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Basic Skills in a Complex Task: A Graphical Model Relating Memory and Lexical Retrieval to Simultaneous Interpreting

4.1 Introduction

Simultaneous interpreting (SI) is a complex skill that involves speaking and listening in different languages at the same time. It requires comprehension of input, which involves the temporary storage and extraction of meaning of this input, while the interpreter is involved in formulating the meaning of an earlier part of the speaker's speech in the output language and producing yet another part (e.g., De Groot, 2000; Gerver, 1976; Padilla et al., 1995; Rinne et al., 2000). Meanwhile, the interpreter is working under severe time constraints because the flow of input is continuous; the interpreter has no control over the input rate of the source speech. SI is, therefore, a very demanding cognitive skill. Not surprisingly, it is prone to error even under normal listening conditions and very sensitive to unfavorable conditions such as noise, faster than normal delivery of speech, poor pronunciation, and technical complexity of the speech (Gerver, 1976; Gile, 1997). Yet, high quality output is important if one considers that far reaching decisions may depend on the accuracy of interpreting in, for instance, international politics.

SI is probably one of the most complex language processing tasks imaginable (Frauenfelder & Schriefers, 1997). No other language task combines the need to comprehend and produce speech simultaneously, and to simultaneously command and control two languages. Understanding SI may be of great interest to cognitive psychologists and psycholinguists because of the demanding nature of SI in terms of online processing and control. Despite these intriguing characteristics of the task, experimental data on SI is scarce (see Christoffels & De Groot, in press, Chapter 2, for a review). Since SI is an extremely complex cognitive skill, our approach in this study was to break SI down into its processing components to explore what basic cognitive subskills are important to SI. Of a larger set of possible subskills, we focused on the roles of basic language skills and of memory.

4.1.1 Language skills

In SI efficient language processing may be very important; when little attentional processing is required for certain aspects of language processing, more processing capacity will be available for other task components and the results of those processing steps are more quickly available for further processing. There is some evidence of a relationship between SI experience and efficient language processing. For example, Fabbro and Darò (1995) reported greater resistance to the detrimental effects of delayed auditory feedback in students of SI than in monolingual participants. Fabbro and Darò concluded these students of SI were more resistant to the interfering effects of delayed auditory feedback because they had developed high general verbal fluency and because they had learned to pay less attention to their own verbal output. Furthermore, Bajo, Padilla and Padilla (2000) compared the performance of interpreters, students of interpretation, bilinguals, and professionals from other fields on a categorization task. They showed that interpreters categorized nontypical exemplars of the categories faster than the students and the bilinguals. This finding indicates faster semantic access in interpreters than in other participant groups.

A specific aspect of language processing is the ability to quickly access and retrieve words. Although the word processing level may be considered too basic a level to be important in interpreting, which usually involves comprehension and production of complete discourse, there are reasons to believe that basic lexical retrieval efficiency may be relevant after all. For instance, if finding an appropriate word for a concept during SI takes a long time, it is likely that the interpreting process may break down due to the loss of valuable processing capacity and time. In other words, the time required to retrieve the word that corresponds to a given concept should be as short as possible. Even more important may be the time required to retrieve the translation of an input word. Although the interpreter usually does not attempt to literally translate each word from the source language into the target language, some literal word-to-word translation is likely to play a role in SI. In fact, although the details of the actual translation process during interpreting are unknown, several authors theoretically distinguish two presumably coexisting translation routes (or strategies) in SI: A transcoding route and a meaning-based route (e.g., Anderson, 1994; Bajo et al., 2000; De Groot, 1997, 2000; Fabbro & Gran, 1994; Isham & Lane, 1994; Massaro & Shlesinger, 1997; Paradis, 1994). The transcoding route involves literal transposition of words or multi-word units, whereas in meaning-based interpreting the meaning of the input is initially fully comprehended and conceptually represented. From this nonverbal conceptual representation of the input’s meaning, production takes place in the target language (see, Christoffels & De Groot, in press, Chapter 2). Especially if interpreting proceeds by means of transcoding, efficiency in the retrieval of translation equivalents may be crucial. Among other things, this study attempts to explore the relevance of these two specific aspects of basic language processing in SI: The retrieval of a word for a given concept and the retrieval of a translation equivalent for a given word.
4.1.2 Memory skills

Working memory is also likely to play a substantial role in SI. The working memory system is conceived of as a short-duration memory system that is capable of simultaneously storing and processing information. Working memory is known to play a significant role in normal language processing (e.g., Gathercole & Baddeley, 1993), but in SI we may expect it to be especially important. The delay between input and output in SI is on average about two to three seconds or four to five words (Anderson, 1994; Barik, 1973; Christoffels & De Groot, 2003, Chapter 3; Gerver, 1976; Goldman-Eisler, 1972; Treisman, 1965). This factor alone is reason to assume that interpreting is demanding in terms of storage capacity in memory. Moreover, in SI many processes have to take place simultaneously, placing heavy demands on the executive control function of working memory. It is generally assumed that working memory capacity is limited and that the processing and storage functions compete for this limited capacity (e.g., Gathercole & Baddeley, 1993; Just & Carpenter, 1992; Shah & Miyake, 1999). This trade-off between storage and processing may be a bottleneck in SI, where both functions are important (Gile, 1997).

