

Cross Recurrence Quantification Analysis of indefinite anaphora in Swedish dialog. An eye-tracking pilot experiment

Philip Diderichsen

Lund University Cognitive Science
philip.diderichsen@lucs.lu.se

Abstract

A new method is used in an eye-tracking pilot experiment which shows that it is possible to detect differences in common ground associated with the use of minimally different types of indefinite anaphora. Following Richardson and Dale (2005), cross recurrence quantification analysis (CRQA) was used to show that the tandem eye movements of two Swedish-speaking interlocutors are slightly more coupled when they are using fully anaphoric indefinite expressions than when they are using less anaphoric indefinites. This shows the potential of CRQA to detect even subtle processing differences in ongoing discourse.

1 Introduction

There exists an extensive literature within linguistics on the topic of referring expressions and their discourse function (Ariel, 1990; Gundel, Hedberg & Zacharski, 1993; Lambrecht, 1994; Prince, 1981; Walker & Prince, 1993). Almost everyone agrees that pronouns need to be ‘in focus’, i.e. highly mentally accessible, to be used felicitously, while full indefinite noun phrases, at the other end of various types of givenness scales or hierarchies, do not need to be accessible to the same degree.

These issues have been extensively studied within linguistics, and also in many reading experiments within psycholinguistics. But, mainly for technical reasons, it has not been as thoroughly studied whether the theories also hold for unconstrained spoken conversation. This study

is a first step to do just that. In the spirit of Trueswell and Tanenhaus (2005), it will be attempted to bridge the methodological gap between psycholinguistics and the more qualitative conversation analysis tradition, in order to evaluate hypotheses about the mental status of entities referred to using anaphora.

A specific anaphor type will be targeted here, namely indefinite *one*-anaphora (Dahl, 1985). Contrasting examples of a ‘regular’, definite pronoun, and an indefinite *one*-anaphor are shown in example (1) and (2) below.

- (1) A: I heard that Ahmed bought a Ferrari.
B: That’s right! I saw **it** outside the stadium yesterday.
- (2) A: I heard that Ahmed bought a Ferrari.
B: Really? I saw **one** outside the stadium yesterday.

This relatively rare type of pronoun is chosen for its unique set of features, which intersect at two extremes of certain givenness scales (Gundel et al.’s *Givenness Hierarchy*, for instance). These anaphora are at the same time pronominal and indefinite noun phrases. Therefore, accounts like the *Givenness Hierarchy* do not account well for this type of expression. Gundel et al. propose that referents in focus — typically expressed using pronouns — must necessarily be uniquely identifiable and ‘type identifiable’ as well. Indefinite pronominal expressions like *one*-anaphora are in focus¹ as well as type identifiable, but not uniquely identifiable. How can this be? Either, indefinite *one*-anaphora are not really in focus, or the *Givenness Hierarchy* is unable to account for them.

¹ — as demonstrated in examples (1) and (2): the meaning of *one* depends on an antecedent just as much as *it* does.

It will be shown that more anaphoric indefinites are indeed more in focus than less anaphoric indefinites. This supports a new integrated account of givenness with multiple independent cognitive dimensions, see figure 1.

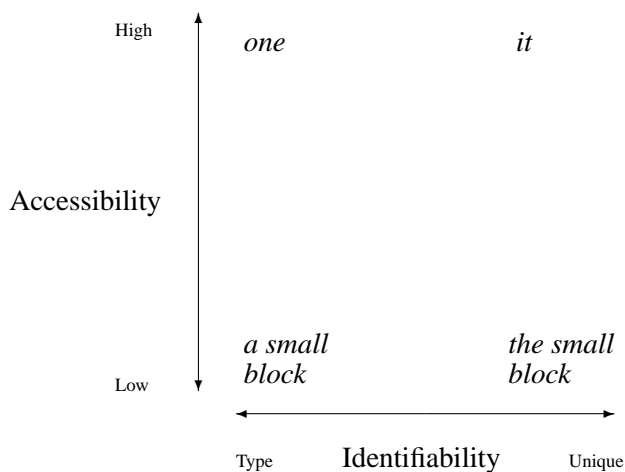


Figure 1: Two-dimensional model of cognitive statuses licensing referential form. Assumed accessibility in the listener licenses pronominalization and assumed identifiability in the listener licenses definiteness.

