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Anticipatory Processes in Sentence Processing

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Abstract

Anticipation is an essential ability for the human cognitive system to survive in its surrounding environment. The present article will review previous research on anticipatory processes in sentence processing (comprehension). I start by pointing out past research carried out with inadequate methods, then move on to reviewing recent research with relatively new, more appropriate methods, specifically, the so-called 'visual-world' eye-tracking paradigm, and neuropsychological techniques. I then discuss remaining unresolved issues, both methodological and theoretical.

Anticipating Language?

It is a well-known fact that people are capable of anticipating what will come next in the sequence of events they are encountering. For example, by observing and anticipating the trajectory of a ball, a goal keeper can adjust his/her position and successfully block a shot in a football match. Also, it is a common phenomenon that, when watching other people's arm movements, we shift our eyes to the predicted movement and point, anticipating the full form of the movement. Thus, it seems that anticipation is almost an epiphenomenon of recognizing moving objects in various day-to-day situations.

The present article investigates anticipation in language processing. Anticipation of language might be slightly less intuitive than anticipation of motion trajectory, but nevertheless, the occurrence is common enough. For example, speakers often feel their interlocutors 'finish' their sentences before they finish speaking. Such a phenomenon occurs particularly often when the speaker and listener share a large amount of mutual knowledge. Also skilled listeners can easily aid non-skilled speakers (e.g. toddlers, second-language learners) by completing the utterance for the speakers.

For practical reasons, the focus of the present article is limited to anticipatory processes in sentence comprehension in normal native speaking adults. Ultimately, research in anticipation in language comprehension, however, should aim at a better understanding of effects of anticipation during online dialogues (in such situations as above; see Pickering and Garrod 2004, 2007). Also it is worth pointing out that understanding

anticipation processes in normal adults would certainly help understanding processing difficulties in adults and children with language deficits (cf. Nation et al. 2003, applying a method developed for adult language processing to research in children with reading difficulties). It is therefore hoped that the present exploration into anticipation in sentence comprehension will contribute to research in both perception and production and the relation between the two in larger frameworks.

As with any cognitive operation, there are potential advantages and disadvantages to anticipatory processes in language processing. In general, one of the most prominent benefits of anticipation is the ability to help the cognitive system (e.g. language processor) to prepare for the future. For example, good preparation for the future should free up cognitive capacity for subsequent events the system encounters. However, possible disadvantages of anticipation are equally apparent. For instance, a prediction could turn out to be incorrect, in which case extra costs might be required for repairing the incorrect commitment. Also, processing extra information in addition to the stimuli at hand would be particularly costly when the processing involves continuous, incremental inputs and outputs, as in language processing. Thus, it seems that the system should be designed to anticipate only when the benefits overweigh the costs. Research in anticipatory processes could be described as an attempt to identify characteristics of such situations.

In the reminder of the present article, the term 'anticipation' will be used not only to mean that the processor expects something to follow in a forthcoming portion of the language input, but also to suggest that it can specify certain aspects of what will follow. However, the exact content of prediction can be varied, and this issue will be discussed later. The terms 'anticipation' and 'prediction' will be used interchangeably henceforth.

Why Study Anticipation?

It will be useful to clarify at this stage why it is important to study the link between anticipation processes and language processing (comprehension). First, exploring the anticipation mechanism could provide valuable insights into incrementality of language processing. The majority of psycholinguistic or computational linguistic theories largely agree that comprehending utterances involve the continuous mapping of incoming items onto mental representations under construction. For example, very few theories suggest that the processor must wait until all the words in a sentence have appeared in order to start processing the sentence structure (with a few exceptions of theories that presuppose a head-driven processor; for example, Abney 1989; Pritchett 1991). Furthermore, this immediate incremental characteristic of the human sentence processor has been repeatedly demonstrated in experimental work, most notably in the processing of head-final languages (e.g. Bader and Lasser 1994; Koh 1997; Kamide and

Mitchell 1999). Anticipation goes one step further; a processor with an anticipatory function should be able to handle incoming items without a delay, build a representation for upcoming items, and incorporate them into the existing representation. Thus, anticipation can be regarded as a radical extension of incremental sentence processing, as anticipatory processes automatically presuppose incremental processing of items that have just been encountered. Therefore, finding evidence for anticipation would naturally also contribute to the understanding of incremental sentence processing.

Also it is worth mentioning that the notion of predictability has been discussed widely in the reading, especially eye-tracking, literature. Those studies have addressed the relationship between the predictability of a forthcoming item and the eye movements onto that item. More specifically, it has been found that 'predictable' words are more likely to be skipped, or fixated for a shorter period of time if not skipped (e.g. Rayner and Well 1999; Rayner et al. 2001; McDonald and Shillcock 2003). 'Predictability' is defined differently in different studies: some studies are concerned with contextual coherency, whereas others are concerned with lexical co-occurrence probabilities.

A predictive function has been explicitly or implicitly included in numerous sentence processing models/theories. Perhaps not surprisingly, one can find more theoretical proposals of predictive processing in computational linguistics. For example, a number of computational parsers assume a type of intrinsic predictive function; typically in those models, the parser projects forthcoming constituents based on grammatical rules of the language (e.g. top-down, left-to-right parsers). Also, prediction has been regarded as a crucial characteristic in some probabilistic parsers (e.g. Jurafsky 1996; Crocker and Brant 2001; Hale 2003). Similarly, there have been a few attempts to build networks that can successfully learn to predict certain features of subsequent words in sentences (e.g. Hinton 1980; Hinton et al. 1986; Elman 1990, 1991; McRae et al. 1998). Elman (1990), for instance, trained his SRN (simple recurrent network) on 29 different lexical items in 12 categories in 15 different fixed sentence frames. For example, there were six categories for the nouns tested in the simulation: NOUN-HUMAN (*man*, *woman*); NOUN-ANIM (*cat*, *mouse*); NOUN-INANIM (*book*, *rock*); NOUN-AGRESS (*dragon*, *monster*); NOUN-FRAG (*glass*, *plate*); and NOUN-FOOD (*cookie*, *break*). Also the verbs were grouped into the following six categories: VERB-INTRAN (*think*, *sleep*); VERB-TRAN (*see*, *chase*); VERB-AGPAT (*move*, *break*); VERB-PERCEPT (*smell*, *see*); VERB-DESTROY (*break*, *smash*); and VERB-EAT (*eat*). The network then successfully learned to predict the next word in the sequence (e.g., input: *woman* → output: *smash*; input: *smash* → output: *plate*). Importantly, the network also learned to provide alternative outputs in the same category (e.g. it learned to predict '*woman smash plate*' and '*woman smash glass*' but not '*woman smash book*'), although

the categories for the words were not explicitly given to the network in the training session. This shows that distinctive semantic categories emerged as a result of learning.