Engle, Tuholski, Laughlin and Conway (1999) concluded from a factor analysis that short-term memory and working memory reflect separate but highly related constructs that are differentially related to higher order cognitive abilities. It seems sensible to at least distinguish between short-term memory and working memory in the sense that different tasks appear to primarily test either the storage capacity or the online processing resources of the memory system. For example, the digit span task assesses passive recall abilities and may be regarded as an indication of the participant’s short-term memory capacity. Measures that tax both processing and recall may be regarded as measures of the participant’s working memory capacity, where the focus is more on online processing. For example, the reading span task, introduced by Daneman and Carpenter (1980), combines temporary processing and storage demands. This type of task correlates higher with measures of language comprehension and other language processing tasks than measures that tap only storage capacity (see Daneman & Merikle, 1996, for a meta analysis).

Padilla et al. (1995) and Bajo, Padilla and Padilla (2000) provided evidence that interpreting is indeed associated with efficient (working) memory skills. Padilla et al. compared experienced interpreters with two groups of student interpreters in the second and third year of their study and with non-interpreters. They administered a simple digit span task and a reading span task. According to both tasks, the interpreters had a higher average memory capacity than all other participant groups. In a similar experiment, Bajo et al. (2000) reported comparable results across interpreters, student interpreters, and non-interpreters.

A relevant question regarding interpreting is whether there are functional capacity differences in memory between the first and second language: when memory tasks are administered in a second language (L2) the results are often found to differ from performance in the first, native language (L1). For passive recall tasks, like the digit span task, part of the between-language difference in recall is due to differences in articulation
rate between the L1 and L2. It seems, however, that short-term memory capacity may not be the same in the native and a second language, even when the differences in articulation rate are taken into account (Chincotta & Underwood, 1997, 1998a).

A few studies have also investigated tasks that assess working memory, such as the reading span, in different languages. Harrington and Sawyer (1992) found differences in word span and digit span in two languages, but no difference in reading span. Service, Simola, Metsaenheimo and Maury (2002) reported data that suggest that working memory capacity may interact with language proficiency. L1 (Finnish) reading span was higher than L2 (English) reading span for a participant group that was relatively less proficient in the L2 (psychology students), but there were no differences for more advanced speakers of the L2 (students majoring in English). Service et al. concluded that sentence processing in a language that is not completely automated consumes extra working memory resources so that the reduction in overall capacity can be detected by working memory span tasks.

4.1.3 The present study

In the present study we focused on the role of two possible subskills of SI that are likely to be important: lexical retrieval and working memory. Unlike previous studies, we explored the relation of lexical retrieval and working memory with SI for participants without any prior experience in interpreting. In doing so, we capitalized on naturally occurring individual differences in interpreting ‘talent’. If these basic skills are indeed important in SI, individual differences in lexical retrieval efficiency and working memory capacity should correlate with individual differences in SI performance.

To assess SI performance an SI task was administered in which the participants were instructed to translate an auditorily presented text into the target language online. In addition, two common psycholinguistic tasks were used that tap into language processing at the word level and give an indication of the efficiency of word retrieval: word translation and picture naming. In a word translation task, a word is presented in one language and the participant is asked to give its translation equivalent as quickly as possible in the target language. This task provides a measure of how quickly a word in the source language activates its counterpart in the target language and is subsequently produced. In a picture naming task a picture is presented for which the participant is to name the concept that it represents. This task gives an indication of the time needed to retrieve the word that names a concept and to produce it.

We assessed memory skills by administering a simple verbal digit span and a reading span task. As mentioned earlier, the digit span task is not as predictive for higher order language processing such as reading comprehension skills as, for example, the reading span task is (Daneman & Merikle, 1996). Similarly, Harrington and Sawyer (1992) obtained lower correlations between a simple word or digit span in L2 and L2 reading ability than between L2 reading span and L2 reading ability. In this study, we nevertheless included the
digit span task to find out whether short-term memory capacity, as assessed by the digit span task, captures part of the memory requirements in interpreting. Finally, in contrast to Padilla et al. (1995), and Bajo et al. (2000), who only administered the reading span in L1, we administered two matched versions of the reading span task in two languages because working memory capacity in L2 may be more important in restraining processing in SI than capacity in L1.