The data are collected using an adaptation for dialog of the ‘visual world’ eye-tracking paradigm popularized by Michael Tanenhaus and colleagues (Tanenhaus et al., 1995; Tanenhaus & Trueswell, 2005). This enables one to follow ongoing spoken language processes without interfering too much with the task. Eye-tracking is an ideal technique to use to investigate whether pronouns really are ‘in focus’ for the listener, as is claimed in most accounts. Eye movements presumably reflect attentional states in regard to a visual scene more transparently than any other measure currently available. It will be possible to determine when an entity referred to is in visual focus relative to the utterance of a certain type of referring expression, and if there are systematic differences in the amount of attention paid to the referents of various anaphor types.

The data analysis is inspired by the work of Richardson and Dale (2005), who employed cross recurrence quantification analysis (CRQA) to show that speakers’ and listeners’ eye movements are coupled when producing and listening to monologs about a picture of the cast of a sitcom. They found that the highest recurrence of gaze patterns occurs at a lag of 1650 ms in the listener’s gaze pattern relative to the speaker’s. Hadelich and Crocker (2006) found somewhat longer ‘eye-

eye spans’ in conversational dialog, defined as the time between the onset of a speaker’s last fixation on an object before mentioning it and the onset of a listener’s first fixation on it after hearing it mentioned. The eye-eye spans ranged from about 1700 ms to about 2000 ms, and were shorter the more narratively grounded (i.e. given) the expressions were. Richardson and Dale state that results like these are in the approximate range of the combined results from eye-tracking studies of isolated production (Griffin & Bock, 2000) and comprehension (Tanenhaus, Spivey-Knowlton, Eberhard & Sedivy, 1995). Griffin and Bock find an eye-voice span of about 900 ms, Tanenhaus et al. reported voice-eye lags of 145 to 250 ms after the offset of the uniquely specifying word in an expression, depending on distractors and pragmatic context. Furthermore, Chambers et al. (2002) found lags of 350-400 ms after the onset of target words when processing was not facilitated by pragmatic context. But in addition to this, several studies have shown shorter ‘voice-eye spans’ than the 400-800 ms mentioned by Richardson and Dale, and sometimes even predictive eye movements, depending on the context (Allopenna et al., 1998; Kamide et al., 2003).

On the basis of the widely held view that pronouns must be ‘in focus’, it is hypothesized that more anaphoric expressions will be associated with higher recurrence rates. It is also hypothesized that the listener’s eye movements will parallel the trajectory of the speaker for longer stretches of time when more anaphoric expressions are used.

2 Materials and method

2.1 Participants and experimental setup

The experimental task was a version of the picture copy task (see for instance Gullberg et al. (1997)), implemented as a virtual building block task. One person told another to build a simple ‘space invaders’-style pixel mosaic figure from a representation of the finished figure on the screen.

Four native speakers of Swedish volunteered for the experiment. They were assigned to two conversational dyads. Each participant acted as instructor once and as constructor once, yielding 4 conversations in all. The instructor had visual access to a representation of the constructor’s screen.

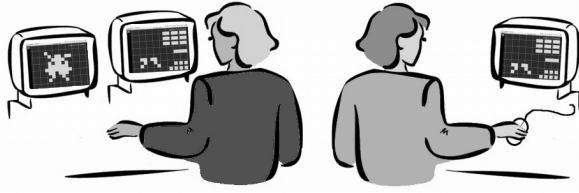


Figure 2: The experimental setup. The instructor (on the left) can see a copy of the constructor's (on the right) screen image. Both participants have their eye movements tracked during the task.

The instructor's task was to freely describe the target figure in such a way that the constructor would be able to build an exact copy of it. The constructor was free to respond. No constraints with respect to choice of expressions or strategy were put on either instructor or constructor.

As for the technical setup, the instructor had two computer screens in front of him or her, both Apple 19" flat panel LCDs. One of them was connected to an Apple G4 PowerMac, and had the sole purpose of displaying the target figure. The other was connected to an Apple G5 PowerMac, and mirrored the constructor's display. The constructor had one display, also a 19" flat panel LCD. This display was also connected to the G5. Only the constructor was allowed to use the mouse, which was used to build the figure by dragging and dropping blocks.

Both conversation partners were wearing bicycle helmets, each mounted with an SMI eye-tracker, a head camera, and the Polhemus head tracking system. The sound side of the interaction was captured by two Sony ECM-66B tie clip microphones. Each conversation was preceded by a 13-point calibration procedure.