The psycholinguistic literature has also seen a few accounts with an explicit, elaborate predictive function. The syntactic prediction locality theory (Gibson 1998), for example, specifically attempts to explain human empirical data using a mechanism associated with prediction. The theory assumes that the processor accesses syntactic rules of the language once an input item is encountered, and then it (partially) activates representations for syntactic requirements (e.g. an obligatorily transitive verb requires its direct object). In this framework, it is proposed that an unfulfilled prediction incurs processing costs until it is satisfied by an input. This mechanism predicts that processing the doubly nested sentence (1a) should be more difficult than the singly nested one (1b), as confirmed in experiments by Warren and Gibson (2002):

(1a) The reporter who the chancellor who the woman met attacked ignored the prime minister.
(1b) The woman met the chancellor who attacked the reporter who ignored the prime minister.

According to Gibson (1998), a noun phrase predicts that a thematic role assigner, a verb, will appear, and holding noun phrases in memory without a thematic role assigned is costly. Given that, the processor has three role-less noun phrases before the first verb '*met*' appears in (1a), whereas each noun phrase receives a thematic role directly after its appearance in (1b).

Before reviewing previous experimental research, let us consider the way in which the psycholinguistic literature deals with elements that can trigger prediction ('*predictors*') and those that can be predicted ('*predictees*'). Indeed, generally speaking, these questions are exactly what each investigation is aiming to address. As seen below, research has shown that a variety of types of information can be predictors. Equally, different properties of language have been found to be predictees. One of the central research foci, inevitably, centres around efforts to specify what types and amount of contextual information are required to serve as a predictor for a certain predictee. In addition, since a sentence unfolds incrementally, and anticipation is by definition constrained by a race against time, the research needs to stress the importance of the time course of processing.

Early Experimental Research: Methodological Stumbling Blocks

Despite the rich interests in anticipatory (or predictive) processes in sentence processing theories, the psycholinguistic literature has enjoyed only a handful of experimental studies that directly explore prediction and successfully provide reliable evidence for (or against) prediction, as we will

examine later. That is not to say, however, that empirical research in psycholinguistics has been completely unaware of anticipatory processing in language comprehension; rather, the issue has been addressed in circuitous ways, for example, as a sideline of a related topic, as an experimental manipulation, or with an unsuitable methodology.

In what follows, I will briefly review a few experimental studies in which the authors explicitly linked their findings to an anticipatory function in language processing to varying degrees. In all studies below, the relation between a preceding context and a target was crucially manipulated. The main prediction in those studies was that the right contexts should help to process the target. For example, processing '*bridge*' might be easier after (2a) than (2b), due to the semantic congruency in the first continuation:

(2a) The boy swam under the . . .
(2b) The boy slept under the . . .

However, one might be tempted to interpret the facilitation at the target word in (2a) as evidence for pre-activation of the representation of the word (and for other possible candidates) before the word is received (i.e. *prediction* interpretation). However, crucially, the data is equally compatible with an account that argues that congruent targets are more easily integrated into the preceding context (integration interpretation). Thus, such contextual effects can be consistent with both a prediction and null hypotheses (see van Berkum et al. 2005; Delong et al. 2005; Federmeier 2007; for a similar line of argument).

One of the research paradigms that has been most (implicitly or explicitly) associated with anticipation is priming. In the last several decades, the psycholinguistic literature has seen an overwhelming number of efforts to demonstrate a priming effect of the prime on the target in a sequence of two sets of linguistic stimuli presented in the serial order (i.e. prime followed by target) (e.g. Meyer and Schvaneveldt 1971; Schuberth and Eimas 1977; Becker 1980; Stanovich and West 1981). Priming effects can largely be classified into two categories: syntagmatic priming and paradigmatic priming. Syntagmatic priming concerns effects between a word and another that can naturally follow the other word according to a grammar (e.g. '*cat*' primes '*sleeps*'), while paradigmatic priming involves words from the same form class (e.g. '*cat*' primes '*dog*') (Bock and Griffin 2000). Out of these two types of priming, anticipation could be associated with the former.

In general, it is rarely the case that a priming experiment attempts to show anticipation specifically; rather, the aim of the studies tends to be to demonstrate that the relatedness between the prime and target facilitates the processing of the target, as mentioned above. In those studies, the issue of anticipation may or may not be explicitly discussed. However, some priming studies have more explicitly sought out implications to the prediction issue, and I will present such examples below.

Ferretti, McRae, and colleagues (Ferretti et al. 2001; McRae et al. 2005) conducted a series of priming experiments in order to address the question of use of real-world knowledge in forming expectations in sentence processing. Ferretti et al. (2001) tested whether verbs prime related nouns, varying the relationship between the prime verb and the target noun (e.g. agent: *entertaining* → *comedian*; patient: *serving* → *customer*; instrument: *painted* → *brush*; and location: *slept* → *bedroom*). On the other hand, McRae et al. (2005) focused on priming of an inflected verb by the noun (e.g. agent: *actor* → *performing*; patient: *ball* → *thrown*; instrument: *axe* → *chopping*; and location: *bathroom* → *showering*). Overall, these studies found that the target word was processed faster when it was preceded by a related prime than by an unrelated one in either a category-judgement task (Ferretti et al. 2001) or a naming task (McRae et al. 2005). The findings are very valuable in that the manipulation of verb inflection enabled them to tap onto sentence comprehension processes with a word-on-word priming technique. However, a relevant question for our discussion is whether the experimental method was sufficient to tease apart predictive and integration processes. MacRae et al. (2005) make an explicit link between their findings and predictive processes: they note that '(their) results support the hypothesis that during sentence comprehension, the processing of nouns leads to anticipatory semantic computation of the verbs (or semantic class of verbs) with which they may combine later in the sentence' (p. 1181). Yet, it seems that this conclusion is rather too ambitious – by design, the priming method does not allow the authors to examine the processing of the prime itself. Consequently, the priming effects obtained in MacRae et al. (2005) or Ferretti et al. (2001) could well represent post-lexical integration processes at the target.

