all supermarkets were converted into leisure centres, they would be very busy at weekends. Mary could take her children to the supermarket to swim/ shop and battle the crowds of families.

128.

If a family were considering a holiday to Cairo, I would describe the sightseeing attractions. People could visit Cairo to see the Louvre/ pyramids and take photos for their album.

If Cairo were the capitol city of France, it would be a popular destination with tourists. People could visit Cairo to see the Louvre/ pyramids and take photos for their album.

129.

If husbands wanted a gift for their wives, shoe shops offer a range of exciting merchandise. Husbands could go to a shoe shop to buy some roses/ trainers and their wives would be happy.

If shoe shops sold only flowers, there would be lots of choice for buying gifts for loved ones. Husbands could go to a shoe shop to buy some roses/ trainers and their wives would be happy.

130.

If a plumber had the appropriate tools, he could do his job a lot faster. Sarah could call a plumber to fix her broken ankle/ toilet and she would be very relieved.

If a plumber were trained in medicine, he would be very useful indeed. Sarah could call a plumber to fix her broken ankle/ toilet and she would be very relieved.

131.

If you wanted to change your hairstyle completely, your friends would be very impressed. You could have your hair cut by a dentist/ hairdresser and show it off at parties.

If you were willing to have your hair cut by an amateur, your friends might think it was funny. You could have your hair cut by a dentist/ hairdresser and show it off at parties.

132.

If birds were a rare species, they would attract a lot of attention from wildlife lovers. School pupils could go to the countryside to study birds swimming/ flying and write a report about it.

If all birds lived underwater like fish, it would be fascinating to observe their existence. School pupils could go to the countryside to study birds swimming/ flying and write a report about it.

133.

If we had enough money, travel agents would be keen to help us find a suitable holiday. We could go to Greenland in November to sunbathe/ sledge and escape work for a week.

If Greenland had really hot winters like Dubai, it would be popular with tourists of all ages. We could go to Greenland in November to sunbathe/ sledge and escape work for a week.

134.

If someone were interested in the law, they would be encouraged to study at a good university. A student could become a solicitor by studying medicine/ Law and impress his family and friends.

If aspects of the law were only taught in a medical course, there would be lots of books to read. A student could become a solicitor by studying medicine/ Law and impress his family and friends.

135.

If a young couple wanted to enjoy a good night out, there's a lot to choose from in a big city. John could invite Mary to the cinema for a dance/ movie and they would have great fun.

If all cinemas were transformed into a nightclub, they would be a popular with young people. John could invite Mary to the cinema for a dance/ movie and they would have great fun.

136.

If cats are hungry, they usually pester their owners until they get fed. Families could feed their cat a bowl of carrots/ fish and listen to it purr happily.

If cats were vegetarians, they would be cheaper for owners to look after. Families could feed their cat a bowl of carrots/ fish and listen to it purr happily.

137.

If Mum were organising a children's party, games and refreshments would need to be planned. Young children could drink bottles of vodka/ milk and dance long into the night.

If children were only allowed to drink alcoholic drinks, they would be likely to get over-excited. Young children could drink bottles of vodka/ milk and dance long into the night.

138.

If newspaper reporters wanted to impress the boss, they would have to discover a big story. Reporters could carry out an interview with Elvis/ Kylie and ask what inspired the music.

If it were possible to travel back to the 1950's, our newspapers would be full of exciting stories. Reporters could carry out an interview with Elvis/ Kylie and ask what inspired the music.

139.

If Shakespeare had wanted to make his plays longer, he shouldn't have killed off the main characters. Romeo and Juliet could have communicated by text/ letter and their families wouldn't have known.

If mobile phones were the only way to communicate in the 1500's, literature would be very different. Romeo and Juliet could have communicated by text/ letter and their families wouldn't have known.

140.

If ants feel threatened on the ground, they would have to move fast to escape the danger. A colony of ants could escape from predators by flying/ climbing and building their nests in trees.

If ants had wings instead of legs, they would feel safer from the predators that hunt them. A colony of ants could escape from predators by flying/ climbing and building their nests in trees.

141.

If you wanted to go somewhere interesting, it's good to hear what people recommend. Groups of friends could see kittens in a zoo/ farm and maybe get to feed them.

If all kittens lived in zoos, they would be popular with visitors as they are very cute. Groups of friends could see kittens in a zoo/ farm and maybe get to feed them.

142.

If Steve wanted to take a week off work, I would recommend he travel around Europe. Steve could see the Eiffel Tower in Germany/ France and boast to friends at home.

If the Eiffel Tower were moved to Berlin, it would be gratefully received by the community. Steve could see the Eiffel Tower in Germany/ France and boast to friends at home.

143.

If Tony Blair wanted to attract a big audience, he would need to host events for the public. Crowds of people could watch Tony Blair lead an opera/ campaign and hopefully they would enjoy it.

If Tony Blair were famous as an opera singer, he would put on a fabulous show for his audiences. Crowds of people could watch Tony Blair lead an opera/ campaign and hopefully they would enjoy it.

144.

If you are hungry while out of the house, supermarkets have a lot of choice available. You could enjoy a milkshake by the slice/ glass and have energy till the evening.

If milkshakes were frozen to ice cream, it would be popular with people of all ages. You could enjoy a milkshake by the slice/ glass and have energy till the evening.

145.

If Kevin had a problem with his senses, a doctor could give him something to help. Kevin could wear a hearing aid to help him see/ hear and his friends would be relieved.

If a hearing aid restored a person's vision, it would be common among the elderly. Kevin could wear a hearing aid to help him see/ hear and his friends would be relieved.

146.

If Gillian were preparing for a big night out, she would spend a whole day pampering herself. Gillian could paint sparkly pink nail varnish onto her eyelids/ nails and look beautiful all night long.

If nail varnish were for use on the face, there would be lots of bright colours to choose from. Gillian could paint sparkly pink nail varnish onto her eyelids/ nails and look beautiful all night long.

147.

If Peter were looking for a cheap holiday, travel agents would have lots of suggestions. Peter could fly to New York City in a spaceship/ aeroplane and quietly admire the picturesque scenery.

If New York City were a city on the moon, it would be very expensive to get there. Peter could fly to New York City in a spaceship/ aeroplane and quietly admire the picturesque scenery.

148.

If Mum wanted to impress her friends and relatives, she would have to work hard. Mum could use margarine in her hair/ baking and impress her friends and family.

If margarine contained a detergent, it would have many useful domestic uses. Mum could use margarine in her hair/ baking and impress her friends and family.

149.

If holidaymakers want to get a great tan, they would need to leave lots of time for sunbathing. People could sunbathe on the beach at midnight/ midday and wear lots of strong sunscreen.

