Activation and Persistence of Implicit Causality Information in Spoken Language Comprehension

Pirita Pyykkönen[1] and Juhani Järvikivi[2]

[1]Department of Psychology, University of Turku, Finland
[2]Max Planck Institute for Psycholinguistics, Nijmegen, The Netherlands

Abstract. A visual world eye-tracking study investigated the activation and persistence of implicit causality information in spoken language comprehension. We showed that people infer the implicit causality of verbs as soon as they encounter such verbs in discourse, as is predicted by proponents of the immediate focusing account (Greene & McKoon, 1995; Koornneef & Van Berkum, 2006; Van Berkum, Koornneef, Otten, & Nieuwland, 2007). Interestingly, we observed activation of implicit causality information even before people encountered the causal conjunction. However, while implicit causality information was persistent as the discourse unfolded, it did not have a privileged role as a focusing cue immediately at the ambiguous pronoun when people were resolving its antecedent. Instead, our study indicated that implicit causality does not affect all referents to the same extent, rather it interacts with other cues in the discourse, especially when one of the referents is already prominently in focus.

Keywords: implicit causality, visual world eye-tracking, pronoun resolution, spoken language comprehension

Natural language allows the communication of events in a subtle, often minimal way, and sometimes even without explicit cues to its interpretation. Therefore, in order to fully understand the unfolding discourse, it is important to be able to infer rapidly, for example, what the implicit causes and consequences of the recounted events might be. In the following, grammatically similar, sentence fragments *John frightened Bill because...* and *John feared Bill because...*, the interpersonal verbs *frighten* and *fear* direct attention to different participants: Verbs like "frighten" highlight the first participant of the event, John, whereas verbs like "fear" highlight the second participant, Bill, as shown by several tasks where people have been asked to continue such sentences (for a recent review, see Guerry, Gimenes, Caplan, & Rigalleau, 2006). Since the inference in the above cases is based on who is thought to be responsible for the fear or fright, respectively, this verb-based bias toward either of the participants is referred to as implicit causality. However, even though studies on pronoun resolution have demonstrated strong effects of implicit causality on referential processing during both offline and online tasks (e.g., Crinean & Garnham, 2006; Garnham, Traxler, Oakhill, & Gernsbacher, 1996; Garvey & Caramazza, 1974; Garvey, Caramazza, & Yates, 1975; Greene & McKoon, 1995; Koornneef & Van Berkum, 2006; Stewart, Pickering, & Sanford, 2000), there is still no consensus as to when exactly during the course of processing this information is activated and used.

The Clausal Integration Account states that implicit causality information affects comprehension during a late semantic clausal integration phase, when implicit causality information in the main clause is integrated with the explicitly stated causal information in the subordinate clause (Garnham, 2001; Garnham et al., 1996; Stewart et al., 2000). Therefore, this predicts that implicit causality should not affect the relative activation of the potential antecedents until people have enough information to determine whether the information in the subordinate clause is in agreement or disagreement with the implicit causality bias in the main clause. In contrast, the Immediate Focusing Account claims that implicit causality information is used much earlier to focus one of the referents at the expense of the other and would thus affect reference resolution immediately when a pronoun is encountered (Greene & McKoon, 1995; Koornneef & Van Berkum, 2006; McDonald & MacWhinney, 1995; McKoon, Greene, & Ratcliff, 1993; Van Berkum, Koornneef, Otten, & Nieuwland, 2007).

Consistent with the integration view, Garnham et al. (1996) observed an implicit causality effect in probe recognition for probes presented toward the end of the sentence, but not for those presented immediately after the pronoun. Also, Stewart et al. (2000) found no early effects of implicit causality in self-paced reading experiments, but, instead, found late facilitation for sentences with consistent implicit and explicit causes. In contrast, McDonald and MacWhinney (1995) did observe an early effect of implicit causality on probes presented immediately after the pronoun (see also Long & DeLey, 2000; McKoon et al., 1993). Similarly, Koornneef and Van Berkum (2006) found an effect of implicit causality

shortly after people read the gender marked pronoun in experiments using self-paced reading and eye-tracking. Furthermore, Van Berkum et al. (2007) found a P600 effect appearing 400–700 ms after the onset of a gender marked pronoun which mismatched with the verb bias.

Although seemingly supportive of either focusing or integration, much of the evidence is in fact less conclusive than it first appears. For example, in Stewart et al. (2000) the participants read the sentences in two fragments, and thus it is possible that some of the differences found at the later fragment were spill-over effects related to the pronoun presented at the end of the first fragment. In Koornneef and Van Berkum's (2006) study, the implicit causality effect appeared after the pronoun in self-paced reading (Experiment 1); and with eye-tracking (Experiment 2), the early measures (first fixation duration) did not show an effect until the third word after the pronoun, and the only significant effect on the pronoun was observed in the regression path. Thus, neither study is clearly incompatible with focusing or integration. Moreover, even though the later work by Van Berkum et al. (2007) supports focusing more clearly, none of the available studies allow us to determine whether implicit causality information was activated elaboratively prior to the gender disambiguated pronoun.

A strong interpretation of focusing would predict that implicit causality affects attention to the participants in the event immediately after verb information becomes available. Therefore, one might argue that the effect should occur before the pronoun. This activation should then persist until a pronoun is encountered, at which point the antecedents with consistent implicit causality bias would have an immediate advantage over the inconsistent antecedents as the preferred referents of the pronoun, provided that no definite disambiguating information, such as gender marking, is available.

A further important issue related to the timing of the effect is whether implicit causality is an inherent property of verbs (e.g., Au, 1986; Crinean & Garnham, 2006; Pickering & Majid, 2007); particularly, whether the effect is tied to the occurrence of an explicit marker needed to trigger its activation. Although many studies suggest that the occurrence of the implicit causality effect may depend on the presence of the causal connective *because* (e.g., Ehrlich, 1980; Koornneef, 2008; Stevenson, Crawley, & Kleinman, 1994; Stevenson, Knott, Oberlander, & McDonald, 2000), other evidence suggests that this is not the case (McDonald & MacWhinney, 1995).

In sum, even though there is evidence supporting both integration and focusing, the exact timing of the activation of implicit causality information has remained unresolved. One reason for the failure to resolve this issue may be methodological: Firstly, much of the mutually inconsistent evidence comes from probe recognition, which may reflect special strategies specific to the task itself rather than normal language comprehension (Gordon, Hendrick, & Foster, 2000); and secondly, despite the fact that reading and event-related potentials methods are temporally sensitive, they are each dependent on a mismatch between implicit causality and other information (e.g., gender), thus allowing for the effect to be indexed only after the point where the violation occurs, that is, at the pronoun or after. One way

to avoid this is to use the visual world eye-tracking technique that offers the possibility of following the time course of the effects as the linguistic information unfolds without the need for such violations (Cooper, 1974; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995).