Other studies have used sentence-reading methods in order to address the issue of anticipation in sentence processing. One of the earliest studies of this kind was conducted by Taraban and Mcclleland (1988). They explored effects of 'content-based' expectations on attachment preferences in structurally ambiguous sentences in order to evaluate the minimal attachment principle in the Garden-path theory (Frazier 1978). Previously, Rayner et al. (1983) had contrasted sentences such as (3a) and (3b):

(3a) The spy saw the cop with binoculars.
(3b) The spy saw the cop with a revolver.

Both (3a) and (3b) are structurally ambiguous up to '*with*': the prepositional phrase can be attached to either the verb phrase headed by the main verb '*saw*' or the noun phrase *'the cop'*. However, the final noun phrase '*a revolver*' pragmatically disambiguates the ambiguity in (3b), as a revolver is not a suitable instrument for seeing. In contrast, for (3a), pragmatic knowledge suggests that binoculars could be an instrument for seeing, but also could easily be an object in a cop's possession, which leaves the

ambiguity unsolved. According to the Garden-path theory, however, the verb phrase attachment decision should be preferred for (3a), as it requires a fewer nodes than the alternative noun phrase attachment decision (minimal attachment). Rayner et al.'s (1983) eye-tracking study revealed shorter reading times for the final noun phrase in the final prepositional phrase in (3a) than (3b), which is consistent with the theory's prediction that the simpler structure should be preferred. However, Taraban and Mcclelland (1988) pointed out that the verbs used in Rayner et al.'s (1983) materials seemed to evoke expectations for a verb phrase (minimal) attachment structure rather than a noun phrase (non-minimal) one. To investigate the issue, they created an additional set of materials using verb and object continuations whose content was unlikely to prefer minimal attachment, such as in (4a) and (4b):

(4a) The reporter exposed corruption in the article.
(4b) The reporter exposed corruption in the government.

First, Taraban and Mcclelland (1988) conducted a rating study in which they asked their participants to rate how 'expected' they thought the final nouns in sentences like (3a–4b) were. The rating study confirmed the manipulation about the degree of expectation: for Rayner et al.'s materials, the final nouns were rated as more 'expected' in the minimal attachment condition (3a) than in its non-minimal attachment counterpart (3b), whereas, for Taraban and Mcclleland's materials, the pattern was the opposite. Then, a self-paced reading experiment further revealed that the minimal attachment sentences required more reading times for Rayner et al.'s stimuli, replicating the original results, whereas the pattern was opposite for Taraban & McClleland's stimuli [i.e. '*article*' in (4a) required more reading time than '*government*' in (4b)]. These findings were taken by the authors as an indication 'that the particular content of a sentence evokes expectations for the on-line processing of constituents in advance of the input that fully specifies the constituent, and that violations of these expectations result in a slowing of processing' (p. 621). However, their chosen method cannot avoid the same criticism as the word-on-word priming studies mentioned above; it does not allow us to distinguish between the prediction and integration interpretations. Thus, although Taraban and McClleland's (1988) study clearly made a valuable contribution by raising awareness of the prediction issue in the sentence processing literature, the method does not seem to live up to their stronger conclusion.

Similarly, Altmann's (1999) study falls into the same category of past research that provided valuable discussions for anticipation in reading but weak experimental evidence. Using a 'stop-making sense' task (cf. Boland et al. 1995), he examined whether a preceding context could narrow down the domain of possible theme (direct) objects in a target sentence. The following (5a) and (5b) present example context sentences, and (6) shows an example target one:

(5a) A car was driving downhill when it suddenly veered out of control. In its path were some pigeons and a row of bollards.
(5b) A car was driving downhill when it suddenly veered out of control. In its path were some dustbins and a row of bollards.
(6) It injured several bollards . . .

The experiment revealed that reading times and 'no' response rates at '*bollards*' in reading (6) were found to be increased when it was preceded by a discourse context that introduced an animate object as a potential object to be missed by the car, (5a), compared with the condition in which it was not, (5b). Altmann (1999) discussed a possible interpretation of the results. At the verb (e.g. '*injured*'), semantic constraints for its permissible objects are activated predictively and mapped with the existing discourse structure. He notes that 'one interpretation of these data is that the processor projects, at the verb, the upcoming postverbal referring expression and attempts to establish, given the thematic criteria (selectional restrictions) imposed by the verb, whether there are any discourse antecedents with which it could be coreferential' (p. 131). However, as with all the other studies mentioned above, his results are also compatible with the possibility that the mapping occurred at the 'bollards' with no relation to prediction at the verb (integration view).

To summarize, a number of studies have expressed their interests in, and provided implications for, anticipation (prediction) in sentence comprehension by examining the processing time for a predictable target item, relative to the time for a less predictable one (e.g. Taraban and McClleland 1988; Ferretti et al. 2001; Altmann 2004; MacRae et al. 2005). However, the methods used are inherently unsuitable for direct examination of anticipation processes per se. Therefore, more direct methods have been called for, especially as an increasing volume of interests has been shown in anticipatory processes in the psycholinguistic literature.

Quests for Direct Examination: Recent Research

Alongside the increased amount of interest in anticipation in sentence processing, psycholinguistics has started to enjoy more advances in its experimental methodology in the past decades. The newly popularized methods have been, as a natural progression, used for exploration of the anticipation issue, as well as various other issues in the field.

The first class of newly emerging methods is the so-called '*visual-world*' eye-tracking paradigm (originally by Cooper 1974). In experiments using the technique, both visual and auditory linguistic stimuli are (often simultaneously) presented to participants, while participants' eye movements are tracked. This technique notably allows us to time-lock each eye event (fixation, saccade) against the linguistic stream of sound, and hence to investigate the incremental processes by which listeners map language

onto a 'visual-world' as the language unfolds with time. Tanenhaus and colleagues (e.g. Tanenhaus et al. 1995) were the first to (re)introduce the experimental paradigm to sentence processing research. Tanenhaus et al. (1995) arranged a few objects in front of participants, and played spoken sentences for them to follow by acting out the instructions. The experiment attempted to emulate the referential context effects on the resolution of verb phrase/noun phrase attachment ambiguity found in reading studies (e.g. '*Put the apple on the towel . . .*'; Crain and Steedman 1985; Altmann and Steedman 1988), using visually presented referential contexts. The referential context was manipulated by varying the number of the target objects in the display – in one condition, there was only one object of the same kind (e.g. *an apple on a towel, an empty towel, an empty box, a pencil – one-referent condition*), while, in the other condition, there were two objects of the same kind (e.g. *an apple on a towel, an apple on a napkin, an empty towel, an empty box – two-referent condition*). The experiment showed that, shortly after '*towel*', the incorrect Goal object (the empty towel) was looked at more often in the one-referent condition than in the two-referent condition, replicating previous findings that the introduction of multiple objects of the same kind weakened the verb phrase attachment preference in reading.