Performance on the picture naming, translation, reading span, and possibly also the digit span tasks was expected to correlate with interpreting performance. We also performed a graphical models analysis. Such an analysis indicates by means of partial correlations what, if any, the interrelations between the variables are.

4.2 Method

4.2.1 Participants

Twenty-four students of the University of Amsterdam participated in return for either course credit or payment. All participants were native speakers of Dutch. Their mean age was 21 years. They received at least six years of formal training in English as a second language, for about 3 to 4 hours a week, at secondary school. Subsequently, at university they are required to read English since most textbooks are in English. The participants have also been exposed informally to English from early childhood, via film, television and music. We administered a language questionnaire designed to evaluate the language history of our participants. On a 7-point scale (1 = no knowledge of English and 7 = native level) the mean self-rating of their passive knowledge of English was 6.2; their mean rating of active knowledge was 5.7. None of the participants rated themselves lower than 5 on these scales.

4.2.2 Tasks and stimuli

Lexical retrieval. The word translation task was administered in both language directions separately, from English (L2) into Dutch (L1) and from Dutch into English. On each trial, a word was presented on the screen and the participant was asked to give its translation as quickly as possible. The stimuli were 72 English and 72 Dutch words. Two word characteristics were manipulated: word frequency and cognate status. Cognates are similar to their translation equivalents in the other language in both meaning and form (e.g., English ‘cat’ – Dutch ‘kat’). The items from the four conditions (high frequency cognates, low frequency cognates, high frequency noncognates, and low frequency noncognates) were matched on both word length and word concreteness. Further information on these stimuli can be found in Appendix 2. These four kinds of words were included to ensure the generalizability of our findings to different types of words.
The picture naming task was administered in both English and Dutch. Pictures were presented on a screen and participants had to respond verbally as quickly as possible by giving the name of the depicted object. Seventy-two pictures were selected from the Snodgrass and Vanderwart (1980) set, which consists of black line drawings on a white background. As for the word translation task, both frequency and cognate status were manipulated. The name agreement percentages for the pictures of the four subsets of words were equally large, and word length was matched across subsets. Further information on the properties of the stimuli is given in Appendix 3.

Both the word translation task and the picture naming task started with four practice stimuli that differed from the experimental stimuli. For each participant the stimuli were presented in a different random order. On each trial a fixation cross was presented for 500 ms, accompanied by a beep. A stimulus appeared 100 ms later and stayed on screen until the participant responded, but not longer than 7 s. The reaction time was measured by means of a sound-activated switch (voice-key). The experimenter typed the participant’s response and triggered the next trial.

Memory. The reading span task was administered in both English and Dutch. The participant read aloud sentences that were shown centered on the monitor while trying to remember the last word of each sentence. As soon as the participant read out the last word of a sentence, the experimenter triggered the next trial, a white screen appeared for 500 ms, a beep sounded, and then the next sentence appeared. The sentences were presented in increasing set sizes that consisted of two to five sentences. There were three series of each set size, which added up to 42 recall words per task. After presentation of the last sentence in each set the participants were signaled on screen to write down all final words of the set they recalled. They were instructed not to start with writing down the last word presented to them. No other restrictions on recall order were given. The sentences of the English task were partly derived from Harrington and Sawyer (1992). The final words of the English and Dutch versions of the task were matched across the two languages on length and frequency (See Appendix 4 for the properties of the final words and a sample of sentences). Sentence length was between 11 and 13 words for both the Dutch and English version of the task (on average 11.8 words for English and 11.7 for Dutch). For each participant the total number of correctly recalled words was calculated.

The digit span task was administered in Dutch. The participants were asked to repeat verbally presented sequences of an increasing number of (pseudo) random digits (i.e., no immediate repetitions of the same digit and no obviously meaningful order) in the exact order of presentation and to start recalling them immediately after the last digit was read to them. The digits were read aloud at a rate of one per second, starting with a sequence of four digits. There were three series of each number of digits: after presentation of three series of four digits, the next sequence contained five digits. The task continued until the participant

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2 Practical constraints prevented presentation of the digit span in English.
was no longer able to correctly recall one out of the three series. The largest number of digits recalled before an error made was taken as the participants’ digit span.