If the sun only came out during the night, it would change the way we spend our holidays. People could sunbathe on the beach at midnight/ midday and wear lots of strong sunscreen.

150.

If tourists in Spain had currency to spare, they would be encouraged to spend it. Tourists could go to Spain to spend dollars/ Euros and buy tacky souvenirs for friends.

If Spain used the same currency as America, it would make travel easier for tourists. Tourists could go to Spain to spend dollars/ Euros and buy tacky souvenirs for friends.

151.

If parents were in a good mood at Christmas, they might let their children play till late. Children could stay awake at Christmas to look for Elvis/ Santa and discover what their presents are.

If it were Elvis who gives presents at Christmas, he would be very popular with children. Children could stay awake at Christmas to look for Elvis/ Santa and discover what their presents are.

152.

If Australia had a better system of motorways, travel would be much easier for tourists. People could drive the length of Australia in a day/ month and view all the picturesque scenery.

If Australia were the same size as Northern Ireland, travel would be much easier for tourists. People could drive the length of Australia in a day/ month and view all the picturesque scenery.

153.

If a ferry wanted to set a new world record, the crew would need to be very efficient at their jobs. A ferry could travel across the Atlantic Ocean in the air/ sea and reach America in record time.

If a ferry were converted into a flying vessel, it might save travelling time for holidaymakers. A ferry could travel across the Atlantic Ocean in the air/ sea and reach America in record time.

154.

If Isaac Newton had wanted to become more influential, he would have spent more time researching. Isaac Newton could have documented his research on a laptop/ typewriter and we'd all learn from it.

If Isaac Newton had had the benefit of modern technology, it would have been easier to publicize research. Isaac Newton could have documented his research on a laptop/ typewriter and we'd all learn from it.

155.

If sheep were very hungry, they are likely to help themselves to any food they find around them. Farmers could leave their sheep in the field to eat rabbits/ grass and concentrate on other farm work.

If sheep were carnivorous like wolves, they would be a lot less work to be looked after. Farmers could leave their sheep in the field to eat rabbits/ grass and concentrate on other farm work.

156.

If cats are bored and want something to do, they are usually good at letting their owners know. Judith could listen to her cat talk/ meow and play joyfully with its toys.

If cats had developed language skills like humans, it would be interesting to hear their opinions. Judith could listen to her cat talk/ meow and play joyfully with its toys.

157.

If footballers wanted to win an important match, they would need to be skilful and work as a team. Footballers could pass the ball using their hands/ feet and run into a clear space.

If footballers were only allowed to touch the ball with their hands, it would be an easy game to play. Footballers could pass the ball using their hands/ feet and run into a clear space.

158.

If the pope had some spare time, he would receive a lot of invitations to meet the public. Loyal supporters could watch the pope in a ballet/ church and take photos to show friends.

If the pope were a famous dancer, he would attract a great deal of encouragement from fans. Loyal supporters could watch the pope in a ballet/ church and take photos to show friends.

159.

If school children wanted to carry out a project on elephants, there is a lot they would find out. Children could learn that an elephant weighs about five ounces/ tonnes and draw pictures of its trunk.

If an elephant were the size of a mouse, there would be a lot to learn about how their body works. Children could learn that an elephant weighs about five ounces/ tonnes and draw pictures of its trunk.

160.

If sharks were spotted near a tourist beach, the public would want to know immediately. Parents could consider swimming with sharks as harmless/ dangerous and remember to tell their children.

If sharks only ate plants, they would be less of a threat to humans and other animals. Parents could consider swimming with sharks as harmless/ dangerous and remember to tell their children.

Experimental Items used in Experiment 5

1.

If Jenny wanted to make her house very clean, there would be lots of preparation involved. Jenny could use a toothbrush to brush her floors/ teeth and make them look sparkling clean.

If toothbrushes were not so small, they would be useful for improving hygiene in homes. Jenny could use a toothbrush to brush her floors/ teeth and make them look sparkling clean.

2.

If cats are hungry, they usually pester their owners until they get fed. Families could feed their cat a bowl of carrots/ fish and listen to it purr happily.

If cats were not carnivores, they would be cheaper for owners to look after. Families could feed their cat a bowl of carrots/ fish and listen to it purr happily.

3.

If Mum were organising a children's party, games and refreshments would need to be planned. Young children could drink bottles of vodka/ cola and dance long into the night.

If children were not allowed to drink soft drinks, they would have to get used to it. Young children could drink bottles of vodka/ cola and dance long into the night.

4.

If Peter were looking for a cheap holiday, New York City would be a popular suggestion. Peter could fly to New York City in a spaceship/ aeroplane and quietly admire the busy capital.

If New York City were not a city on earth, it would be very expensive to get there. Peter could fly to New York City in a spaceship/ aeroplane and quietly admire the busy capital.

5.

If Mum wanted to impress her friends and relatives, she would have to work hard. Mum could use margarine in her hair/ baking and impress her friends and family.

If margarine did not contain oils, it would have many uses around the house. Mum could use margarine in her hair/ baking and impress her friends and family.

6.

If sharks were spotted near a tourist beach, the public would want to know immediately. Parents could consider swimming with sharks as harmless/ dangerous and remember to tell their children.

If sharks were not man-eaters, they would be less of a threat to humans and other animals. Parents could consider swimming with sharks as harmless/ dangerous and remember to tell their children.

7.

If people were interested in learning how gorillas live, they would find it interesting. People could admire gorillas in the garden/ jungle and carefully feed them special food.

If gorillas were not wild animals, they would be popular to keep as pets. People could admire gorillas in the garden/ jungle and carefully feed them special food.

8.

If a tramp felt tired, he would have to look out for somewhere to rest for a while. The tramp could afford to live in a palace/ shack and share it with cheerful friends.

If a tramp were not poor, he would be able to use the money to change his life. The tramp could afford to live in a palace/ shack and share it with cheerful friends.

9.

If someone wanted a relaxing holiday abroad, I would recommend an Island paradise like Hawaii. Holidaymakers could visit Hawaii to stay in an igloo/ villa and admire views from their window.

If Hawaii did not have hot weather, the locals would need to keep warm in winter. Holidaymakers could visit Hawaii to stay in an igloo/ villa and admire views from their window.

10.

If a chef wanted to make some traditional food with vinegar, he would look for a recipe. Chefs could use vinegar to make a cake/ dressing and charge high prices in restaurants.

If vinegar were not bitter, children would enjoy having a lot more of it in food. Chefs could use vinegar to make a cake/ dressing and charge high prices in restaurants.

11.

If an athlete trained relentlessly, they would do their best to beat the effects of gravity. Athletes could high jump about two miles/ metres and set soaring new world records.