Tanenhaus et al.'s (1995) innovative study provoked an influx of new studies with the dual-modal paradigm, addressing a wide range of psycholinguistic issues. There is very little surprise that the issue of anticipation was one such topic dealt with by the new paradigm. The first set of visual-world experiments on anticipation (Altmann and Kamide 1999) aimed to address the 'prediction at verb' hypothesis discussed by Altmann (1999) in a more direct way. In their experiments, the 'visual world' was provided as a semi-realistic visual 'scene' with several clipart drawings, and participants were simply instructed to look at the pictures and listen to spoken sentences at the same time. In one of the trials, for example, participants were presented with a picture containing *a boy*, *a birthday cake*, *a toy car*, *a toy train set*, and *a ball*, while they heard a spoken sentence, either (7a) or (7b) in the following:

(7a) The boy will eat the cake.
(7b) The boy will move the cake.

The items were created in such a way that there was only one do-able object in the picture for one condition (7a), while there were more than one for the other condition (7b). The experiment aimed to examine whether verb's semantic constraints on its possible objects – *selectional (or selection) restrictions* (Chomsky 1965) – is used to narrow down the domain of plausible objects to follow. If so, the listeners should move their eyes towards the target object, the cake in the example picture, more frequently in the '*eat*' condition than in the '*move*' condition before encountering the actual referring expression '*cake*'. Altmann and Kamide (1999) termed

the relatively frequent eye movements to the predicted objects prior to the onset of the referring expression as '*anticipatory*' eye movements – terminology borrowed from the eye movement literature. The experiments confirmed the prediction: between the onset of the verb and the onset of the critical noun (e.g. '*eat_the_*': '_' represents a pause; mean duration – 703 msec), the proportion of the trials with a saccade towards the target object (e.g. *cake*) was higher in the '*eat*' condition (54%) than in the '*move*' condition (38%). Further analyses confirmed that the difference was statistically warranted at as early as the verb itself [29% (*eat*) vs. 22% (*move*); mean duration – 403 msec]. Thus, it was suggested that listeners incrementally integrate auditory linguistic information and visual context, and more importantly, that the integration takes place rapidly enough to make anticipation of a semantic domain of a forthcoming object possible.

Since Altmann and Kamide's (1999) study, numerous studies using the experimental paradigm have been conducted to investigate further types of information that could trigger prediction of a forthcoming item. For example, Kamide et al. (2003) presented three experiments to follow Altmann and Kamide (1999), varying the sentence structure, type of plausibility, and also type of language, from the original study. In Experiment 2 in Kamide et al. (2003), for example, they extended the main focus to the use of the combined restrictions of the verb and the agent on a possible theme. One of the item sets had the picture in Figure 1 presented

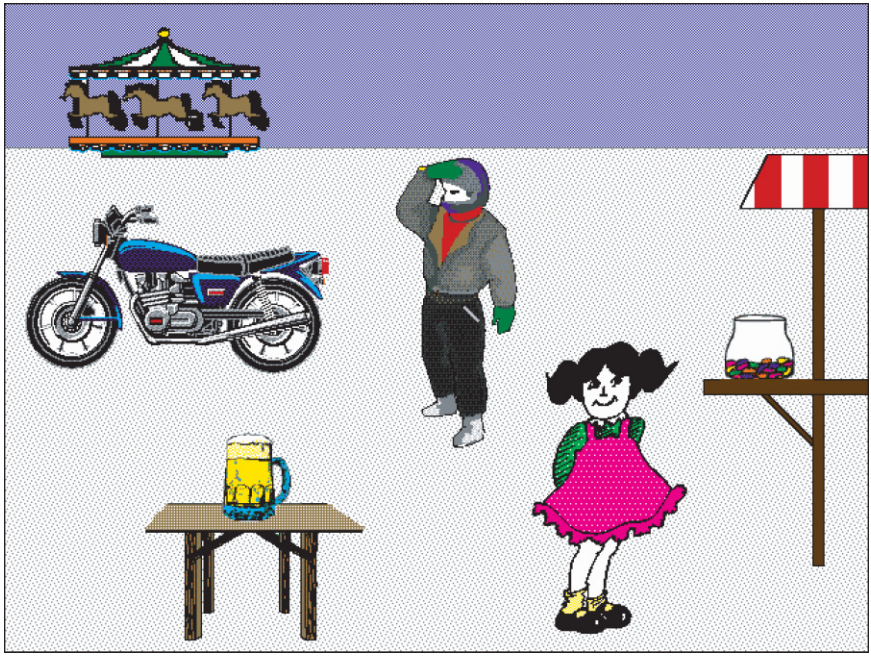

Fig. 1. An example visual stimulus used in Experiment 2, Kamide et al. (2003).

with one of the following sentences [for (8c) and (8d), the positions of the man and the girl were swapped and they were mirror imaged in order for the agent object of all four sentences to be in the same position within the picture and also to face towards roughly in the same direction]:

(8a) The man will ride the motorbike.
(8b) The man will taste the beer.
(8c) The girl will ride the carousel.
(8d) The girl will taste the sweets.

The experiment aimed to explore the time course of the integration of the constraints imposed by the agent (subject) and the verb. For analyse purposes, the objects in the pictures were classified into four categories for each sentence: (i) *Combinatory Objects*: the eventual theme objects (e.g. the motorbike for '*The man will ride . . .*'); (ii) *Verb Objects*: the ones that satisfy the selectional restrictions of the verb, but are more associated with the other agent (e.g. the carousel for '*The man will ride . . .*'); (iii) *Agent Objects*: the ones that are associated with the agent but do not satisfy the selectional restrictions of the verb (e.g. the beer for '*The man will ride . . .*'); and (iv) *Irrelevant Objects*: the objects that are least associated to the sentence (e.g. the sweets for '*The man will ride . . .*'). In the analyses, the critical region consisted of two sub-regions – between the onset of the verb and the offset of the verb (e.g. '*ride*': mean duration – 398 msec), and between the offset of the verb and the onset of the referring noun ('*_the_*': mean duration – 240 msec). During the verb region, the combinatory objects were looked at more frequently than any other objects, while the other three types of objects did not differ in their fixation proportion among them (percentage of trials with a saccadic eye movement towards each type of object: combinatory – 8.7%; verb – 6.3%; agent – 6.0%; and irrelevant – 5.9%). This suggests that the constraints from the subject and verb of the sentence were combined as soon as the verb appeared and used to anticipate the most appropriate object to follow. In the next region ('*_the_*'), the anticipatory effect continued (combinatory – 10.6%; verb – 7.4%; agent – 3.7%; and irrelevant – 3.4%). However, interestingly, the verb objects also received more looks than the other two types of objects (agent and irrelevant objects) during this region, which suggests that meeting the verb requirements manifests advantages over meeting the agent requirements or no requirement, but the manifestation takes place later than meeting both the verb and agent requirements.