2.2 Data analysis

The occurrence of singular referring expressions in a specified part of the interactions were counted. Only the referring expressions used to refer to blocks presumed to be 'unused' (cf. Prince's term), i.e. available for use to the right on the constructor's screen, were counted. It is a widely held assumption that definite noun phrases require uniquely identifiable referents, and since there are not many of these among the unused blocks, singular definite expressions were expected to be used seldom.

The referring expressions were classified with

respect to ellipsis, definiteness value, and modification. Ellipsis is when the head noun is missing from a noun phrase. This category includes pronouns. Full noun phrases are those that have a head noun. There are two definiteness values: *definite* and *indefinite*. Modification is classified into the two categories *unrestricted* and *restricted*. Unrestricted noun phrases are those that have no modifiers, or at most non-descriptive and uninformative ones. An example of a modified, but unrestricted noun phrase would be *en till s n*, lit. 'one more such'. Restricted noun phrases are those that have descriptive and informative modifiers (restricting the meaning of the noun phrase), such as *en till s n mellanl ng* 'one more such half-long'. As can be seen from this example, restricted noun phrases may include non-descriptive modifiers as well as descriptive ones. These examples of unrestricted and restricted noun phrases are all elliptical, but full noun phrases can also be either unrestricted or restricted, whether they are modified or not. This sometimes depends on the amount of information in the head noun. For instance, an expression like 'a/the block' is an unrestricted full NP, while *en fyrrar* 'a four-block'² is considered a restricted full NP.

After tabulating the singular referring expressions it was clear that there were almost exclusively indefinite noun phrases, and that most of them lacked a nominal head (see table 1 below). The indefinite, elliptical noun phrases could be subdivided further into two groups, unrestricted and restricted elliptical expressions. The unrestricted ellipsis group can be considered fully anaphoric, whereas the restricted group resemble full noun phrases because of the informative modifier(s), and are therefore less anaphoric. Importantly, most types of singular indefinite noun phrase begin with (or consist of) the same word, namely *en* 'a/one', in the Scandinavian languages³. This means that one cannot always know from the first word in a referring expression whether it is a pronominal form or not.

Eye movements were measured in a time window of 3 seconds before and after the onset of the word *en*. These eye movement sequences were compared against each other using cross recurrence quantification analysis (CRQA) (Marwan & Kurths, 2002; Marwan, Thiel & Nowaczyk, 2002).

² *fyrrar* is a nominalization of the numeral *fyra*, 'four'.

³ Just as is the case with definite full noun phrases and definite pronouns, e.g. *den* 'it/the/that'

CRQA is a method of non-linear data analysis originally used within physics, and consists of a number of quantitative measures carried out on cross recurrence plots (CRPs). CRPs are a way of visualizing the coupling between the time series from two different dynamical systems. CRPs are produced by plotting black and white dots in a coordinate system where both axes are time axes, one for each of the time series being compared. For each point on the x axis, a dot is plotted on each point of the y axis: black if the state of one system is close to the state of the other system (i.e. *recurrent*), white if it is not. In this way, each point in time of one time series is compared to all points in time of the other time series. The state of each system is in this case simply defined as the two-coordinate gaze position of each interlocutor. Example CRPs are shown in figure 3 below.

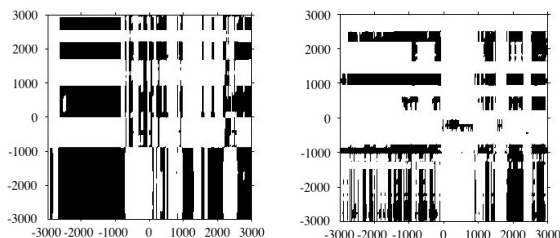


Figure 3: Cross recurrence plots. The plot on the left is from the unrestricted group, the one on the right from the restricted group. Both axes are time axes centered at the onset of *en* ‘a/one’. The unrestricted CRP is more dense than the restricted one, which was generally the case in the data.