If gravity did not exist on earth, we would be able to do amazing acrobatics. Athletes could high jump about two miles/ metres and set soaring new world records.

12.

If Mum had just bought a new fridge for the kitchen, she would look forward to trying it out. Mum could put chicken in the fridge to keep warm/ cool and serve it for Sunday lunch.

If a fridge were not cold, it would still be a useful appliance in a family home. Mum could put chicken in the fridge to keep warm/ cool and serve it for Sunday lunch.

13.

If students were having difficulty with algebra, a tutor would be able to assist. All pupils could become expert in algebra at age three/ sixteen and work hard at other subjects.

If algebra were not very hard to learn, students wouldn't complain about it so much. All pupils could become expert in algebra at age three/ sixteen and work hard at other subjects.

14.

If Tom were in a bad mood, he would be likely to take his frustrations out on things around him. Tom could stamp on a sheet of glass to make it bend/ shatter and throw it around his room.

If glass were not a brittle material, it would be safe to use around children. Tom could stamp on a sheet of glass to make it bend/ shatter and throw it around his room.

15.

If mosquitoes want to breed, they must make sure they congregate in their optimum environment. Mosquitoes could be in abundance in Iceland/ Thailand and frustrate all the local residents.

If mosquitoes did not thrive in warm climates, they would need to find a suitable habitat. Mosquitoes could be in abundance in Iceland/ Thailand and frustrate all the local residents.

16.

If Victoria Beckham agreed to be weighed in public, fans would be intrigued to know her weight. Victoria Beckham could weigh the same as Pavarotti/ Kylie and spend a fortune on clothes.

If Victoria Beckham were not very slim, the British public would be very surprised. Victoria Beckham could weigh the same as Pavarotti/ Kylie and spend a fortune on clothes.

17.

If you wanted to see polar bears in the wild, you would need to go to their natural environment. We could see polar bears roaming the Rainforest/ Antarctic and observe their relations with other species.

If polar bears had not evolved to favour cold climates, we would be interested in their behaviour. We could see polar bears roaming the Rainforest/ Antarctic and observe their relations with other species.

18.

If we bought a Barbie doll that performs actions, we would need to find out how to power it. Barbie dolls could get energy from food/ batteries and remain active throughout the day.

If toys were not lifeless objects, they would be good companions for children. Barbie dolls could get energy from food/ batteries and remain active throughout the day.

19.

If you had building blocks remaining from a build, it would be tempting to fiddle with them. We could hit a building block to make it wobble/ crack and re-use the blocks elsewhere.

If building blocks were not hard, it would be interesting to play with them. We could hit a building block to make it wobble/ crack and re-use the blocks elsewhere.

20.

If a researcher were interested in dogs, their reproduction would be fascinating. Environmentalists could watch dogs give birth to eggs/ puppies and check they are kept safe.

If dogs were not mammals, their behaviour would be interesting to examine. Environmentalists could watch dogs give birth to eggs/ puppies and check they are kept safe.

21.

If Steve wanted to see a lizard in its natural habitat, he would need to go abroad. Steve could see a big lizard in Siberia/ Florida and boast to friends at home.

If lizards did not require warm climates, they would have to find a suitable habitat. Steve could see a big lizard in Siberia/ Florida and boast to friends at home.

22.

If you are hungry while out of the house, supermarkets have a lot of choice available. You could enjoy a milkshake by the slice/ glass and have energy till the evening.

If milkshakes were not liquid, they would be popular with people of all ages. You could enjoy a milkshake by the slice/ glass and have energy till the evening.

23.

If Australia had a better system of motorways, travel would be much easier for tourists. People could drive the length of Australia in a day/ month and view all the picturesque scenery.

If Australia were not so large, travel would be much easier for tourists. People could drive the length of Australia in a day/ month and view all the picturesque scenery.

24.

If school children wanted to carry out a project on elephants, there is a lot they would find out. Children could learn that an elephant weighs about five ounces/ tonnes and draw pictures of its trunk.

If an elephant were not so large, there would be a lot to learn about how their body works. Children could learn that an elephant weighs about five ounces/ tonnes and draw pictures of its trunk.

25.

If a jeweller's were known for selling diamonds, it would be very busy at Christmas time. Jewellers could sell huge diamonds costing pennies/ millions and they would look impressive on.

If diamonds were not expensive, they would be widespread among women. Jewellers could sell huge diamonds costing pennies/ millions and they would look impressive on.

26.

If an astronaut were preparing for a trip to the moon, we would follow the journey on the TV. A trip to the moon could take one hour/ month and we would see fantastic views.

If the Earth and the Moon were not so far apart, it would be an exciting journey between the two. A trip to the moon could take one hour/ month and we would see fantastic views.

27.

If you wanted a cultural holiday, there is plenty to see and do in the UK. Tourists could visit the UK to meet their President/ Queen and watch big colourful street parades.

If the UK did not have a monarchy, it would create a new head of the country. Tourists could visit the UK to meet their President/ Queen and watch big colourful street parades.

28.

If you were shopping for a holiday to Dubai, it would be good to know what weather to expect. Visitors to Dubai could wake up in January to see snow/ sun and dress suitably for the weather.

If Dubai were not hot all year round, it would affect the local tourist industry. Visitors to Dubai could wake up in January to see snow/ sun and dress suitably for the weather.

29.

If Santa had enough time, he would work hard to deliver presents like in the storybooks. Santa could give presents to children who'd been bad/ good and they would be very excited.

If Santa Claus did not give presents to well-behaved children, he would still be a very busy person. Santa could give presents to children who'd been bad/ good and they would be very excited.

30.

If you wanted to go somewhere interesting, it's good to hear what people recommend. The public could look at cute kittens at zoos/ home and maybe get to feed them.

If kittens were not domestic animals, they would remain popular as they are very cute. The public could look at cute kittens at zoos/ home and maybe get to feed them.

31.

If dentists were invited into schools to talk to children they would offer good advice. Dentists could warn children about the dangers of eating carrots/ sweets and hopefully they would take note.

If tooth cavities were not caused by sugar, children would need to alter their diet. Dentists could warn children about the dangers of eating carrots/ sweets and hopefully they would take note.

32.

If you wanted to add flavour to food, including chillies adds a new taste to a dish. Cooks could use chillies to make food bland/ spicy and make a deliciously filling meal.

If chillies were not piquant, people would need to change the way it is used in recipes. Cooks could use chillies to make food bland/ spicy and make a deliciously filling meal.

Experimental Items used in Experiment 6

1.

Toothbrushes are regularly used in most homes in Britain. If toothbrushes were not so small, they would be useful for improving hygiene in homes. Jenny could use a toothbrush to brush her floors/ teeth and make them look sparkling clean.

2.