Boland (2005) has also used the visual-world paradigm to investigate anticipation processing in listening. The main motivation of her study was to make a distinction between real-world knowledge and syntactic constraints as a driving force of anticipation. In her Experiment 3, Boland (2005) contrasted the following sentences:

(9a) One window was broken, so the handyman mentioned it right away to the owners.
(9b) One window was broken, so the handyman fixed it hurriedly for the owners.

(9a) contains a dative verb ('*mentioned*'), and, therefore, the crucial noun phrase '*the owners*' functions as an argument (recipient). In contrast, (9b) contains a monotransitive action verb ('*fixed*'), and '*the owners*' function as an adjunct (benefactor). Thus, if the linguistic status influences anticipation, 'the owners' would be anticipated more often in (9a) than (9b), other factors being equal. First, Boland (2005) investigated co-occurrence frequency between the verbs and target nouns in her item set ('*mention*' – '*owner*'; '*fix*' – '*owner*'), using World Wide Web search engines (Google & Lycos Exact Phrase). The searches revealed that the frequency of the co-occurrence with the nouns was statistically indistinguishable between the dative verb (9a) and the monotransitive verb (9b) conditions. Then, in a visual-world eye-tracking study, auditory sentences like (9a) and (9b) were presented with a slide with four photographed objects (e.g. *a broken window*, *a handyman*, *owners* and *tools* for (9a) and (9b) above). The results showed that, during the time window between 500–1000 msec after the verb onset (the prepositional onset came at about 1,275 msec after the verb onset), the target objects (owners) were looked at more often when the verb was dative [in (9a)] than when it was monotransitive [in (9b)], whereas the proportions of the looks to the instrument objects (tools) were the same between the two condition [*recipient/benefactor (owners)*: dative – 49%, monotransitive – 34%; *instrument (tools)*: dative – 16%, monotransitive – 15%]. Boland (2005), therefore, indicated that the linguistic argument status differentiates arguments from adjuncts qualitatively in anticipatory processing (i.e. arguments are more likely to be anticipated than adjuncts).

Thus, these studies show that the human language processor is able to integrate verb-based lexical information and visual information, and then use the information to anticipate what will come next in the speech stream. However, in theory, linguistic information sources for prediction do not have to be restricted to verbs. Experiment 3 in the aforementioned Kamide et al.'s (2003) study investigated whether an argument can be anticipated by a sequence of other case-marked noun phrases prior to the verb in a head-final language, Japanese. In one example item set, participants heard one of the following sentences with a semi-realistic picture containing *a waitress*, *a customer*, *a hamburger*, and *a dustbin* (distractor):

(10a) ウェイトレスが客に楽しげにハンバーガーを運ぶ。
weitoresu-ga kyaku-ni tanosigeni hanbaagaa-o hakobu.
waitress-nom customer-dat merrily hamburger-acc bring.
'The waitress will merrily bring the hamburger to the customer.'

(10b) ウェイトレスが客を楽しげにからかう。
weitoresu-ga kyaku-o tanosigeni karakau.
waitress-nom customer-acc merrily tease.
'The waitress will merrily tease the customer.'

In Japanese, nominative-, dative-, and accusative-marked noun phrases are likely to serve the agent, goal and theme roles, respectively, for most verbs. A sequence of a nominative-marked noun phrase and *dative*-marked noun phrase [e.g. '*weitoresu-ga kyaku-ni . . .*' in (10a)] therefore indicates that, if the noun phrase is not an adjunct, an accusative-marked noun phrase is likely to follow unless the verb turns out to be one of a few monotransitive verbs taking a dative-marked theme. Within the accompanying picture, the hamburger is the most plausible object to be the theme. In contrast, a sequence of a nominative-marked noun phrase and an *accusative*-marked noun phrase [e.g. '*weitoresu-ga kyaku-o . . .*' in (10b)] indicates that either a dative-marked noun phrase or a monotransitive verb should follow unless the noun phrase is an adjunct. In the scene picture, however, there is no plausible object to play the Goal (neither the hamburger nor dustbin would be a plausible Goal). Thus, after the first two noun phrases, people should look at the hamburger more often in (10a) than in (10b). This pattern was observed during the adverb region '*merrily*' in the experiment. Thus, this Japanese experiment suggested that the sentence processor starts building the sentence structure prior to the verb (inconsistent with the head-driving parsing account; for example, Pritchett 1991), and achieves anticipation of forthcoming arguments if the pre-verbal information, especially case-marking information combined with real-world knowledge, is sufficiently constraining.

So far, we have seen examples of visual-world experiments that focus on the interplay of linguistic and real-world knowledge in anticipatory processing. Altmann and Kamide (1999), Kamide et al. (2003) and Boland (2005) all assume that real-world knowledge should be accessed by information in both the linguistic and visual contexts provided as the experimental stimuli. The real-world knowledge in those studies was what people should already know from their own experience. However, it is also possible to set up a particular, somewhat unusual even, contextual 'world' via the visual stimuli: such a setting would help to understand how rapidly the visual and linguistic information could be integrated without much intervention of real-world knowledge. In fact, one could argue that one of the most prominent problems with the visual-world experiments is that the technique does not make it easy to qualify and quantify the factors that contribute to the anticipation, due to the complexity of the information derived from the visual stimuli. For example, in Kamide et al.'s (2003) English experiment mentioned above, the man in Figure 1 easily looked like someone who would ride a motorbike. This was not a problem for their experiment, as such visual information was treated as