Activation of Implicit Causality and Its Use in Pronoun Resolution

One line of evidence suggesting early activation of semantic information comes from studies demonstrating that semantic features may become activated even in contexts in which they would not be helpful for building immediate coherence, such as in elaborative inferences (e.g., Garnham, Oakhill, & Reynolds, 2002; Pyykkönen, Hyönä, & Van Gompel, in press). For example, using the visual world method, Pyykkönen et al. showed that on hearing a word like *secretary*, which had been independently rated as a highly female-stereotyped occupation, participants did not wait until they needed to integrate this word into the discourse context later at the anaphor, but instead activated the stereotype information when first encountering the word. In accordance with the elaborative activation of stereotypes, implicit causality information, as another dimension of verb semantics, can be hypothesized to become activated immediately after the verb when its meaning becomes available.

However, although implicit causality could be activated following the verb and even before the causal conjunction, this in itself does not necessarily imply that it would be used when interpreting an ambiguous pronoun later in the context. On the one hand, it may be that ambiguous pronoun resolution is also driven first and foremost by structural factors, as suggested by evidence from other types of ambiguity resolution in sentence processing such as garden path sentences (e.g., Ferreira & Clifton, 1986; Frazier, 1987), and that other types of information, including semantic implicit causality, are used only later at the integration phase (e.g., Gordon & Hendrick, 1998; Garnham et al., 1996). Thus, regardless of the early activation of implicit causality information, people may use structural factors earlier when resolving an ambiguous pronoun which they encounter later in the discourse. This implies that information that can be called structural, such as order-of-mention, grammatical role, and parallel syntactic function of the pronoun and the potential antecedents, would affect pronoun resolution earlier in time than semantic implicit causality (Chambers & Smyth, 1998; Grober, Beardsley, & Caramazza, 1978; Sheldon, 1974; Smyth, 1994).

On the other hand, current interactive models of ambiguity resolution in sentence processing (e.g., McRae, Spivey-Knowlton, & Tanenhaus, 1998; Trueswell, Tanenhaus, & Garnsey, 1994; Tyler & Marslen-Wilson, 1977) do assume that all structurally based alternatives and other sources of information, semantic and pragmatic, are activated and used in parallel to determine which of the analyses should be adopted. Thus, in line with the focusing account (e.g., McDonald & MacWhinney, 1995; McKoon et al., 1993), implicit causality information may be readily available from early on and incrementally integrated with other information

as the utterance unfolds (see also Koornneef & Van Berkum, 2006 for a similar view). The extent to which this information then affects ambiguous pronoun resolution would depend on its relation to other available information affecting the relative salience of the potential antecedents at the moment of encountering the pronoun.

Experiment

We investigated the above issues in spoken language comprehension. The two main questions were as follows: (1) Is implicit causality information activated prior to the pronoun after encountering the verb and before the causal conjunction is encountered, or, does the activation occur only after a pronoun when this information is needed to resolve the referential relationship between the ambiguous pronoun and its potential antecedents? (2) If implicit causality is activated prior to the pronoun, does the activation persist until the pronoun and is implicit causality used as a focusing cue immediately at the pronoun in reference resolution?

In order to answer these questions, we employed the visual world eye-tracking method (Cooper, 1974; Tanenhaus et al., 1995). By tracking participants' eye movements to pictures presented on the computer screen while they were listening to the spoken stimuli, we were able to assess how they interpreted the linguistic material. Studies with this method have shown that people's eye movement behavior is closely time locked with language processing (e.g., Allopenna, Magnuson, & Tanenhaus, 1998; Dahan, Magnuson, & Tanenhaus, 2001; Sedivy, Tanenhaus, Chambers, & Carlson, 1999). Previous studies have also shown that the method is ideal for investigating pronoun resolution: The increased probability of fixating one entity over another reveals how people resolved the pronoun and the factors that they used to arrive at their decision (Arnold, Brown-Schmidt, & Trueswell, 2007; Arnold, Eisenband, Brown-Schmidt, & Trueswell, 2000; Järvikivi, Van Gompel, Hyönä, & Bertram, 2005; Kaiser & Trueswell, 2008). It has also been shown that this method is effective in revealing the elaborative activation of semantic features of words in discourse (Pyykkönen et al., in press).

Taking advantage of these possibilities, we showed people four pictures on the computer screen while they were listening to two-sentence stories in Finnish (Table 1). In order to determine whether implicit causality would have an effect immediately after the verb, the critical second sentence had a subject or object biasing experiencer-stimulus or stimulus-experiencer verb. The pronoun was introduced later in the following subordinate clause, which enabled us also to investigate whether possible activation of implicit causality would persist until the pronoun. In addition, both the subject and the object form of the gender ambiguous third person pronoun, *hän* "s/he" or *hänet* "her/him" was used. Previous research has shown that ambiguous pronouns are preferentially interpreted as coreferential with the subject and first-mentioned antecedent of the preceding clause (Crawley, Stevenson, & Kleinman, 1990; Frederiksen, 1981; Gernsbacher & Hargreaves, 1988; Järvikivi et al., 2005) as well as with the antecedent that has the same grammatical

role as the pronoun (e.g., Chambers & Smyth, 1998; Grober et al., 1978; Sheldon, 1974; Smyth, 1994). We exploited this well-established structural preference in order to investigate whether implicit causality would have an effect only after structural information is used or whether it would be used at the same time or even earlier than structural grammatical role and parallelism information.

To summarize the hypotheses with respect to our first question, if implicit causality information is activated prior to the pronoun and the conjunction, this should trigger more fixations to the character consistent with the implicit causality bias immediately after the verb as soon as its semantics become available. If the activation depends on the presence of a causal conjunction, we should observe more fixations to the consistent characters only after *koska* "because". However, if implicit causality is not activated prior to the pronoun, we should not find such a preference – instead participants would be expected to fixate the subject which was mentioned just before the verb and later the object once it is mentioned. Importantly, the early looks to the subject and later looks to the object should not interact with implicit causality.

With respect to our second question, if implicit causality information is persistent and used as a focusing cue at the pronoun, we should find increased probability to fixate the character that is consistent with the implicit causality bias regardless of the pronoun type. As to the time course of the constraints, it could also be argued that, according to the focusing account, the looks to the implicit causality consistent character should be found at the same time or earlier than structural order-of-mention/grammatical role or parallelism effects. However, if people initially use structural cues prior to semantic cues to resolve the pronoun, we should find more looks to the subject antecedent with the subject pronoun and an increased probability to fixate the object antecedent immediately after the object pronoun.

Method

Participants

Thirty-two undergraduates from the University of Turku participated for course credit. All were native speakers of Finnish with normal or corrected-to-normal vision and no reported hearing problems.

Apparatus

An SR Research EyeLink II eye-tracker was used. The eye-tracker is a near infrared video-based system combined with hyperacuity image processing. A 500 Hz sampling rate was used. Spatial accuracy was better than 0.5 degrees of arc. Viewing was binocular; only one eye was recorded.