Greenland has many attractions to tempt tourists. If Greenland did not have really cold winters, it would be popular with tourists of all ages. We could go to Greenland in November to sunbathe/ sledge and escape work for a week.

3.

Cats are popular pets in British households. If cats were not carnivores, they would be cheaper for owners to look after. Families could feed their cat a bowl of carrots/ fish and listen to it purr happily.

4.

Children are often requested to eat and drink what they are told. If children were not allowed to drink soft drinks, they would have to get used to it. Young children could drink bottles of vodka/ juice and dance long into the night.

5.
New York City is currently a popular destination for city breaks. If New York City were not a city on earth, it would be very expensive to get there. Peter could fly to New York City in a spaceship/ aeroplane and quietly admire the picturesque scenery.
6.
Margarine is manufactured in big industries. If margarine did not contain oils, it would have many uses around the house. Mum could use margarine in her hair/ baking and impress her friends and family.
7.
Sheep are popular animals to keep on a farm. If sheep were not vegetarians, they would be a lot less work to be looked after. Farmers could leave their sheep in the field to eat rabbits/ grass and concentrate on other farm work.
8.
Football is a popular sport around the world. If footballers were not allowed to touch the ball with their feet, it would be an easy game to play. Footballers could pass the ball using their hands/ feet and run into a clear space.
9.
Many documentaries have investigated the behaviour of sharks. If sharks were not man-eaters, they would be less of a threat to humans and other animals. Parents could consider swimming with sharks as harmless/ dangerous and remember to tell their children.
10.
Tooth decay is an important issue among children. If tooth cavities were not caused by sugar, children would need to alter their diet. Dentists could warn children about the dangers of eating carrots/ cakes and hopefully they would take note.
11.
Gorillas are at risk of becoming endangered animals. If gorillas were not wild animals, they would be popular to keep as pets. People could admire gorillas in the garden/ jungle and carefully feed them special food.
12.
Tramps are often friendly and intelligent people. If a tramp were not poor, he would be able to use the money to change his life. The tramp could afford to live in a palace/ shack and share it with cheerful friends.
13.
Morocco has many attractions to entertain tourists. If Morocco were not hot all year round, it would be a popular destination to visit. We could go to Morocco in December to ski/ sunbathe and talk to the local people.
14.
Hawaii is an island that makes up part of America. If Hawaii did not have hot weather, the locals would need to keep warm in winter. Holidaymakers could visit Hawaii to stay in an igloo/ villa and admire views from their window.
15.
Wine is made in vineyards around the world. If wine did not taste pleasant, it would be a popular weapon with criminals. Gangsters could happily give a bottle of wine to their enemies/ friends and tell others in the gang.
16.
Chillies can be red or green and are often used in cooking. If chillies were not piquant, people would need to change the way it is used in recipes. Cooks could use chillies to make food bland/ spicy and make a deliciously filling meal.
- 17.

Vinegar is sold in many varieties at the supermarket. If vinegar were not bitter, children would enjoy having a lot more of it in food. Chefs could use vinegar to make a cake/ dressing and charge high prices in restaurants.

18.

Fish live very active lives and are often found in groups. If fish did not live underwater, they would be able to see more of the world. We could observe a salmon resting in the forest/ lake and wish we could eat one.

19.

Gravity was first discovered by Sir Isaac Newton. If gravity did not exist on earth, we would be able to do amazing acrobatics. Athletes could high jump about two miles/ metres and set soaring new world records.

20.

Flu is common during the cold winter months. If all flu symptoms were not treated with drugs, it would cost the NHS a lot of money. Doctors could cure a headache with an operation/ aspirin and expect a quick recovery time.

21.

Fridges are quite expensive to run by electricity. If a fridge were not cold, it would still be a useful appliance in a family home. Mum could put chicken in the fridge to keep warm/ cool and serve it for Sunday lunch.

22.

Many books exist that depict the life and activities of Hitler. If Hitler had not been an unpleasant man, he would have been a popular leader of Germany. Children could learn that Hitler was renowned for his smile/ severity and students would learn about him.

23.

Onions are commonly used to add flavour to food. If onions were not a savoury food, they would be more popular at meal-times. People could use fresh onions to make a cake/ casserole and offer it to dinner guests.

24.

Algebra is commonly taught at school in maths lessons. If algebra were not very hard to learn, students wouldn't complain about it so much. All pupils could become expert in algebra at age three/ sixteen and work hard at other subjects.

25.

The Antarctic is a very under-populated part of the world. If the Antarctic were not snowy, it would be a popular destination all year round. Visitors to the Antarctic could take a trip to see alligators/ penguins and take photos to show friends.

26.

Glass is a common material used in homes. If glass were not a brittle material, it would be safe to use around children. Tom could stamp on a sheet of glass to make it bend/ shatter and throw it around his room.

27.

Elton John is a well-known celebrity singer. If Elton John were not homosexual, his fans would be quite surprised by the news. Elton John could be photographed marrying a woman/ man and tabloids would cover the story.

28.

Mosquitoes cause an irritation to many holidaymakers. If mosquitoes did not thrive in warm climates, they would need to find a suitable habitat. Mosquitoes could be in abundance in Iceland/ Thailand and frustrate all the local residents.

29.

Retirement homes are often expensive to join. If retirement homes were not for the elderly, they would make a lot more money. Retirement homes could be full of students/ pensioners and charge high rates for entry.

30.

Victoria Beckham is a famous lady, married to a footballer. If Victoria Beckham were not very slim, the British public would be very surprised. Victoria Beckham could weigh the same as Pavarotti/ Kylie and spend a fortune on clothes.

31.

Football fans tend to get excited about their favourite team's victories. If football terminology were not different from rugby, it would save spectators' confusion. Football fans could cheer when a player scores a try/ goal and wave their flags with excitement.

32.

Polar bears can be dangerous animals in the wild. If polar bears had not evolved to favour cold climates, we would be interested in their behaviour. We could see polar bears roaming the Rainforest/ Antarctic and observe their relations with other species.

33.

Children love to get new toys to play with. If toys were not lifeless objects, they would be good companions for children. Barbie dolls could get energy from food/ batteries and remain active throughout the day.

34.

Building blocks are commonly used to build houses. If building blocks were not hard, it would be interesting to play with them. We could hit a building block to make it wobble/ crack and re-use the blocks elsewhere.

35.

Many people keep dogs as pets and walk them regularly. If dogs were not mammals, their behaviour would be interesting to examine. Environmentalists could watch dogs give birth to eggs/ puppies and check they are kept safe.

36.

Hairdressers are usually full of customers at the weekend. If hairdressers did not sell hair products, it would open up other possibilities for profit. Mrs Jones could go to the hairdressers to buy a dress/ shampoo and save it for special occasions.

37.