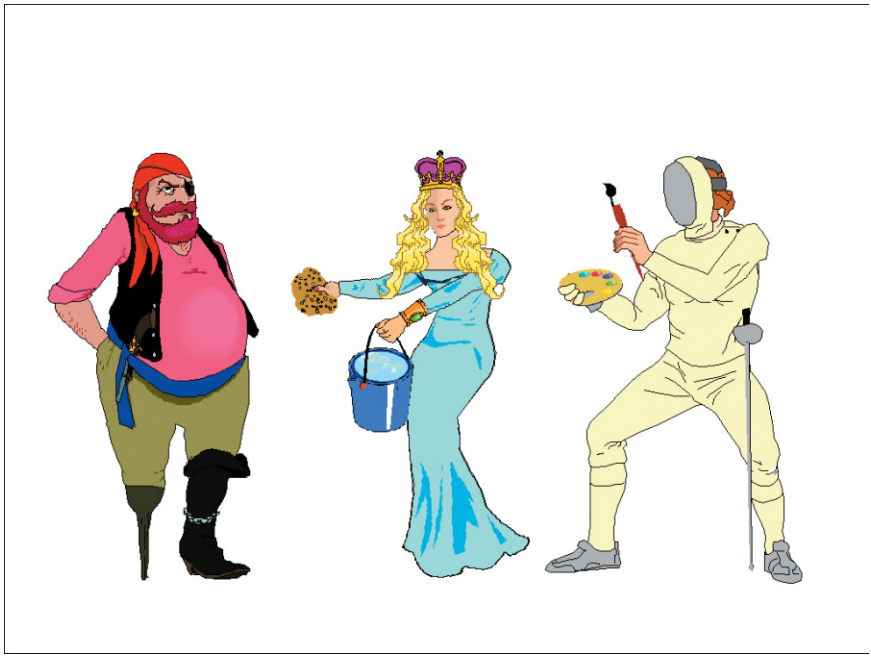

Fig. 2. An example stimulus used in Experiment 1, Knoeferle et al. (2004).

part of the 'context' to promote the link between the particular agent and theme. Yet, it is very difficult to define exactly what contributed to the anticipatory eye movements in this design. To tackle those problems, Knoeferle et al. (2005) constructed rather 'unusual' scenarios in their stimuli: for example, they compared the following German sentences, presented with Figure 2:

(11a) Die Prinzessin wäscht offensichtlich den Pirat.
The princess-nom/acc washes apparently the pirate-acc.
'The princess will apparently wash the pirate.'

(11b) Die Prinzessin malt offensichtlich der Fechter.
The princess-nom/acc paints apparently the fencer-nom.
'The fencer will apparently paint the princess.'

In those sentences, the first noun phrase ('*Die Prinzessin*') is ambiguous in terms of its case (it could be either nominative or accusative). This case-marking ambiguity, in principle, could leave the thematic role for the first noun (e.g. '*the princess*') undetermined until the unambiguously case-marked second noun phrase appears at the end of the sentence. However, the ambiguity could be resolved before the disambiguating

noun phrase, if listeners interpret and map the event in the picture onto the unfolding sentence rapidly enough. In experimental terms, the disambiguation process would be reflected as anticipatory eye movements towards the most likely second noun to follow [*pirate* in (11a); *fencer* in (11b)] during the onset of the verb and the onset of the second noun phrase ('*wäscht/malt_offensichtlich_*'). The experiment revealed no anticipatory effects during the verb. However, at the subsequent region ('*offensichtlich_*'), the eventual patient objects were looked at more often in the subject-first condition (11a) than the object-first condition (11b), whereas the eventual agent objects attracted more looks in (11b) than in (11a). Thus, the data suggested that anticipation of the forthcoming item (the second noun) could be achieved even when the event described in the language and visual world was somewhat unusual (a fencer painting a princess; a princess washing a pirate), indicating a rapid integration of language and vision, without much mediation by long-stored real-world knowledge, in anticipatory processing.

We have seen evidence that the new eye-tracking paradigm has made a significant contribution to offering a new direction in research in anticipatory processes during sentence comprehension. Around the same time, efforts have been made elsewhere to investigate prediction processes without pictorial contexts. Two such studies – both using electrophysiological activities of the brain during language processing – will be reviewed in the rest of this section.

Delong et al. (2005) set out their event-related potential (ERP) study to examine anticipation of a semantically plausible noun by a preceding narrative and verb. They first conducted a cloze probability norming study in which participants completed fragments such as (12):

(12) The day was breezy so the boy went outside to fly . . .

Based on the results, a pair of nouns, a relatively expected word (e.g. 'kite') and a less-expected word (e.g. '*airplane*') were selected for each sentence. The pair of nouns were constructed in such a way that one word requires an article '*a*' and the other '*an*' ('*a kite*' vs. '*an airplane*'; the numbers of these two articles were counterbalanced across the conditions). This manipulation was adopted so that a violation of anticipation could be observed on an item prior to the actual noun (i.e. the article) rather than on the head noun itself ('predictee'). For example, it can be predicated that the article '*an*' should elicit an anomaly effect after (12) in comparison with '*a*', as '*a*' is compatible with the more predictable head noun ('*kite*') whereas '*an*' is not. In a way, such anomaly effects at the article could still only show integration of the current input and the preceding items (see the prediction/integration discussion above). However, Delong et al. (2005) argues that, since there is no semantic difference between '*a*' and '*an*' themselves, the difficulty of integrating both articles in the preceding

context should be the same. Thus, any obtained difference in the electrophysiological activities at the article should be attributed to a difference in the difficulty in integrating the article and the already-predicted head noun. In the subsequent main experiment, participants were asked to read sentences [such as (13a) or (13b) below] silently while their electroencephalogram was recorded:

(13a) The day was breezy so the boy went outside to fly a kite.
(13b) The day was breezy so the boy went outside to fly an airplane.