Materials and Design

Thirty-two experimental stories in four conditions were constructed consisting of two spoken sentences (Table 1). The first sentence introduced one of the two critical characters.

Table 1. Examples of the materials

First sentence	Kitaristi oli valmistautumassa illan esitykseen *The guitarist was preparing for the night's performance*			

Second sentence

First clause	Second clause	Condition	Implicit causality bias	Pronoun
Hovimestari **pelkäsi** kitaristia ravintolasalissa *The butler **feared** the guitarist in the dining room*	koska koko päivän **hän** kummallista kyllä oli näyttänyt erittäin tyytymättömältä huolimatta tulossa olevasta suositusta illasta *because for the whole day **he** curiously enough had seemed extremely unhappy despite the upcoming popular night*	(a)	Object	*Hän*
Hovimestari **pelkäsi** kitaristia ravintolasalissa *The butler **feared** the guitarist in the dining room*	koska koko päivän **hänet** kummallista kyllä oli nähty erittäin tyytymättömänä huolimatta tulossa olevasta suositusta illasta *because for the whole day **him** curiously enough had been seen (to be) extremely unhappy despite the upcoming popular night*	(b)	Object	*Hänet*
Hovimestari **pelotti** kitaristia ravintolasalissa *The butler **frightened** the guitarist in the dining room*	koska koko päivän **hän** kummallista kyllä oli näyttänyt erittäin tyytymättömältä huolimatta tulossa olevasta suositusta illasta *because for the whole day **he** curiously enough had seemed extremely unhappy despite the upcoming popular night*	(c)	Subject	*Hän*
Hovimestari **pelotti** kitaristia ravintolasalissa *The butler **frightened** the guitarist in the dining room*	koska koko päivän **hänet** kummallista kyllä oli nähty erittäin tyytymättömänä huolimatta tulossa olevasta suositusta illasta *because for the whole day **him** curiously enough had been seen (to be) extremely unhappy despite the upcoming popular night*	(d)	Subject	*Hänet*

The second sentence consisted of a main clause and a subordinate clause that always began with the causal conjunction *koska* "because". The first-mentioned subject (hence subject) of the second sentence was a previously unmentioned character and the subject of the first sentence was demoted to object position. In order to increase control over the experimental items, the subject and object biasing verbs always formed a pair within each item so that both shared the same verb stem, for example, *pelätä* "fear" versus *pelottaa* "frighten". In order to ensure ample time for detection of the effects, a semantically nonbiasing adverbial phrase (on average 1,100 ms) was presented between the conjunction and the pronoun. The final interpretation of the pronoun did not definitely disambiguate toward either character.

The experimental verbs were selected using a sentence completion task (e.g., Garvey & Caramazza, 1974). Ninety verbs were embedded in a sentence frame of the form *NP1*

Verb NP2, because... (John met Bill, because...). Fifteen participants completed the sentences. The 16 subject and 16 object biasing verbs selected for the experimental materials fulfilled the criterion of having 62.5% or more completions in the expected direction. Each verb was used twice in the materials.

A gender-neutral third person pronoun was presented in the last clause in either subject (nominative), *hän* "s/he", or object form (accusative), *hänet* "her/him".[1]

The materials were read aloud by a male native speaker in a soundproof room and recorded onto a computer hard disk. In order to avoid prosodic differences across conditions, one reading of each story was selected as the base to which the alternative verb and pronoun were spliced: For example, story 1a (Table 1) was selected, and 1b was created by replacing *he* with *him*; story 1c was created by replacing *feared* with *frightened* in 1a; story 1d was created

---

[1]   Unlike in languages with less flexible word order, in Finnish it is not only grammatical but in this case also felicitous for an object pronoun to begin the sentence. Also, just as with *hän* the referent for *hänet* is ambiguous. Moreover, the meaning of the pronoun is the same as English *her/him*: For example, *minä näin hänet* literally means "I saw him/her". Apart from the interrogative form *kuka* "who", personal pronouns are the only noun phrases (NPs) that have a separate form for the accusative (object) case, which is otherwise homophonous with either a singular genitive or nominative. Accusative case can be partially determined by specific lexical verbs, for example, *nähdä* "see". However, an object is assigned an accusative case if the predicate has a bounded reading (e.g., Kiparsky, 2001; Reime, 1993).

by splicing the whole subordinate clause from 1b to 1c. The selection of the base for the conditions was counterbalanced between items.[2] One of the authors (P.P.), who has a training in phonetics, used Praat phonetic analysis software (Boersma, 2001) to record, edit, and analyze the sound files.

During each trial four separate pictures (each with 150×150 pixels) were presented on the computer screen in quadrangular format. Two of the pictures depicted the subject and object antecedents, for example, butler and guitarist, and two additional pictures depicted entities or events mentioned in the story, for example, a dining room and a stage. The same pictures were used in all conditions of a single item. The position of the pictures was counterbalanced between items. The critical pictures were clearly identifiable photographs depicting familiar role names, such as butler, guitarist, doctor, etc.

The four versions of each story were counterbalanced across four lists: Each participant encountered only one version of a single item, with an equal number of items in all conditions. Each list included the same 32 filler stories. Eight participants were randomly assigned to each list.

Procedure

The participants sat in front of a 21-in. computer screen, at a distance of ~ 70 cm. The eye-tracker was calibrated using a 9-point grid extending over the entire computer screen. On each trial, after the participant fixated on the fixation point, the experimental pictures appeared. The sound started 50 ms later and lasted for 13.5–16 s. Participants were instructed to look at the pictures while listening to the stories for comprehension. They were occasionally asked to continue orally the story that they had just heard using the characters and entities presented in that story. Each participant produced 10 continuations. Six practice trials preceded the first experimental trial. Each session lasted ~ 40 min.

Results and Discussion

For each 20 ms time frame following the verb, the subordinate conjunction, and the pronoun onset, we determined whether participants fixated the subject or object character. For the statistical analyses, we aggregated these time frames into larger segments of 300 ms. The total analysis regions after the verb onset and the conjunction onset were determined by taking the shortest duration before the onset of the conjunction (after the verb) and the onset of the pronoun (following the onset of the conjunction) as the end points, respectively.[3] The time segments after the pronoun onset (0–1,200 ms) correspond to the shortest semantically neutral region before any disambiguating information was available.

The results for these regions are given in Tables 2–4, respectively. Figures 1–4 present the time course of the effects for the analysis regions.

Results After the Verb Onset

The 2×2 analyses of variance (ANOVAs) were conducted with grammatical role (looks to the subject vs. the object of the second sentence) and implicit causality consistency[4] (looks to the antecedent consistent vs. inconsistent with the implicit causality bias of the verb) as within-participant ($F1$) and within-item ($F2$) factors and arcsine transformed proportions of fixations (relative to all looks) to the pictures of the grammatical subject and object as the dependent measure. The results from the statistical analyses are given in Table 2. Figure 1 illustrates the time course of the effects during 0–2,700 ms after the verb onset.