Certain parameters of the recurrence measures have to be specified. The dimensionality m of the underlying phase spaces was set to 2, since the eye movements play out as two-dimensional dots in a plane. The parameter τ represents a time delay between the two time series. This was set to 0. This means that in the basic analyses presented below, the recurrence between two synchronized gaze patterns is measured, see figure 4 below. The parameter ϵ is a distance threshold. When the two gaze positions are within this threshold, they are counted as recurrent. This parameter was set to 70 mm, which roughly corresponds to the height of one cluster of blocks in the ‘unused’ area (there were 3 such clusters in all: long, half-long, and small blocks⁴). Finally, the time window size was fixed at 6 seconds — 3 seconds before, and 3 sec-

⁴ The other two areas were the original figure on the instructor’s screen and the emerging copy in the middle of the constructor’s screen.

onds after the onset of the word *en*. In this way, the amount of recurrence can be assessed at a delay of up to 3 seconds in either direction.

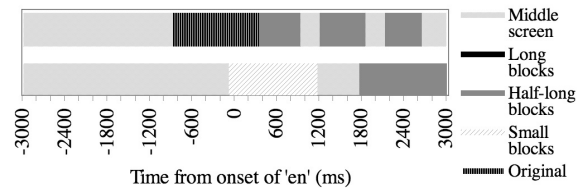


Figure 4: Two synchronized gaze pattern time series centered around the onset of the word *en*. The upper scarf plot shows the instructor’s gaze pattern, and the lower one the constructor’s. The referring expression used by the constructor in this case is *en mellanlång* ‘a medium-long [one]’.

If one of the interlocutors revisits extended portions of the other interlocutor’s gaze path, this behavior will result in extended diagonal lines in the CRP, since looking at the same positions in the same temporal order shows up as dots on a diagonal line. Two measures related to diagonal CRP lines were relevant: Mean length of all diagonal lines in the plot (denoted L), and length of the longest diagonal line in the plot (denoted L_{max}). L and L_{max} were measured for each gaze pattern pair associated with a referring expression (i.e. for each CRP) and averaged. The diagonal line length measures were relevant because it was expected that the more accessible referent type would be looked at faster after being mentioned, and be more likely than the less accessible referent type to already be in visual focus at the time of the onset of the referring expression. Thus, longer diagonal lines were expected in the unrestricted group, but it was not known at which time lag. Therefore, the CRQA methods are suitable, since they quantify these measures in the whole ± 3 second time window. The raw percentage of recurrence (i.e. the percentage of black dots in the whole CRP, denoted RR for ‘recurrence rate’) was also measured. This measure gives an impression of how much the two interlocutors look at the same positions, not necessarily in the same order.

The eye movement measures were only carried out on two of the four dialogs. The other two unfortunately had to be discarded because of a calibration error.

Finally, one dialog was scrutinized more closely in order to get an impression of the eye-voice, voice-eye, and eye-eye spans in the eye movement data. The video editing program Final Cut Pro was used to analyze the data frame-by-frame.

3 Results

3.1 Linguistic data

The referring expressions used to refer to unused blocks were counted. The results are tabulated below.

	Indefinite		Definite		Total
	unrestr.	restr.	unrestr.	restr.	
Ellipsis	10	31*	4	3	48
Full NPs	0	20	0	1	21
Total	10	51	4	4	69

*) 3 of these are uttered by the constructor

Table 1: Singular referring expressions used to refer to unused blocks in dialog 1a, 1b, 2a, and 2b. (All but three of them were uttered by the instructor.)

The first thing that one notices is that there are more indefinite than definite expressions. This is not surprising, given that unused entities are usually referred to using indefinite noun phrases (Prince, 1981).

There are more elliptical expressions than full noun phrases. Since all the entities talked about are blocks, it is not informative to include nouns like ‘block’ or the like in the expressions. Many of the elliptical expressions have restrictive modifiers, however, and this makes them less anaphoric than the unrestricted ones.

The unrestricted indefinite elliptical expressions from two dialogs were compared to the restricted ones in terms of eye movement recurrence (see table 2). This is the focus of the next section.

Elliptical indefinites		
Unrestricted	Restricted	Total
9	25	34

Table 2: The small subset of data analyzed for eye movement recurrence. The data are from dialogs 2a and 2b. The other two dialogs had to be excluded because of corrupted eye movement data.