Ballet is a common activity among youngsters. If ballet were not an elegant sport, risk of injuries would make it dangerous. Stuart could go to a ballet class to practise his tackling/ pirouette and warm up his muscles beforehand.

38.

Foreign language courses are offered at most universities in Scotland. If foreign language courses did not teach linguistics, it would be a popular course for all ages. A student could take a foreign language course to improve his painting/ French and make his parents very proud.

39.

Cairo has many archaeological treasures to see. If Cairo were not in Egypt, it would still be a popular destination with tourists. People could visit Cairo to see the Louvre/ pyramids and take photos for their album.

40.

Cinemas are often very busy at weekends. If cinemas did not show films, they would remain a popular place with young people. John could invite Mary to the cinema for a dance/ movie and they would have great fun.

41. Lizards are part of a larger reptile family. If lizards did not like warm climates, they would have to find a suitable habitat. Steve could see a big lizard in Siberia/ Florida and boast to friends at home.
42. Tony Blair is a well-known man in Great Britain. If Tony Blair were not a politician, he would need to find a new career. Crowds of people could watch Tony Blair lead an opera/ campaign and hopefully they would enjoy it.
43. Milkshakes are very enjoyable during the warm Summer months. If milkshakes were not liquid, they would be popular with people of all ages. You could enjoy a milkshake by the slice/ glass and have energy till the evening.
44. Hearing aids are popular among old-aged people. If a hearing aid did not restore sound, it would need a new purpose for the elderly. Kevin could wear a hearing aid to help him see/ hear and his friends would be relieved.
45. We all love to lie in the sun during the Summer break. If the sun did not come out during the day, it would change the way we spend our holidays. People could sunbathe on the beach at midnight/ midday and wear lots of strong sunscreen.
46. Australia is a very fashionable country to visit. If Australia were not so large, travel would be much easier for tourists. People could drive the length of Australia in a day/ month and view all the picturesque scenery.
47. The Pope has a great deal of loyal supporters around the world. If the pope were not a clergyman, he would be interested in finding a new occupation. Loyal people could watch the pope in a ballet/ sermon and take photos to show friends.
48. Elephants are beautiful and fascinating wild animals. If an elephant were not so large, there would be a lot to learn about how their body works. Children could learn that an elephant weighs about five ounces/ tonnes and draw pictures of its trunk.
49. Writing has become an integral part of human communication. If humans did not use their hands to write, they would need to adapt their skills appropriately. Students could write an essay using their feet/ hands and hopefully get a good grade.
50. Scotland's weather is a source of constant complaints among residents. If Scotland's climate were not so cold, locals would still complain noisily about the conditions. People living in Scotland could experience monsoons/ snow and beware of the temperamental weather.
51. The Scottish Isles are popular among the fit for walking holidays. If the Scottish Isles were not surrounded by sea, it would make travel easier. Visitors could travel between the Islands by bus/ ferry and avoid the usual dirty pollution.
52. Wide opinion is that policemen are respectable people. If policemen did not prevent crime, they would lose a lot of public admiration. Policemen could mastermind an assault/ arrest and tell the story to journalists.
- 53.

Prince Charles' popularity has grown over recent years. If Prince Charles were not alive, there would be a period of public mourning. Crowds of people could watch Prince Charles' funeral/ coronation and wave big Union Jack flags.

54.

Disputes between the sexes are common in everyday life. If men did not live on planet Earth, women would have to travel to visit their partner. A wife could travel to see her husband in a rocket/ train and leave when he became annoying.

55.

Babies require a lot of hard work to take care of. If babies were not intellectually juvenile, they would be a joy for mums to look after. A baby could make his mum proud by graduating/ crawling and show photos to her friends.

56.

Diamonds are often seen in many types of fashionable jewellery. If diamonds were not exclusive, they would be widespread among women. Jewellers could sell huge diamonds for very cheap/ expensive and they would look impressive on.

57.

Building bricks have many features to make them ideal for construction. If building bricks were not flammable, safety would still be an issue in their maintenance. A house fire could cause the bricks to melt/ burn and many firemen would be called.

58.

Exploring the moon is an adventure many people crave. If the Earth and the Moon were not so far apart, it would be an exciting journey between the two. A trip to the moon could take one hour/ month and we would see fantastic views.

59.

Our daily sleep cycles are of great interest to some scientists. If humans were not daytime creatures, the pattern of our lives would change dramatically. People could sleep all through the day/ night and struggle to wake up quickly.

60.

The history and culture of the UK makes it popular with tourists. If the UK did not have a monarchy, it would need a new head of the country. Tourists could go to the UK to meet the President/ Queen and watch big colourful street parades.

61.

Hospitals have to treat broken bones regularly. If broken bones did not require so long to heal, patients would be relieved. Timmy's broken leg could be mended in two hours/ months and his Mum wouldn't be worried.

62.

Vehicles enable us to travel around the country quickly. If vehicles did not run on fuel, they would need to find an alternative source of energy. Drivers could fill their car with cola/ petrol and buy sandwiches for their lunch.

63.

If the Royal Family were not selected by inheritance, everyone would be happy with the choice. The next King of England could be chosen by ballot/ heredity and the coronation broadcast on TV.

64.

David Beckham is a much-loved sports star. If David Beckham were not good at football, he would try to develop a new skill. David Beckham could impress women at the pool/ pitch and get offered good sponsorship deals.

65.

Fishmongers tend to be busy places with hard-working staff. If a fishmonger did not sell fish to eat, it would need to develop a new retail purpose. Sam could go to the fishmonger to buy goldfish/ scampi and his family would be happy.

66.

Dubai is a city near the Arabian Sea. If Dubai were not hot all year round, it would affect the local tourist industry. Visitors to Dubai could wake up in January to see snow/ sun and dress suitably for the weather.

67.

Tooth decay is a worrying risk among health specialists. If sugar were not the cause tooth decay, parents would tailor the family's diet accordingly. Children could get tooth decay from eating too many carrots/ sweets and cry about visiting the dentist.

68.

Many books depict teleporting as a mythical way to travel. If teleporting did not just happen in fiction, foreign travel would be easy. Victoria could get from Newcastle to Bangkok in a second/ day and visit the beautiful local attractions.

69.

Owls are nocturnal birds that tend to live in forests. If owls did not have feathers all over their bodies, they would be fascinating to look at. Owls could be described as feeling smooth/ fluffy and their claws would be sharp.

70.

Santa Claus is a legendary Christmas character. If Santa Claus did not give presents to well-behaved children, he would still be a very busy person. Santa could give presents to children who'd been bad/ good and they would be very excited.

71.

Sweets are very popular treats for people of all ages. If sweets did not have to be manufactured, they would be found elsewhere in nature. We could pick up lollypops from the woods/ shops and eat them as a treat.