There were no statistical differences at the verb onset ($\chi^2(1) = .068$, $p = .79$). There was a main effect of grammatical role in all time segments, showing more looks to the subject than the object antecedent.

Importantly, we found a statistically significant main effect of implicit causality consistency starting 900 ms after the verb onset indicating that people looked relatively more often to the character that was consistent with the implicit causality bias, that is, subject after subject-biasing verbs and object after object-biasing verbs. As the verb lasted on average for 560 ms and was followed immediately by the object antecedent, it is clear that the implicit causality effect appeared just after participants had encountered both the subject and the object antecedents.

Apart from the 2,100–2,400 ms segment, we found no consistent interaction between grammatical role and implicit causality bias. The interaction in this particular segment was due to there being more looks to the subject with consistent than inconsistent implicit causality bias ($t1(31) = 3.61$, $p < .01$; $t2(31) = 3.73$, $p < .01$), but no difference between the consistent and inconsistent object ($ts < 1$).

Results After the Conjunction Onset

The 2×2 ANOVAs conducted as above showed a consistent main effect of grammatical role in all time windows, denoting a preference for the subject over the object antecedent. There was also a significant main effect of implicit causality consistency in the first time window (0–300 ms) that was marginally significant in the next time window (300–600 ms), showing relatively more looks to the character consistent with the implicit causality bias. This suggests that the implicit causality activation is persistent until people encounter the causal conjunction. However, this effect was qualified by a significant interaction between grammatical

---

Table 2. Results of the time course analyses for the time segments following the onset of the verb for the factors implicit causality consistency (looks to characters with consistent vs. inconsistent implicit causality bias) and grammatical role (looks to subject vs. object) ($df_{1,2} = 1, 31$)

	Factor					
	Implicit causality consistency		Grammatical role		Implicit Causality Consistency × Grammatical Role	
Time segment	$F1\ (\eta_p^2)$	$F2\ (\eta_p^2)$	$F1\ (\eta_p^2)$	$F2\ (\eta_p^2)$	$F1\ (\eta_p^2)$	$F2\ (\eta_p^2)$
0–300	< 1	< 1	22.61 (.422)***	31.78 (.506)***	< 1	< 1
300–600	< 1	< 1	132.26 (.810)***	330.90 (.914)***	1.12 (.035)	1.70 (.052)
600–900	< 1	1.83 (.056)	494.88 (.941)***	926.30 (.968)***	< 1	4.87 (.136)*
900–1,200	3.27 (.095)†	4.94 (.138)*	336.29 (.916)***	736.54 (.960)***	< 1	< 1
1,200–1,500	8.74 (.220)**	15.89 (.339)***	62.17 (.667)***	219.96 (.876)***	2.37 (.134)†	< 1
1,500–1,800	4.12 (.117)*	4.64 (.130)*	6.67 (.177)*	43.44 (.584)***	2.62 (.078)	1.98 (.060)
1,800–2,100	6.22 (.167)*	2.87 (.085)†	1.07 (.033)	5.79 (.158)*	1.30 (.040)	1.17 (.036)
2,100–2,400	5.86 (.159)*	4.73 (.132)*	1.62 (.050)	4.35 (.123)*	12.56 (.288)**	7.63 (.197)*
2,400–2,700	4.63 (.130)*	5.11 (.142)*	9.14 (.228)**	20.34 (.396)***	1.20 (.037)	1.56 (.048)

Note. Numbers in parentheses are effect sizes in η_p^2. Effect sizes are not reported when the F values are below 1. †$p < .1$; *$p < .05$; **$p < .01$; ***$p < .001$.

Table 3. Results of the time course analyses for the time segments following the onset of the conjunction *koska* "because" for the factors implicit causality consistency and grammatical role ($df_{1,2} = 1, 31$)

		Time window after the offset of the conjunction *koska* "because"			
		0–300 ms	300–600 ms	600–900 ms	900–1,200 ms
Implicit causality consistency	$F1\ (\eta_p^2)$	4.83* (.135)	3.32† (.097)	1.93 (.059)	2.64 (.078)
	$F2\ (\eta_p^2)$	5.08* (.141)	2.86† (.085)	3.98† (.113)	3.46† (.100)
Grammatical role	$F1\ (\eta_p^2)$	14.94*** (.325)	9.98** (.244)	9.45** (.233)	6.62* (.176)
	$F2\ (\eta_p^2)$	13.09*** (.297)	8.81** (.221)	11.94** (.278)	7.91** (.203)
Implicit Causality Consistency × Grammatical Role	$F1\ (\eta_p^2)$	8.15** (.208)	6.77* (.179)	1.98 (.060)	< 1
	$F2\ (\eta_p^2)$	9.50** (.235)	8.77** (.220)	2.58 (.077)	< 1

Note. Numbers in parentheses are effect sizes in η_p^2. Effect sizes are not reported when the F values are below 1. †$p < .1$; *$p < .05$; **$p < .01$; ***$p < .001$.

role and implicit causality consistency in both time windows. Simple effects showed that in both time windows there were more looks to the subject character with subject-biased than with object-biased verbs denoting an effect of implicit causality for the subjects (0–300 ms: $t1(31) = 3.14$, $t2(31) = 3.21$, $ps < .01$; 300–600 ms: $t1(31) = 2.91$; $t2(31) = 2.71$; $ps < .05$), but not for the objects (all $ts < 1$). These findings are reported in Table 3 and illustrated in Figure 2.

Results After the Pronoun Onset

The $2 \times 2 \times 2$ ANOVAs were conducted with grammatical role, implicit causality consistency, and pronoun type (subject pronoun *hän* vs. object pronoun *hänet*) as within-participant and within-item factors. The results again showed a consistent main effect of grammatical role across all analysis windows, depicting an overall preference for the subject antecedent over the object antecedent. The findings are reported in Table 4 and illustrated in Figures 3 and 4. We found a main effect of implicit causality consistency in the first time window, that is, during the pronoun, which disappeared in the next two time windows (300–600 and 600–900 ms) and reappeared 900 ms after pronoun onset, indicating more looks to the implicit causality consistent antecedents than inconsistent antecedents. The main effect of implicit causality was qualified by a marginal interaction with grammatical role in the last two time windows (600–900 and 900–1,200 ms). Simple effects showed that there were more looks to the subject character with subject-biased than with object-biased verbs. This effect was significant in the item analysis in both time windows but significant by participants in the latter window only (600–900 ms: $t1(31) = 1.59$, $p > .12$; $t2(31) = 2.15$, $p < .05$; 900–1,200 ms: $t1(31) = 2.42$, $p < .05$; $t2(31) = 3.14$, $p < .01$). There was no effect of