3.2 Eye movement data

A frame-by-frame analysis of the elliptical indefinites in dialog 2b was carried out. It turned out that the speaker did not always fixate the target category (i.e. the next block type to be mentioned) on the mirror of the constructor’s screen prior to uttering an instruction, but equally often looked at the original figure for information on the next block. This is of course not too surprising after all, since the task was to copy an existing object, not building a new one. In fact, all but one of the 20 instructions given by this particular instructor were preceded by a gaze on the original. All 20 gaze patterns had a very similar structure. Typically, a few gazes back and forth between the original figure and the copy were followed by a gaze at the target block type, sometimes followed by gazes back and forth between the copy and the target block. The onset of the looks at the target were located around time 0, i.e. the onset of *en* ‘a/one’, ranging from –920 ms to 1240 ms. On average, target gazes associated with unrestricted expressions started a bit earlier (–80 ms) than gazes associated with restricted expressions (–23 ms). Data were too sparse to verify if this difference was significant.

It was clear that the onset of the first target gaze of the speaker should not serve as the point of departure of eye-voice measures, since this first gaze often followed after the onset of *en*, and in fact sometimes seemed to be triggered by the constructor manipulating the target rather than by any language production processes, as shown in figure 5.

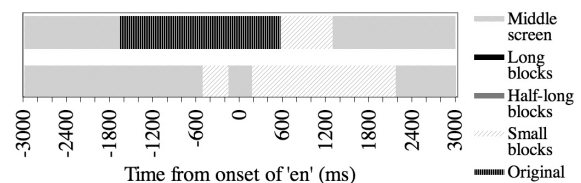


Figure 5: The instructor (upper scarf) looks at the target after, and perhaps triggered by, the constructor (lower scarf). The referring expression used by the constructor in this case is *en liten till* ‘a small [one] more’.

Instead, the eye-voice span was measured from the onset of the last gaze on the original figure before time 0. The voice-eye span was measured from 0 to the onset of the first gaze on the target after 0. If a target gaze started before 0 and

crossed it, a value of 0 was recorded⁵. Combined, these two figures yield the ‘eye-eye spans’ in the data, see table 3.

	Eye-voice	Voice-eye	Eye-eye
Unrestr.	1280 ms	376 ms	1656 ms
Restr.	1643 ms	557 ms	2200 ms

Table 3: Eye-eye spans for dialog 2b.

These data closely parallel those of Hadelich and Crocker (2006), and the unrestricted measure is almost identical to Richardson and Dale’s (2005) point of maximal recurrence.

It was measured how much attention was paid to targets on average. The constructor spent almost exactly equally much attention on the target areas in unrestricted (1000 ms) and restricted cases (1011 ms). The listener spent 1888 ms gazing at unrestricted targets, and 2489 ms on restricted targets.

Thus, the constructor in this particular dialog on average looked at the target earlier, and fixated it for a shorter time in connection with unrestricted expressions.

On the assumption that the speaker looks approximately equally much at the intended referent type in both groups, a difference in gaze patterns might materialize because the listener could already have the intended referent type in focus in the case of unrestricted anaphora (indeed, this could be the speaker’s principal reason for using a fully anaphoric form), but less so in the case of restricted anaphora. Put differently, unrestricted anaphora might be more accessible to the listener, yielding the shorter voice-eye span observed. This alone would not necessarily affect the recurrence rate, however. If only the voice-eye lags differ, overall recurrence might not differ. On the other hand, if listeners look at the intended referent for different durations depending on the type of expression, as suggested by the analysis of dialog 2b above, then the overall recurrence rate (*RR*) would be affected. The *RR* increases with the similarity of the distribution of attention on the different

⁵ Others have analysed this kind of data from a point of departure 200 ms after 0 in order to only consider eye movements that could plausibly have been driven by the linguistic form considered (Chambers et al., 2002). Here, however, target fixations seem to occur only in connection with the utterance of relevant instructions, and predictive eye movements are included because of the very possibility of pronouns being uttered in contexts where the listener might be assumed to already have the intended referent ‘in focus’.

areas of interest in the two gaze patterns, regardless of the order of the gazes. The speaker in dialog 2b spent equal amounts of attention on the targets in the two groups. The amount of attention spent on the unrestricted expression referents by the listener was lower than the amount spent on the restricted referents, and thus more similar to the speaker’s amount of attention on the target referents. If this is a general pattern, a higher *RR* would be expected in the unrestricted case.

The *RR* results confirm this hypothesis. There is a significant difference in the expected direction in overall recurrence ($t(32) = 1.76$, $p < 0.05$ one-tailed). See figure 6.