The sentences were visually presented word-by-word, with each word presented for 200 msec with a 500-msec stimulus onset asynchrony. Based on the results from the pretest above, (13a) contains a more expected noun ('*kite*') whereas (13b) contains a less expected noun ('*airplane*'). Thus, if prediction occurs before the head noun, reading the prenoun article should cause problems in (13b) but not in (13a). The results showed anticipation effects: at the article ('*a*' or '*an*'), there was already a notable N400 effect (known as a component that is sensitive to context-dependent semantic anomaly): the incongruent articles ['*an*' (*airplane*) after '. . . *to fly* . . .'] elicited more negative amplitude than the congruent ones around 300 msec after the onset of the article. Also, during the N400 time window (200–500 msec after the onset of the article), the cloze results correlated with the size of the N400 effect: the less frequently the noun was answered in the cloze task, the bigger the N400 effect the preceding article elicited. The correlation effect was strongest over centroparietal sites of the brain, lateralized to the right. After the noun itself was encountered (between 200–500 msec after the noun onset), the N400 effect still continued, indicating that the less predictable noun caused semantic integration difficulties. Overall, the results suggested that people can anticipate a certain object to follow in reading. More specifically, it is important to note that Delong et al.'s (2005) experiment was the first to demonstrate anticipation of a phonological property (i.e. a lexeme) of the forthcoming noun.

A similar experimental design was used by van Berkum et al. (2005) in an inflectionally gender-marked language, Dutch (also see Wicha et al. 2003 for comparable findings in Spanish). Unlike Delong et al.'s (2005) English study, van Berkum et al.'s (2005) manipulation was based on the fact that an adjective and its head noun must agree on the gender in Dutch. Also the stimuli were presented auditorily, instead of visually as in Delong et al. (2005). In each trial, context sentences were followed by a target sentence: for example, a context sentence (14) was followed by either (15a) or (15b):

(14) De inbreker had green enkele moeite de geheime familieklus te vinden.
'The burglar had no trouble locating the secret family safe.'

(15a) Deze bevond zich natuurlijk achter een groot maar onopvallend shilderij.
'Of course, it was situated behind a big but unobtrusive painting.'
(15b) Deze bevond zich natuurlijk achter een grote maar onopvallende boekenkast.
'Of course, it was situated behind a big but unobtrusive bookcase.'

(15a) and (15b) are identical up to '*groot/grote*' (big): '*groot*' [in (15a)] is marked as neuter-gender (or 'zero'-gender), whereas '*grote*' is marked as common-gender. The preliminary cloze test suggested that '*shilderij*' ('painting' – neuter gender noun) would be a more plausible object to follow than '*boekenkast*' ('bookcase' – common gender noun). Thus, '*groot*' and subsequent '*onopvallend*' ('unobtrusive') in (15a) are compatible with the most predicable head noun in terms of their gender, whereas '*grote*' and '*onopvallende*' ('unobtrusive') in (15b) are not. As in Delong et al. (2005), the prehead target region [i.e. '*een groot maar onopvallend/een grote maar onopvallende*' ('*a big but unobtrusive*')] was critical for anticipation. The experiment revealed that there were small positive deflections effect on the inconsistent condition related to the consistent condition between 50–250 msec after the onset of the adjective inflection onset (329 msec after the adjective onset on average). Later in the sentence, a sizeable negativity effect was obtained in the inconsistent condition between 350–400 msec after the noun onset (N400 effect). This pattern of results suggests that the native speakers of Dutch can anticipate morphosyntactic features of the forthcoming item, gender in this example (hence, the positivity effect shortly after the adjective inflection onset) as well as semantic features of the item (hence, N400 effects during the noun itself).

Taken together, as with the visual-world experiments reviewed above, these ERP studies suggested that people can anticipate what will follow in the sentence given the right contexts. However, unlike the visual-world experiments, the ERP studies did not explicitly provide a set of 'predictee' candidates, but let the preceding linguistic items constrain the candidate set ('*The day was breezy so the boy went outside to fly . . .*' for '*a kite*', Delong et al. 2005; '*The burglar had no trouble locating the secret family safe*. '*. . . it was situated behind a big but unobtrusive . . .*' for '*painting*', van Berkum et al. 2005). Also, those contexts were not presented simultaneously with the target sentences but followed by them in the ERP studies, which could be regarded as a strength of the experiment designs compared with the visual-world ones.

Remaining Issues

Thus, it seems that both the eye-tracking and ERP techniques have allowed researchers to investigate anticipatory processes in sentence processing

by directly looking at behaviours at the predictors (e.g. Altmann and Kamide, 1999; Kamide et al. 2003, Experiment 2) or regions between the predictors and the predictees (e.g. Kamide et al. 2003; Boland, 2005; Knoeferle et al. 2005, Experiment 3; Delong et al. 2005; van Berkum et al. 2005), obviating the prediction/integration problem discussed above. Although it may sound rather straightforward, the psycholinguistic literature had to wait until recently for the technological advances to allow such experimental designs. However, these new studies have not solved all issues related to anticipatory processing. In the remainder of the present article, I will first discuss technical limitations in the visual-world experiments – all limitations shed light on the generalizability of findings obtained using the paradigm. Then, I will move on to more general theoretical issues related to anticipatory processes in language processing.

The first, and presumably most severe, problem with the visual-world paradigm concerns the fact that the visual contexts provide a range of candidates for a 'predictee' up front. Since constraining contexts are vital to successful prediction, it seems fair to view typical visual-world settings as extreme cases in which contexts are so constraining that prediction can be achieved in processes akin to answering multiple-choice questions. Indeed, presenting a limited candidate set is not a new or limited to the visual-world technique – for example, we have seen Altmann's (1999) reading study in which potential theme objects, '*some pigeons*', were explicitly mentioned before the target verb '*injured*' [(15a) and (16)]. However, we have also seen other non-visual world studies, Delong et al. (2005) and van Berkum et al.'s (2005), whose discourse context served to narrowed down the domain of a possible candidate set without mentioning candidates explicitly [(13a), (14) and (15a)]. In contrast, it is difficult for the visual-world paradigm to allow possible candidates to be inferred in a similar way to Delong et al. (2005) and van Berkum et al.'s (2005).

The second problem is also related to the presentation of visual contexts. In typical visual-world settings, not only contexts provide an explicit candidate set for the 'predictee', but also a candidate set is present when the 'predictor' is encountered. This is not the case in reading experiments. To give us an example, let us translate Altmann and Kamide's (1999) example picture and target sentence into the following narrative:

(16) It is raining outside today, so the boy is playing on his own in the living room. On the floor, there are a toy car, a train set, a ball, and a cake. Then, the boy eats/moves . . .