Table 4. Results of the time course analyses in Experiment 1 for the time segments following the onset of the pronoun for the factors. Implicit causality consistency, grammatical role, and type of pronoun ($df_{1,2}$ = 1, 31)

		Time window after the onset of the pronoun			
		0–300 ms	300–600 ms	600–900 ms	900–1,200 ms
Implicit causality consistency	$F1$ (η_p^2)	5.19* (.143)	1.39 (.043)	< 1	5.04* (.140)
	$F2$ (η_p^2)	7.16* (.188)	1.78 (.054)	< 1	6.84* (.181)
Grammatical role	$F1$ (η_p^2)	8.92** (.223)	15.89*** (.341)	17.78*** (.364)	10.52** (.253)
	$F2$ (η_p^2)	10.98** (.262)	16.53*** (.348)	26.13*** (.457)	26.27*** (.459)
Pronoun	$F1$ (η_p^2)	< 1	< 1	< 1	< 1
	$F2$ (η_p^2)	< 1	< 1	< 1	< 1
Implicit Causality Consistency × Grammatical Role	$F1$ (η_p^2)	< 1	1.81 (.055)	3.06† (.090)	2.19 (.066)
	$F2$ (η_p^2)	< 1	1.99 (.060)	3.80† (.109)	6.66* (.177)
Implicit Causality Consistency × Pronoun	$F1$ (η_p^2)	< 1	< 1	< 1	1.07 (.033)
	$F2$ (η_p^2)	< 1	< 1	< 1	1.06 (.033)
Grammatical Role × Pronoun	$F1$ (η_p^2)	< 1	< 1	< 1	5.63* (.154)
	$F2$ (η_p^2)	1.40 (.043)	< 1	< 1	5.32* (.146)
Three-way interaction	$F1$ (η_p^2)	< 1	1.91 (.158)	< 1	< 1
	$F2$ (η_p^2)	< 1	1.80 (.055)	< 1	< 1

Note. Numbers in parentheses are effect sizes in η_p^2. Effect sizes are not reported when the F values are below 1. † $p < .1$; * $p < .05$; ** $p < .01$; *** $p < .001$.
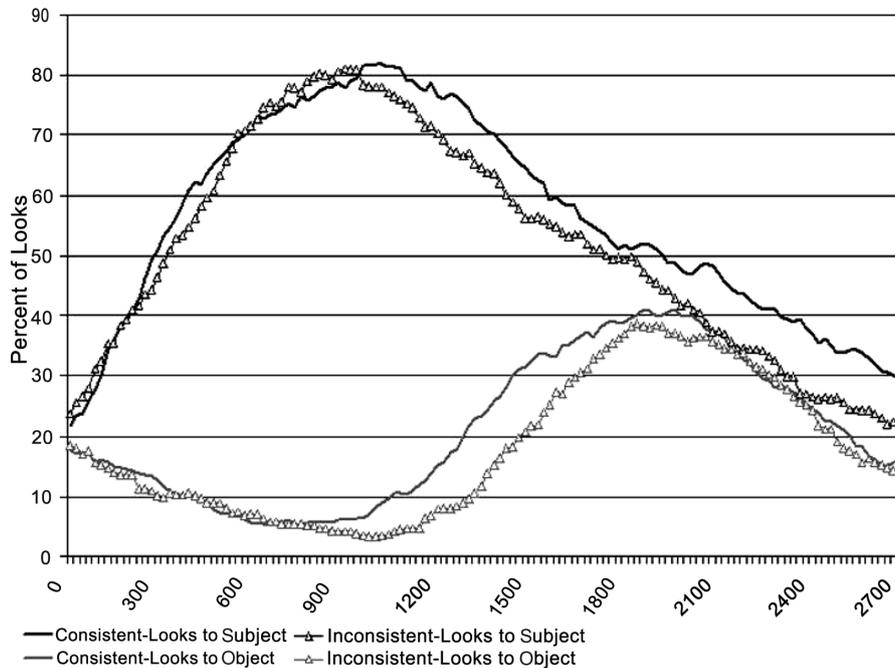

Figure 1. Percentage of looks (out of all looks) to the pictures depicting the subject and object with consistent and inconsistent implicit causality bias during 0–2,700 ms after the onset of the verb in the main clause of the second sentence.

implicit causality consistency for the object antecedents within this region (600–900 ms: $ts < 1$; 900–1,200 ms: $ts < 1.5$, $ps > .16$).

We found no effect of pronoun type and no other interactions, except for the expected interaction between pronoun type and grammatical role that was reliable in the 900–1,200 ms segment. Further analyses showed that the interaction was due to there being significantly more looks to the object antecedent with the object pronoun *hänet* than with the subject pronoun *hän* ($t1(31) = 2.16$, $p < .05$;
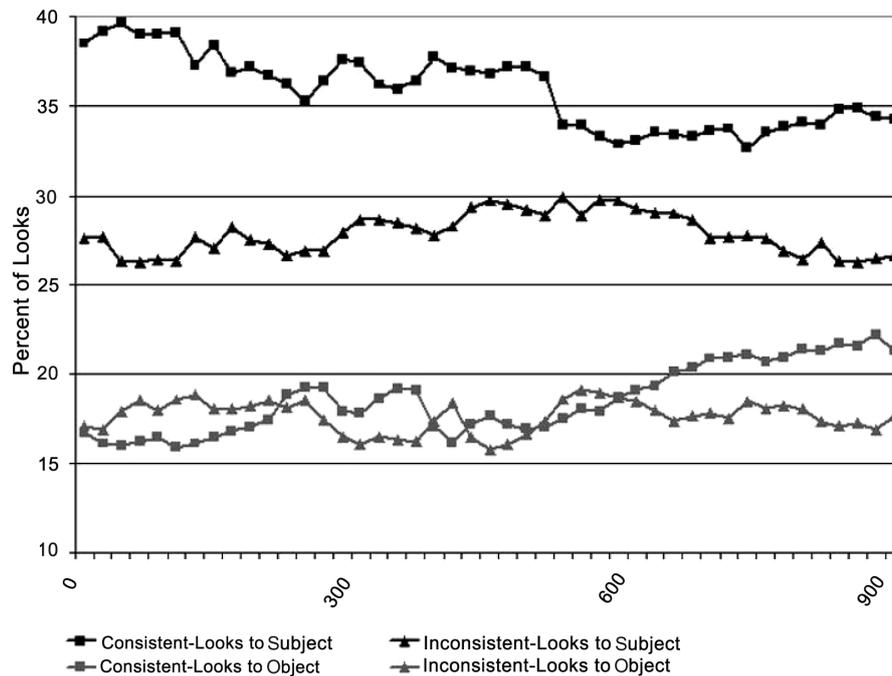
Figure 2. Percentage of looks (out of all looks) to the pictures depicting the subject and object with consistent and inconsistent implicit causality bias during 0–900 ms after the onset of the conjunction (koska) in the subordinate clause of the second sentence.
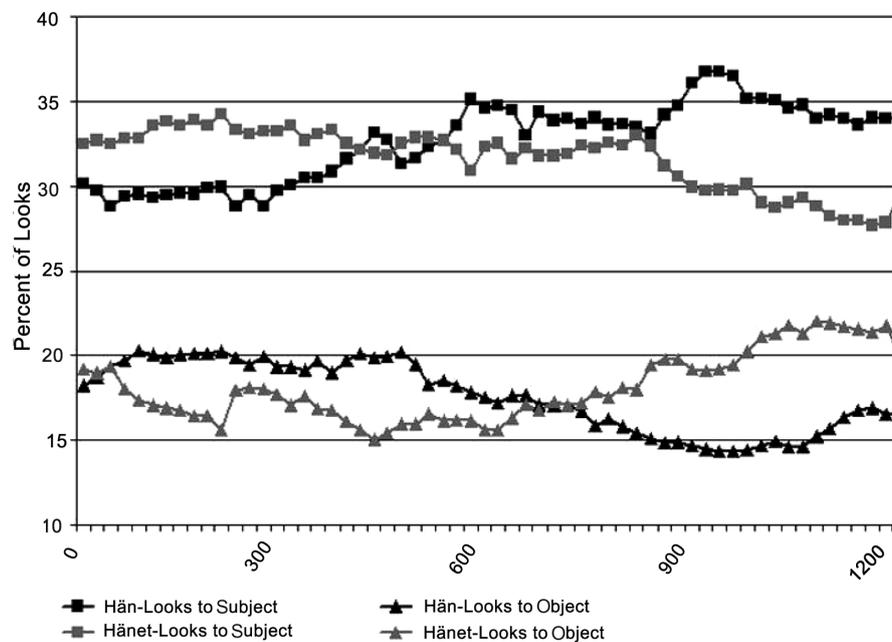