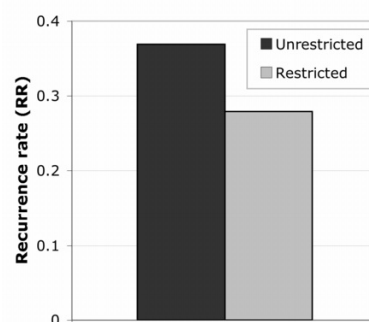


Figure 6: *RR* of the two types of referring expressions. The difference is significant ($p < 0.05$).

This result indicates that the two interlocutors look more at the same positions overall during the 6 second time window when a fully anaphoric expression is used. The frame-by-frame analysis suggests that this comes about because the more anaphoric (i.e. unrestricted), and presumably more accessible forms require less attention from the listener.

The recurrence rate gives a measure of how much the two interlocutors look at the same things, but it is not sensitive to the order of the fixations. The measures of the diagonal lines in the CRPs remedy this. A diagonal line means that the same areas are fixated a number of data points in a row by the two interlocutors, possibly at a lag. If the interlocutors look at the same areas at the same *time*, the line appears on the $x=y$ diagonal (called the *line of incidence*, or LOI).

Since the frame-by-frame analysis showed that the unrestricted target gazes of the listener were more similar than the restricted ones to those of the speaker, it was expected that the gaze patterns of speaker and listener would be similar for longer stretches of time in the unrestricted group, yielding longer diagonal lines in the CRP.

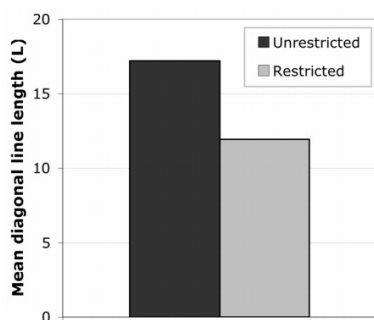


Figure 7: L of the two types of referring expressions. The difference is significant ($p < 0.01$).

The results for L and L_{max} both show significant differences in the expected direction (L : $t(32) = 2.88$, $p < 0.01$ one-tailed; L_{max} : $t(32) = 3.06$, $p < 0.01$ one-tailed). See figures 7 and 8.

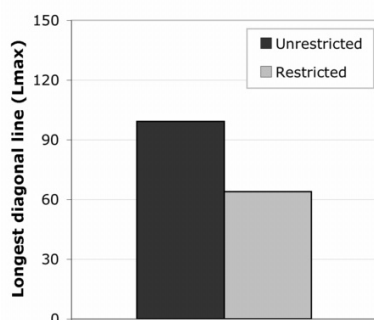


Figure 8: L_{max} of the two types of referring expressions. The difference is significant ($p < 0.01$).

These results suggest that the gaze positions of the instructor and the constructor recur for longer stretches in connection with the unrestricted expressions, just as expected.

4 Discussion

The results presented above are very promising, in that it has been shown on the basis of very limited data that there are subtle differences in eye movement trajectory recurrence depending on the use of minimally different types of referring expressions. This is consistent with the idea of fluctua-

tions in the moment-by-moment activation of concepts in common ground motivating linguistic forms of varying anaphoricity. The results constitute the next step towards the documentation of well-known and widely accepted assumptions about anaphor processing in ongoing discourse.

It was shown that more anaphoric indefinite expressions lead to more recurrence overall, and longer uninterrupted stretches of tandem eye movement patterns.

This pattern of results generally supports the hypothesis that accessibility licences anaphoricity, possibly in a graded manner. The fact that these results come from a study of different types of indefinite forms suggests that accessibility may indeed be independent from identifiability, as sketched in figure 1 above.

To be fair, the threshold ϵ , set to 70 mm, is relatively large. It comprises almost one fourth of the screen height. This means that the two gaze points can be quite far apart and still be counted as recurrent. On the other hand, the threshold corresponds to the height of each cluster of unused block types, so in order to capture all gaze pairs that fall within the same category of blocks, a threshold of this size is necessary. Therefore, this threshold size is justified.

Relevant future work will obviously be to carry out a full-scale version of this experiment, and to create new versions of it specifically designed to target other expression types (e.g. singular definite referring expressions).

In conclusion, the CRQA methods show considerable promise as a toolbox for the quantitative study of ongoing anaphor use in relatively natural conversation.

5 Acknowledgements

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