72.

Yachts are expensive to buy and call for expertise to run. If yachts were not powered by wind, they would require an alternative source of power. A yacht captain could be in charge of the engine/ mainsail and staff would look after passengers.

73.

Martial arts classes are becoming increasingly popular in the UK. If a martial arts class did not teach students combat, people would excel at different skills. A martial arts teacher could demonstrate expertise in cookery/ fighting and students would be in awe.

74.

Many people consider their hair to be an important feature. If you did not want a good haircut, your friends might think it was funny. You could have your hair cut by a dentist/ hairdresser and show it off at parties.

75.

Beetles are one of the most common insects. If beetles did not have legs, they would feel safer from the predators that hunt them. A beetle could escape from predators by flying/ climbing and building their nests in trees.

76.

Many breeds of cats and kittens exist in the UK. If kittens were not domestic animals, they would remain popular as they are very cute. The public could look at cute kittens at zoos/ home and maybe get to feed them.

77.

The Eiffel Tower is a beautiful iron construction. If the Eiffel Tower were not in France, it would be relocated to an alternative site. Steve could see the Eiffel Tower in Berlin/ Paris and boast to friends at home.

78.

Glasgow is well known for its fantastic shopping. If Glasgow were not on the British mainland, it would be popular with day-trippers. People could travel from London to Glasgow by boat/ bus and buy postcards for their friends.

79.

Sangria is a popular holidaymaker's drink. If sangria were not traditionally a Spanish drink, it would be linked to another region instead. Stag groups could drink authentic sangria in Dublin/ Madrid and enjoy the city's lively atmosphere.

80.

Christian people follow the word of the Bible closely. If Christians did not celebrate their own religious holidays, they would find other occasions to rejoice. Christian revellers could celebrate Passover/ Christmas and spend time with their families.

Experimental Items used in Experiment 7

1.

If a plumber had the appropriate tools, he could do his job a lot faster.
Sarah could call a plumber to fix her broken sink/ foot and she would be very relieved.

If a plumber were trained in medicine, he would be very useful indeed.
Sarah could call a plumber to fix her broken sink/ foot and she would be very relieved.

2.

If cats are hungry, they usually pester their owners until they get fed.
Families could feed their cat a bowl of fish/ carrots and listen to it purr happily.

If cats were vegetarians, they would be cheaper for owners to look after.
Families could feed their cat a bowl of fish/ carrots and listen to it purr happily.

3.

If Peter were looking for a cheap holiday, travel agents would have lots of suggestions.
Peter could fly to New York City in a plane/ spaceship and quietly admire the picturesque scenery.

If New York City were a city on the moon, it would be very expensive to get there.
Peter could fly to New York City in a plane/ spaceship and quietly admire the picturesque scenery.

4.

If sheep were very hungry, they are likely to help themselves to any food they find around them.
Farmers could leave their sheep in the field to eat grass/ rabbits and concentrate on other farm work.

If sheep were carnivorous like wolves, they would be a lot less work to be looked after.
Farmers could leave their sheep in the field to eat grass/ rabbits and concentrate on other farm work.

5.

If a tramp felt tired, he would have to look out for somewhere to rest for a while.
The tramp could afford to live in a shack/ palace and share it with cheerful friends.

If a tramp won the lottery, he would be able to use the money to change his life.
The tramp could afford to live in a shack/ palace and share it with cheerful friends.

6.

If hunters wanted to plan an event in the countryside, there would be lots of preparation involved.
Hunters could go to Wales to hunt foxes/ elephants and keep their activities a secret.

If Wales had the same wildlife as Kenya, it would lead to lots of interest in the animals.
Hunters could go to Wales to hunt foxes/ elephants and keep their activities a secret.

7.

If someone wanted a relaxing holiday abroad, I would recommend an Island paradise like Hawaii.
Holidaymakers could visit Hawaii to stay in a small villa/ igloo and admire views from their window.

If Hawaii had the same weather as the Arctic, the locals would need to keep warm in winter.
Holidaymakers could visit Hawaii to stay in a small villa/ igloo and admire views from their window.

8.

If penguins want to survive, they must understand the risks in their home environment.
Penguins could learn to outrun polar bears/ cheetah and find food for their young.

If all penguins lived in the African desert, they would have to adapt to the environment.
Penguins could learn to outrun bears/ cheetah and find food for their young.

9.

If we had enough money for a holiday to Egypt, books would advise us where to visit.
Gary could go to Egypt to climb the mountains/ sand dunes and get suntan to his face.

If Egypt had the same landscape as Switzerland, it would be a beautiful country to visit.
Gary could go to Egypt to climb the mountains/ sand dunes and get suntan to his face.

10.

If parents knew more about the causes of tooth decay, they would tailor the family's diet accordingly.
Children could get tooth decay from eating too many sweets/ carrots and cry about visiting the dentist.

If tooth decay were only caused by eating vegetables, parents would tailor the family's diet accordingly.
Children could get tooth decay from eating too many sweets/ carrots and cry about visiting the dentist.

11.

If a couple fancied some Italian cuisine, they are likely to choose a traditional dish.
Lovers could go to an Italian restaurant to eat a stir-fry/ pizza and feel very full all night.

If Italian cuisine were the same as Chinese, we would buy cookbooks for the recipes.
Lovers could go to an Italian restaurant to eat a stir-fry/ pizza and feel very full all night.

12.

If a golfer were keen to win the tournament, he would need to sharpen up his technique.
A golfer could hurt his shoulder from swinging his club/ racket and visit a physio for treatment.

If golf used the same equipment as tennis, players would work hard to improve their technique.
A golfer could hurt his shoulder from swinging his club/ racket and visit a physio for treatment.

13.

If a caterpillar had eaten enough leaves, it would be ready to transform into its next stage.
A caterpillar could mature into a butterfly/ sparrow and enjoy testing its new wings.

If caterpillars turned into birds in the chrysalis, it would be an amazing transformation to study.
A caterpillar could mature into a butterfly/ sparrow and enjoy testing its new wings.

14.

If you had planned to visit America, it is recommended that you watch a local sporting event.
Visitors could go to America to watch baseball/ bullfights and join the crowds of spectators.

If America had the same national sport as Spain, it would be a popular destination for enthusiasts.
Visitors could go to America to watch baseball/ bullfights and join the crowds of spectators.

15.

If you monitored a spider's daily activities, you would be fascinated by their accomplishments.
A spider could spend all day producing webs/ honey and admire its hard work later.

If spiders had the same biological systems as bees, we would see evidence of their hard work.
A spider could spend all day producing webs/ honey and admire its hard work later.

16.

If Mum wanted to impress her friends and relatives, she would have to work hard.
Mum could use margarine in her baking/ hair and impress her friends and family.