Figure 3. Percentage of looks (out of all looks) to the pictures depicting the subject and object with consistent and inconsistent implicit causality bias during the semantically neutral region (0–1,200 ms) after the onset of the pronoun in the subordinate clause of the second sentence.

$t2(31) = 2.03$, $p = .050$) and marginally more looks to the subject antecedent with *hän* than with *hänet* ($t1(31) = 1.59$, $p = .12$; $t2(31) = 1.89$, $p = .067$), indicating an effect of grammatical role parallelism.

Discussion

The current visual world eye-tracking study is the first to show that implicit causality information is activated immediately
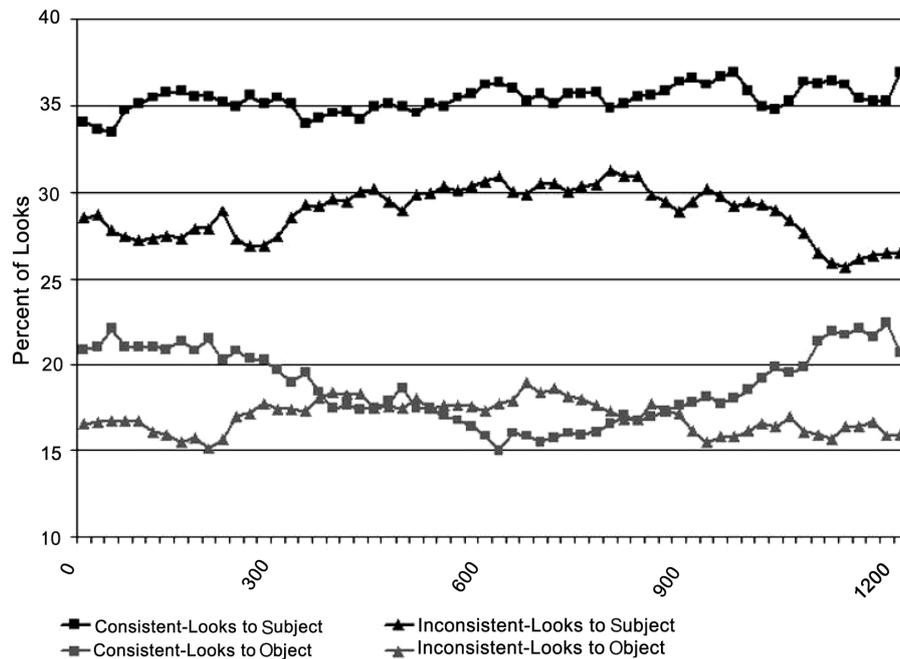
Figure 4. Percentage of looks (out of all looks) to the pictures depicting the subject and object as a function of grammatical role (subject and object) and pronoun (*hän* and *hänet*) during the semantically neutral region (0–1,200 ms) after the onset of the pronoun in the subordinate clause of the second sentence.

after encountering an implicit causality verb before the pronoun, as predicted by the immediate focusing account (Greene & McKoon, 1995; Koornneef & Van Berkum, 2006; McKoon et al., 1993; Van Berkum et al., 2007). Clearly, the early activation of implicit causality information prior to the pronoun goes against the clausal integration account which argues that the processor becomes aware of implicit causality only late after the pronoun when the implicit and explicit causal information in the main and subordinate clauses are integrated into a single coherent representation (Garnham, 2001; Garnham et al., 1996; Stewart et al., 2000).

Interestingly, we observed the effect of implicit causality even before participants had encountered the causal conjunction. Thus, it seems that, in contrast to previous studies which suggested that the effect was dependent on the presence of the connective *because* (e.g., Ehrlich, 1980; Stevenson et al., 1994, 2000), our results are consistent with evidence suggesting that implicit causality information can be activated independently of an explicit causal conjunction (McDonald & MacWhinney, 1995).

Implicit Causality in Pronoun Resolution

We also found an effect of implicit causality consistency during the presentation of the pronoun (0–300 ms from its onset). As all looks were included in the data analyses, the effect of implicit causality in the first time window may be at least partly due to a lingering spill-over effect

of the earlier inferred activation of implicit causality. This is also likely, if we acknowledge that it takes about 200 ms to plan and execute a saccade (Matin, Shao, & Boff, 1993), suggesting that this information was activated before the pronoun was processed completely. Interestingly, the main effect of implicit causality was absent in the time windows following the pronoun (300–900 ms after pronoun onset) and reappeared only after 900 ms from the pronoun onset. Nevertheless, the interaction between implicit causality consistency and grammatical role did achieve significance in the previous time window (600–900 ms), indicating an implicit causality effect for the first-mentioned subject but not for the object.