In principle, we could assume that the visual context and target sentence in Altmann and Kamide (1999) and the narrative sentences in (16) should provide comparable information. However, can we also assume that comparable information is available to the processor in both situations for anticipation of the forthcoming object at the critical verb? Here, the

question is whether the representation for the target object (cake) would be maintained at the verb ('*eat/move*') in (16) as strongly as in the visual-world setting. Indeed, this problem has not been unnoticed in the visual-world literature. To address the question, Altmann (2004) conducted a visual-world experiment using a similar set of stimuli as Altmann and Kamide (1999) with a different presentation procedure: the picture was first presented without the sentence, then replaced by a white display accompanied by the auditory sentence, somehow emulating the procedure of reading narratives like (16) (*blank screen* technique). Altmann (2004) found that the proportion of saccades to the target objects (cake) was significantly higher in the 'eat' condition than in the 'move' condition as early as the verb, providing the same pattern as Altmann and Kamide's (1999) original experiment. Therefore, the replication suggests that anticipatory eye movements could occur even when a set of candidates for the 'predictee' (e.g. cake) is not present when the 'predictor' (e.g. '*eat*') appears.

Third, it could limit the scope of the paradigm that the contexts are provided as pictures. It could be hypothesized, for example, that accessing information related to an entity is easier when the entity is presented as a picture than as a word. For example, it has been repeatedly shown that pictures are encoded more easily and recalled better than words (*picture superiority* effect; Nelson et al. 1976; Paivio 1971). As mentioned earlier, research in anticipatory processes attempts to clarify the amount and quality of information, or context, which is strong enough for anticipation. Therefore, the intrinsically better accessibility of pictorial contexts could make it easier for the processor to access context information, which could help to promote anticipation compared with verbally provided contexts. [Indeed, this problem could seriously counterargue the claim that one could use Altmann's (2004) blank paradigm as a warranty to extend visual-world findings to the issue of reading.]

Fourth, it is important to point out that the paradigm bears a complex experimental setting. It involves one extra modality compared with some of traditional single-modal experimental techniques. Also the paradigm requires participants to process two different types of stimuli often at the same time – pictures and language. Therefore, the particular duality in the modality and information type could also limit the generalizability of the research outcomes.

The final concern is related to the fact that the visual-world paradigm relies on eye movements to objects. In other words, the process the technique taps onto is mainly referential (i.e. the processing of objects). This can limit the capacity of the paradigm; the paradigm only enables us to investigate anticipation of depicted/actual objects in front of the listeners. In contrast, in real-world linguistic settings, listeners could anticipate more varied aspects of language; they could predict objects that are not present, properties of the objects that are not present, syntactic or phonological properties of forthcoming noun phrases (Delong et al. 2005; van Berkum

et al. 2005), or even verbs in verb-final clauses. Thus, in general, although the paradigm provides a good platform to explore a variety of aspects of the 'context' in anticipatory processing, it imposes a severe restriction on the range of aspects of the 'predictee' the research can demonstrate.

In addition, the question of anticipatory processes faces with a number of more general, theoretical unresolved issues. First, it is critical to address the question of whether anticipation is a function to which the language processor automatically engages itself in any circumstances, or a function to which the processor does not commit itself in some circumstances, such as those in which the estimated costs would be much larger than the estimated benefits. If the latter, it is then necessary to clarify the mechanism by which the costs and benefits are computed and evaluated against each other. Another crucial question is concerned with the costs of an incorrect prediction: does a wrong prediction lead to processing costs that are quantively and qualitatively similar to those of reanalysing already-encountered items; or are the costs of recovering from an incorrect prediction smaller, presumably because the 'depth' of processing (i.e. the degree of elaboration in the established representations) is shallower in anticipatory processes?

Also anticipatory processes need to be clarified in terms of a wide range of more general issues that are also the centre of debates in other research topics in psycholinguistics. Some of the unresolved questions belong to the following categories. First, we need to address the question of serial/parallel processing in anticipation. That is, can the processor make a commitment to only one choice at a time (serial processing), or more than one (parallel processing)? If parallel anticipation is possible, are all choices favoured equally or are they favoured in a ranked order (weighted parallel processing)? Second, the question of individual differences and language development should be addressed. For example, the following problems are yet to be solved: do people with a larger verbal memory span achieve anticipation more successfully? How does anticipation relate to development of other language skills in L1 (first-language) and L2 (second-language) learning? Do language learners (L1 or L2) acquire the anticipation mechanism as a reading/listening strategy? Third, the neuropsychological basis of predictive processes should be investigated further. For instance, what is the relationship between the ability in anticipation and the ability (or inability) in other aspects of language processing in people with neurological deficits? Also, could one identify the locus of a 'prediction centre' in the brain?

Finally, it is worth pointing out that a theory has been put forward recently that hypothesizes that language comprehenders use the production system in order to predict upcoming linguistic items (Pickering and Garrod 2007). According to the theory, comprehenders construct an 'emulator' based on the production system while receiving linguistic input. The emulator's main aim is to predict the next input unit in the current linguistic sequence at different levels (phonology, syntax and semantics)

simultaneously. The emulator dynamically assigns a probability to one or multiple predictions based on all relevant available contexts, and receives feedback as soon as the input has been analysed in the input analysis system. Although Pickering and Garrod (2007) do not provide definitive evidence that the production system is involved in predictive processes in the emulator, that is, prediction, they discuss numerous phenomena that suggest a close link between comprehension and production. For instance, it has been found that listening or viewing speech-related lip movements enhances excitability of the motor units related to speech production in the brain (Watkins et al. 2003). Based on converging evidence that interlocutors often covertly imitate each other at different linguistic levels in dialogue (e.g. Garrod and Anderson 1987; Branigan et al. 2000), Pickering and Garrod (2007) claim that the production system makes predictions through imitation, and the predictions then facilitate comprehension.

Altogether, one might wonder how much we know about anticipatory processes in sentence processing based on existing evidence. As reviewed above, the credible data have only recently started accumulating. Therefore, we inevitably still face with numerous questions to address, some of which are listed above. However, it is evident that we have certainly seen increased interests and efforts, and the recent developments seem rather promising. It is, therefore, eagerly anticipated that the interests will continue to rise, and more data will be accumulated to clarify the mechanism better.

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Short Biography

Yuki Kamide is a Lecturer in Psychology at the University of Dundee, Scotland, UK. Her research interests are broadly concerned with sentence processing in normal adults. In particular, she is interested in the time course of the use of various types of information in processing typologically different languages (English, Japanese and German). Her other interests centre around the integration of linguistic and visual information, especially in terms of the dynamism of spatial representations during sentence processing. She holds a PhD in Psychology from the University of Exeter, UK, and a BA and MA in Psychology from Kobe University, Japan.

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