If margarine contained a detergent, it would have many useful domestic uses.
Mum could use margarine in her baking/ hair and impress her friends and family.

17.

If travellers in France were interested in tasting local delicacies, they would enjoy the experience.
They could go to France to eat croissants/ sushi and recreate the recipes at home.

If France had the same cuisine as Japan, it would be popular with gastronomic enthusiasts.
They could go to France to eat croissants/ sushi and recreate the recipes at home.

18.

If vets updated their training every few years, there would be lots of new techniques to learn.
Vets could learn how to treat injured puppies/ unicorns and write books to teach others.

If vets were only trained to treat mythical animals, it would be a complicated course to complete.
Vets could learn how to treat injured puppies/ unicorns and write books to teach others.

19.

If building bricks in a house caught fire, it can cause substantial damage to a home.
A house fire could cause the bricks to burn/ melt and many firemen would be called.

If all building bricks were made from ice, safety would be an issue in their maintenance.
A house fire could cause the bricks to burn/ melt and many firemen would be called.

20.

If you were interested in Australia's wildlife, a holiday 'down under' is well worth the money.
Tourists could go to Australia to observe kangaroos/ Triceratops and to buy special Aussie souvenirs.

If Australia were inhabited solely by dinosaurs, expensive holiday tours would be popular. Tourists could go to Australia to observe kangaroos/ Triceratops and to buy special Aussie souvenirs.

21.

If Darwin had made more time for his research, he would have given us much more to learn from.
Darwin could have published a book about the evolution of animals/ aspirin and sold lots of copies.

If Charles Darwin had been famous for his pharmaceutical work, we would learn about it in school.
Darwin could have published a book about the evolution of animals/ aspirin and sold lots of copies.

22.

If you wanted to see polar bears in the wild, you would need to go to their natural environment.
We could see polar bears roaming the Arctic/ Rainforest and observe their relations with other species.

If polar bears had evolved to favour hot climates, we would be interested in their behaviour.
We could see polar bears roaming the Arctic/ Rainforest and observe their relations with other species.

23.

If a fast food joint were very quiet at lunchtimes, it would rely on customers' endorsements.
John could go to the fast food joint to buy some chips/ cat food and recommend it to many friends.

If a fast food joint only sold animal supplies, it would rely on customers' endorsements.

John could go to the fast food joint to buy some chips/ cat food and recommend it to many friends.

24.

If meat were in short supply, workers would need to work hard to keep up with public demand.

Pork meat could be produced in a farm/ lab and we'd enjoy a good dinner.

If all meat were grown in test tubes, no animals would need to be killed to make sausages.

Pork meat could be produced in a farm/ lab and we'd enjoy a good dinner.

Experimental items used in Experiment 8

1.

Janet unpacked the belongings and put the postcard in the cupboard. Later, Janet saw Barry move the postcard from the cupboard to the drawer. Later, Janet wanted to see the postcard so she looked in the cupboard/ drawer and smiled.

Janet unpacked the belongings and put the postcard in the cupboard. While Janet was busy, Barry moved the postcard from the cupboard to the drawer. Later, Janet wanted to see the postcard so she looked in the cupboard/ drawer and smiled.

2.

Mary planted all her seeds in trays and put them on the shelf. Later, Mary spotted her husband move the plants from the shelf to the table. Later, Mary wanted to look at her plants so she looked on the shelf/ table and daydreamed.

Mary planted all her seeds in trays and put them on the shelf. While Mary was distracted, her husband moved the plants from the shelf to the table. Later, Mary wanted to look at her plants so she looked on the shelf/ table and daydreamed.

3.

Joanne collected her clothes and put them into the laundry basket. Later, Joanne saw Alex move the clothes from the laundry basket to the washing machine. Later, Joanne wanted to check the clothes so she looked in the laundry basket/ washing machine and sighed.

Joanne collected her clothes and put them into the laundry basket. But while Joanne was unaware, Alex moved the clothes from the laundry basket to the washing machine. Later, Joanne wanted to check the clothes so she looked in the laundry basket/ washing machine and sighed.

4.

John washed the dishes after his breakfast and left his watch on the table. Later, John noticed Victoria move the watch from the table to the bed. Later, John wanted to find his watch so he looked on the table/ bed and yawned.

John washed the dishes after his breakfast and left his watch on the table. While John was dressing, Victoria moved the watch from the table to the bed. Later, John wanted to find his watch so he looked on the table/ bed and yawned.

5.

Mum bought the Christmas presents and hid them all in the wardrobe. Later, Mum watched Dad move all the presents from the wardrobe to the antique chest. Later, Mum wanted to see the presents again so she looked in the wardrobe/ antique chest and grinned.

Mum bought the Christmas presents and hid them all in the wardrobe. While Mum was busy, Dad moved all the presents from the wardrobe to the antique chest. Later, Mum wanted to see the presents again so she looked in the wardrobe/ antique chest and grinned.

6.

Kevin returned from the shops and put his chocolate in the fridge. Later, Kevin noticed Jessica move the chocolate from the fridge to her handbag. Later, Kevin wanted to eat the chocolate so he looked in the fridge/ handbag and squealed.

Kevin returned from the shops and put his chocolate in the fridge. While Kevin was out, Jessica moved the chocolate from the fridge to her handbag. Later, Kevin wanted to eat the chocolate so he looked in the fridge/ handbag and squealed.

7.

Margaret washed her favourite shirt and put it away in the drawer. Later, Margaret spotted Russell move the shirt from the drawer to the basket. Later, Margaret wanted to find the shirt so she looked in the drawer/ basket and paused.

Margaret washed her favourite shirt and put it away in the drawer. While Margaret was at work, Russell moved the shirt from the drawer to the basket. Later, Margaret wanted to find the shirt so she looked in the drawer/ basket and paused.

8.

Julie entered the classroom and put her finished homework in her desk drawer. Later, Julie spotted Maxine move the homework from the drawer to her bag. Later, Julie wanted to check her homework so she looked in the drawer/ bag and focused.

Julie entered the classroom and put her finished homework in her desk drawer. While Julie was distracted, Maxine jokingly moved the homework from the drawer to her bag. Later, Julie wanted to check her homework so she looked in the drawer/ bag and focused.

9.

Maria packed her suitcase to go on holiday and put the tickets in her suitcase. Later, Maria saw her dad move the tickets from the suitcase to her purse. Later, Maria wanted to check the tickets so she looked in the suitcase/ purse and giggled.

Maria packed her suitcase to go on holiday and put the tickets in her suitcase. While Maria was showering, her dad moved the tickets from the suitcase to her purse. Later, Maria wanted to check the tickets so she looked in the suitcase/ purse and giggled.