The interaction indicates that the implicit causality effect was temporally more pronounced for the subject than for the object antecedents. Although, this is not the first time that this asymmetry has been reported (e.g., McDonald & MacWhinney, 1995; Stewart & Gosselin, 2000; see Long & DeLey, 2000, for the opposite observation), the issue merits a brief discussion. Firstly, as suggested by Stewart & Gosselin (2000), the first-mentioned privilege (e.g., Gernsbacher & Hargreaves, 1988) would make it easier to detect the implicit causality effect with subject- than object-biasing verbs. Secondly, in our case the first-mentioned entity was also the subject as well as the shifted topic of the critical sentence. Earlier research has shown that a topic shift results in temporarily prolonged reading times (e.g., Hyönä, 1995) and in the subsequent activation of the new (shifted) topic. As a result, not only is the topical information highly focused but the information in the

preceding sentence is effectively suppressed immediately following the shifted topic, leading to diminished activation of the nontopical entity, here the object antecedent (Bestgen & Vonk, 2000; Vonk, Hustinx, & Simons, 1992). Consequently, the subject is already in focus and thus highly salient, making it the likely entity to be talked about in the subsequent discourse in its own right. Thus, it is probable that this difference in the information status between the subject and the object was responsible for the interaction in which implicit causality information affected pronoun resolution more consistently when it was congruent with the overall relative salience of the potential antecedents. This difference may also have highlighted the main effect of grammatical role, which was observed in all time windows and which, in all likelihood, was a combined effect of subjecthood, first-mention, and topicality.

In addition, we did not observe an interaction between implicit causality information and pronoun type but we did find an interaction between grammatical role and pronoun type, showing an effect of grammatical role parallelism (Chambers & Smyth, 1998; Smyth, 1994). This indicates that implicit causality information has the same effect on pronoun resolution regardless of the type of pronoun involved. Notably, however, the structural parallelism effect did not appear earlier than the implicit causality effect, suggesting that the use of implicit causality information need not be delayed with respect to structural effects like parallelism in pronoun resolution.

Persistence of Implicit Causality

The rapid activation of implicit causality information prior to the pronoun is in line with the predictions of the focusing account. However, according to the immediate focusing account (Greene & McKoon, 1995; Koornneef & Van Berkum, 2006; Van Berkum et al., 2007) we might have expected the effect of implicit causality to have been more persistent immediately following the pronoun. It may be that the lack of a significant implicit causality effect after the pronoun (300–600 ms) was partly masked by the main effect of grammatical role that was persistent throughout the time windows: The first-mentioned subject may have acted as a stronger and more stable cue than implicit causality when the pronoun was encountered. This would be in accordance with McDonald and MacWhinney (1995; Experiment 1), who found that even though implicit causality information was active at the pronoun, its effect faded following the pronoun and order-of-mention took priority until the end of the sentence where the effect of implicit causality reappeared. As they suggested, it seems that implicit causality information is readily available at the pronoun but the time course of when this information appears as a statistically significant factor after the pronoun depends on the strength of other competing constraints, such as order-of-mention/grammatical role.

As the effect of implicit causality was not persistent after the pronoun, it is not straightforward to view the current findings as directly supportive of the strongest interpretation of the immediate focusing account, which predicts that the activation of this information automatically renders one of the antecedents more privileged as a potential referent than the other(s). Rather, it seems that whether implicit causality affects ambiguous pronoun resolution immediately depends on other structural and discourse factors available at the time when the pronoun is encountered. This result is in line with both the view of implicit causality as one source of (probabilistic) information affecting referential processing (as suggested by McKoon et al., 1993; McDonald & MacWhinney, 1995), and with incremental integration whereby the discourse representation is checked on a word-by-word basis as the utterance unfolds (Koornneef & Van Berkum, 2006). The findings indicate that implicit causality information is not used blindly to focus all referents to the same extent, instead it is used in accordance with other information as the discourse unfolds.

Conclusions

The current study is the first to show that implicit causality information is inferred and activated as soon as people hear an implicit causality verb in discourse. Notably, implicit causality influences attention even before listeners encounter the conjunction, showing that the activation of implicit causality information does not depend on the presence of an explicit trigger, such as the causal connective *because*. Nevertheless, although this activation then persists as the discourse unfolds, implicit causality information may not have a privileged status as a pronoun resolution cue later in the discourse, but may instead interact with, or be temporally masked by, other strong structural and discourse cues active during the pronoun.

Acknowledgments

References

Allopenna, P. D., Magnuson, J. S., & Tanenhaus, M. K. (1998). Tracking the time course of spoken word recognition using eye movements: Evidence for continuous mapping models. *Journal of Memory and Language, 38*, 419–439.

Arnold, J. E., Brown-Schmidt, S., & Trueswell, J. (2007). Children's use of gender and order-of-mention during pronoun comprehension. *Language and Cognitive Processes, 22*, 527–565.

Arnold, J. E., Eisenband, J. G., Brown-Schmidt, S., & Trueswell, J. C. (2000). The rapid use of gender information: Evidence of the time course of pronoun resolution from eye-tracking. *Cognition, 76*, B13–B26.

Au, T. K. (1986). A verb is worth a thousand words: The causes and consequences of interpersonal events implicit in language. *Journal of Memory and Language, 25*, 104–122.

Bestgen, Y., & Vonk, W. (2000). Temporal adverbials as segmentation markers in discourse comprehension. *Journal of Memory and Language, 42*, 74–87.

Boersma, P. (2001). Praat, a system for doing phonetics by computer. *Glot International, 5*(9/10), 341–345.

Chambers, C. G., & Smyth, R. (1998). Structural parallelism and discourse coherence: A test of centering theory. *Journal of Memory and Language, 39*, 593–608.

Cooper, R. M. (1974). The control of eye fixation by the meaning of spoken language: A new methodology for the real-time investigation of speech perception, memory, and language processing. *Cognitive Psychology, 6*, 84–107.

Crawley, R., Stevenson, R., & Kleinman, D. (1990). The use of heuristic strategies in the interpretation of pronouns. *Journal of Psycholinguistic Research, 4*, 245–264.

Crinean, M., & Garnham, A. (2006). Implicit causality, implicit consequentiality and semantic roles. *Language and Cognitive Processes, 21*, 636–648.

Dahan, D., Magnuson, J. S., & Tanenhaus, M. K. (2001). Time course of frequency effects in spoken-word recognition: Evidence from eye movements. *Cognitive Psychology, 42*, 317–367.

Ehrlich, K. (1980). Comprehension of pronouns. *The Quarterly Journal of Experimental Psychology, 32*, 247–255.

Ferreira, F., & Clifton, C. Jr. (1986). The independence of syntactic processing. *Journal of Memory and Language, 25*, 348–368.

Frazier, L. (1987). Sentence processing: A tutorial review. In M. Coltheart (Ed.), *Attention and performance* XII (pp. 348–586). Hillsdale, NJ: Lawrence Erlbaum Associates.

Frederiksen, J. (1981). Understanding anaphora: Rules used by readers in assigning pronominal referents. *Discourse Processes, 4*, 323–347.

Garnham, A. (2001). *Mental models and the interpretation of anaphora*. Hove: Psychology Press.

Garnham, A., Oakhill, J. V., & Reynolds, D. J. (2002). Are inferences from stereotyped role names to characters' gender made elaboratively? *Memory & Cognition, 30*, 439–446.

Garnham, A., Traxler, M., Oakhill, J., & Gernsbacher, M. A. (1996). The locus of implicit causality effects in comprehension. *Journal of Memory and Language, 35*, 517–543.

Garvey, C., & Caramazza, A. (1974). Implicit causality in verbs. *Linguistic Inquiry, 5*, 517–543.

Garvey, C., Caramazza, A., & Yates, J. (1975). Factors influencing assignments of pronoun antecedents. *Cognition, 3*, 227–243.

Gernsbacher, M. A., & Hargreaves, D. (1988). Accessing sentence participants: The advantage of first mention. *Journal of Memory and Language, 27*, 699–717.

Gordon, P. C., & Hendrick, R. (1998). The representation and processing of coreference in discourse. *Cognitive Science, 22*, 389–424.

Gordon, P. C., Hendrick, R., & Fosters, K. L. (2000). Language comprehension and probe-list memory. *Journal of Memory and Language, 26*, 766–775.

Greene, S. B., & McKoon, G. (1995). Telling something we can't know: Experimental approaches to verbs exhibiting implicit causality. *Psychological Science, 6*, 262–270.

Grober, E., Beardsley, W., & Caramazza, A. (1978). Parallel function strategy in pronoun assignment. *Cognition, 6*, 117–133.

Guerry, M., Gimenes, M., Caplan, D., & Rigalleau, F. (2006). How long does it take to find a cause? An online investigation of implicit causality in sentence production. *The Quarterly Journal of Experimental Psychology, 59*, 1535–1555.

Hyönä, J. (1995). An eye movement analysis of topic-shift effect during repeated reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21*, 1365–1373.

Järvikivi, J., Van Gompel, R. P. G., Hyönä, J., & Bertram, R. (2005). Ambiguous pronoun resolution: Contrasting the first-mention and subject preference accounts. *Psychological Science, 16*, 260–264.

Kaiser, E., & Trueswell, J. C. (2008). Interpreting pronouns and demonstratives in Finnish: Evidence for a form-specific approach to reference resolution. *Language and Cognitive Processes, 23*, 709–748.

Kiparsky, P. (2001). Structural case in Finnish. *Lingua, 111*, 315–376.

Koornneef, A. W. (2008). *Eye-catching anaphora*. Utrecht: LOT International Dissertation Series.

Koornneef, A. W., & Van Berkum, J. J. A. (2006). On the use of verb-based implicit causality in sentence comprehension: Evidence from self-paced reading and eye tracking. *Journal of Memory and Language, 54*, 445–465.

Long, D. L., & DeLey, L. (2000). Implicit causality and discourse focus: The interaction of text and reader characteristics in pronoun resolution. *Journal of Memory and Language, 42*, 545–570.

Matin, E., Shao, K. C., & Boff, K. R. (1993). Information-processing time with and without saccades. *Perception & Psychophysics, 53*, 372–380.

McDonald, J. L., & MacWhinney, B. (1995). The time-course of anaphor resolution: Effects of implicit verb causality and gender. *Journal of Memory and Language, 34*, 543–566.

McKoon, G., Greene, S. B., & Ratcliff, R. (1993). Discourse models, pronoun resolution, and the implicit causality of verbs. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19*, 1040–1052.

McRae, K., Spivey-Knowlton, M. J., & Tanenhaus, M. K. (1998). Modeling the influence of thematic fit (and other constraints) in on-line sentence comprehension. *Journal of Memory and Language, 38*, 283–312.

Pickering, M. J., & Majid, A. (2007). What are implicit causality and consequentiality? *Language and Cognitive Processes, 22*, 780–788.

Pyykkönen, P., Hyönä, J., & Van Gompel, R. P. G. (in press). Activating gender stereotypes during online spoken language processing: Evidence from visual world eye-tracking. *Experimental Psychology*.

Reime, H. (1993). Accusative marking in Finnish. In A. Holmberg & U. Nikanne (Eds.), *Case and other functional categories in Finnish syntax* (pp. 89–109). Berlin: Mouton de Gruyter.

Sedivy, J. C., Tanenhaus, M. K., Chambers, C. G., & Carlson, G. N. (1999). Achieving incremantal semantic interpretation through contextual representation. *Cognition, 71*, 109–147.

Sheldon, A. L. (1974). The role of parallel function in the acquisition of relative clauses in English. *Journal of Verbal Learning and Verbal Behaviour, 13*, 272–281.

Smyth, R. (1994). Grammatical determinants of ambiguous pronoun resolution. *Journal of Psycholinguistic Research, 23*, 197–229.

Stevenson, R. J., Crawley, R. A., & Kleinman, D. (1994). Thematic roles, focus and the representation of events. *Language and Cognitive Processes, 9*, 519–548.

Stevenson, R., Knott, A., Oberlander, J., & McDonald, S. (2000). Interpreting pronouns and connectives: Interactions among

focusing, thematic roles and coherence relations. *Language and Cognitive Processes, 15*, 225–262.

Stewart, A. J., & Gosselin, F. (2000). A simple categorisation model of anaphor resolution. In L. R. Gleitman & A. K. Joshi (Eds.), *Proceedings of the twenty-second annual conference of the cognitive science society* (pp. 930–935). Hillsdale, NJ: Erlbaum.

Stewart, A. J., Pickering, M. J., & Sanford, A. J. (2000). The time course of the influence of implicit causality information: Focusing versus integration accounts. *Journal of Memory and Language, 42*, 423–443.

Tanenhaus, M. K., Spivey-Knowlton, M. J., Eberhard, K. M., & Sedivy, J. C. (1995). Integration of visual and linguistic information in spoken language comprehension. *Science, 268*, 1632–1634.

Trueswell, J. C., Tanenhaus, M. K., & Garnsey, S. (1994). Semantic influences on parsing: Use of thematic role information in syntactic ambiguity resolution. *Journal of Memory and Language, 33*, 285–318.

Tyler, L. K., & Marslen-Wilson, W. D. (1977). The on-line effects of semantic context on syntactic processing. *Journal of Verbal Learning and Verbal Behaviour, 16*, 683–692.

Van Berkum, J. J. A., Koornneef, A. W., Otten, M., & Nieuwland, M. S. (2007). Establishing reference in language comprehension: An electrophysiological perspective. *Brain Research, 1146*, 158–171.

Vonk, W., Hustinx, L. G. M. M., & Simons, W. H. G. (1992). The use of referential expressions in structuring discourse. *Language and Cognitive Processes, 7*, 301–333.

Pirita Pyykkönen

FR 4.7 Psycholinguistics
Department of Computational Linguistics
Saarland University
Building C7.1
66041 Saarbrücken
Germany
Tel. +49 681 302 6557
Fax +49 681 302 6561
E-mail pirita@CoLi.Uni-SB.DE