10.

Colin bought a big bottle of vodka and put it in the drinks cabinet. Later, Colin noticed Angela move the whisky from the drinks cabinet to the freezer. Later, Colin wanted to drink the whisky so he looked in the drinks cabinet/ freezer and moaned.

Colin bought a big bottle of vodka and put it in the drinks cabinet. While Colin was unaware, Angela moved the whisky from the drinks cabinet to the freezer. Later, Colin wanted to drink the whisky so he looked in the cabinet/ freezer and moaned.

11.

Lauren wrote about her day in her diary every night and always kept it in a box. One day, Lauren spied her brother move the diary from the box to the wardrobe. Later, Lauren wanted to find her diary so she looked in the box/ wardrobe and groaned.

Lauren wrote about her day in her diary every night and always kept it in a box. One day, Lauren's brother secretly moved the diary from the box to the wardrobe. Later, Lauren wanted to find her diary so she looked in the box/ wardrobe and groaned.

12.

Jamie celebrated buying the house by putting a small tree in the veranda. Later, Jamie saw his dog dig up the tree and drag it from the veranda to the kennel. Later, Jamie wanted to see the tree so he looked in the veranda/ kennel and frowned.

Jamie celebrated buying the house by putting a small tree in the veranda. While Jamie was inside, his dog dug up the tree and dragged it from the veranda to the kennel. Later, Jamie wanted to see the tree so he looked in the veranda/ kennel and frowned.

13.

Linda arrived at work and put her briefcase on the desk. Later, Linda noticed Alan move the briefcase from the desk to the chair. Later, Linda wanted to check her briefcase so she looked on the desk/ chair and groaned.

Linda arrived at work and put her briefcase on the desk. While Linda was unaware, Alan moved the briefcase from the desk to the chair. Later, Linda wanted to check her briefcase so she looked on the desk/ chair and groaned.

14.

Laura left the hostel for breakfast and left her rucksack in the bed. Later, Laura saw the cleaner move the rucksack from the bed to the locker. Later, Laura wanted to collect her rucksack so she looked in the bed/ locker and gulped.

Laura left the hostel for breakfast and left her rucksack in the bed. While Laura was out, the cleaner moved the rucksack from the bed to the locker. Later, Laura wanted to collect her rucksack so she looked in the bed/ locker and gulped.

15.

Gillian cooked a casserole and left it to cool down in the oven. Later, Gillian spotted Mark move the casserole from the oven to the fridge. Later, Gillian wanted to eat the casserole so she looked in the oven/ fridge and salivated.

Gillian cooked a casserole and left it to cool down in the oven. While Gillian was not looking, Mark moved the casserole from the oven to the fridge. Later, Gillian wanted to eat the casserole so she looked in the oven/ fridge and salivated.

16.

Tony brought his concert tickets into work and put them in his coat pocket. Later, Tony spotted Gary move the tickets from the pocket to the bin. Later, Tony wanted to examine the tickets so he looked in the pocket/ bin and coughed.

Tony brought his concert tickets into work and put them in his coat pocket. While Tony was in a meeting, Gary moved the tickets from the pocket to the bin. Later, Tony wanted to examine the tickets so he looked in the pocket/ bin and coughed.

17.

Mum finished making deserts for the birthday party and put them in the oven. Later, Mum watched Dennis move the cakes from the oven to the cupboard. Later, Mum wanted to taste a cake so she looked in the oven/ cupboard and drooled.

Mum finished making deserts for the birthday party and put them in the oven. While Mum was showering, Dennis moved the cakes from the oven to the cupboard. Later, Mum wanted to taste a cake so she looked in the oven/ cupboard and drooled.

18.

Max bought beer for his flat party and put it in the lounge. Later, Max saw Charlie move the beer from the cupboard to the fridge. Later, Max wanted a beer so he looked in the cupboard/ fridge and frowned.

Max bought beer for his flat party and put it in the cupboard. While Max was not looking, Charlie moved the beer from the cupboard to the fridge. Later, Max wanted a beer so he looked in the cupboard/ fridge and frowned.

19.

Shane finished his vigorous gym workout and left his trainers in the locker. Later, Shane noticed the gym staff move the trainers from the locker to the bin. Later, Shane wanted his trainers so he looked in the locker/ bin and shivered.

Shane finished his vigorous gym workout and left his trainers in the locker. While Shane was at a lecture, the gym staff moved the trainers from the locker to the bin. Later, Shane wanted his trainers so he looked in the locker/ bin and shivered.

20.

Dennis bought the expensive Christening present and hid it in the safe. Later, Dennis watched Chloe move the present from the safe to her handbag. Later, Dennis wanted to check the present so he looked in the safe/ handbag and smiled.

Dennis bought the expensive Christening present and hid it in the safe. While Dennis was gardening, Chloe moved the present from the safe to her handbag. Later, Dennis wanted to check the present so he looked in the safe/ handbag and smiled.

21.

Janis arrived at work and put the newspaper article in the filing cabinet. Later, Janis noticed Stephen move the article from the filing cabinet to the desk. Later, Janis wanted to collect the article so she looked in the filing cabinet/ desk and tutted.

Janis arrived at work and put the newspaper article in the filing cabinet. But while Janis was occupied Stephen moved the article from the filing cabinet to the desk. Later, Janis wanted to collect the article so she looked in the cabinet/ desk and tutted.

22.

Doug looked at the beautiful wedding photo and put it on the fireplace. Later, Doug saw Mandy move the album from the fireplace to the bookcase. Later, Doug wanted to see the album again so he looked on the fireplace/ bookcase and daydreamed.

Doug looked at the beautiful wedding photo and put it on the fireplace. While Doug was gardening, Mandy moved the photo from the fireplace to the bookcase. Later, Doug wanted to see the album again so he looked on the fireplace/ bookcase and daydreamed.

23.

Sophia flicked through the pharmacy journal then put it on the chair. Later, Sophia saw the librarian move the journal from the chair to the shelf. Later, Sophia wanted to read the journal so she looked on the chair/ shelf and whistled.

Sophia flicked through the pharmacy journal then put it on the chair. While Sophia was distracted, the librarian moved the journal from the chair to the shelf. Later, Sophia wanted to read the journal so she looked on the chair/ shelf and whistled.

24.

Isobel entered the beautician's room and put her jewellery on the bed. Later, Isobel spotted the therapist move the jewellery from the bed to the chair. Later, Isobel wanted to put her jewellery back on so she looked on the bed/ chair and relaxed.

Isobel entered the beautician's room and put her jewellery on the bed. Without Isobel's knowledge, the therapist moved the jewellery from the bed to the chair. Later, Isobel wanted to put her jewellery back on so she looked on the bed/ chair and relaxed.