**Simultaneous interpreting.** In the *simultaneous interpreting task* stimulus material was presented auditorily to the participant over headphones. The participants were asked to translate the English text as well as possible into Dutch and to start translating while listening. They were told that they should try to translate the meaning of what was being said rather than translate literally. Recordings that had been used as part of a medium level English listening high school exam in the Netherlands, were adapted and used in two practice sessions of one and four minutes, respectively. The experimental SI task-recording was about 4.2 minutes long. It concerned a text on the science of face perception that we assessed to be easy to understand (see Appendix 6). After participation the participants reported no problems in understanding the text. The recorded text was spoken by a native speaker of British English at a rate of 116 words per minute on average. The interpreting output of the participants was recorded on the computer. From these recordings, two different measures of quality of SI performance were derived. The first measure was based on transcriptions of the recordings (SI-T). Ten sentences, approximately equally distributed in the text, were selected from the English text. Two judges rated the sentences on how well the content was translated in Dutch, on a scale from 0 to 3. A score of zero meant that the sentence was not translated at all; a score of 3 meant that almost all of the original text was translated into a proper grammatically correct Dutch sentence. For each participant a performance measure was calculated by adding the scores on the 10 sentences. The second measure (SI-A) was a rating of the translations’ complete audio recording by two judges, both teachers at the school for translation and interpreting of Maastricht, the Netherlands, and experienced simultaneous interpreters themselves. They rated each participant’s performance on a scale from 0 to 5 on how well the text was interpreted. The inter-rater reliability $\rho$ on both performance measures was reasonably high. For SI-T (transcription of the recordings) $\rho$ was 0.91. For SI-A (audio records) $\rho$ was 0.80.

### 4.2.3 Design and procedure

The participants were tested individually in a dimly illuminated room. All the instructions were in Dutch and provided on paper and administered verbally to the participants. After receiving a general instruction, for each separate task a detailed instruction was provided. The experiment was run on two different computers using three software packages. The naming and translation tasks were programmed to run on a Macintosh PPC 4400 with a 15-inch monitor, using the in-house developed software Flexi 4.0.5. All other tasks were run on a Macintosh G3 PowerBook. The memory span tasks were programmed using Psyscope 1.2 and the interpreting task was administered and recorded using DeckIF\textsuperscript{TM} 2.6.1, an audio-
record program enabling us to simultaneously play the stimulus sound file while recording the participants’ response on another track.

The session started with a brief voice-key practice in which participants read aloud English words. The complete session took about 1.5 hours. Apart from brief breaks between tasks a break of five minutes was held halfway through the session. The tasks were administered in two different orders that both started with a voice-key practice and ended with a short language questionnaire on the language background of the participants. Half of the participants performed the tasks according to the following task sequence: picture naming English; translation Dutch-English; reading span English; interpreting practice 1; interpreting practice 2; short break; digit span; reading span Dutch; translation English-Dutch; picture naming Dutch; interpreting task. The remaining half of the participants performed the tasks according to the same task sequence but they started with the Dutch version of the tasks instead of the English version.

4.3 Results and discussion

No main effect for order of presentation approached significance, so we collapsed across presentation orders. For the translation task and the picture naming task, the mean reaction time and percentage of errors for each of the conditions was calculated for each of the participants. All reaction times (RTs) longer than 5000 ms were treated as outliers and were excluded from the analysis. With this procedure less than 0.5 % of the RTs was excluded from the data of both tasks. Furthermore, all RTs of incorrect responses and voice key errors were excluded. All together, less than 11% of the data in both tasks was excluded, of which about 7% were incorrect responses. Means and standard deviations on all tasks are presented in Table 1.

The correlational and graphical models analyses, described next, are of main interest. However, for completeness we briefly report the repeated-measures analyses of variance (ANOVA) that were conducted on the translation and picture naming latencies. Because the number of errors is relatively small, no separate analyses for the errors are presented. There was no speed-accuracy trade-off in either task, since the largest number of errors was found in the condition in which the participants reacted most slowly.

For the translation task, within-subject factors were translation direction (English-Dutch, Dutch-English), cognate status (cognate, noncognate), and frequency (high, low). The ANOVA yielded significant main effects for both cognate status \( F(1, 23) = 118.97, p < .0001 \) and frequency \( F(1, 23) = 97.42, p < .0001 \), which were qualified by an interaction between cognate status and frequency \( F(1, 23) = 11.25, p < .005 \). There was no significant main effect for translation direction \( F(1, 23) = 2.81, p > .10 \). Participants responded faster
to cognates than noncognates, faster to high frequency words than to low frequency words and the latter difference was larger for the noncognate words.

The repeated-measures ANOVA on the *picture naming* task with the factors language, cognate status, and frequency yielded a significant main effect for language ($F(1, 23) = 158.49, p < .0001$), cognate status ($F(1, 23) = 48.40, p < .0001$), and frequency ($F(1, 23) = 57.34, p < .0001$). Furthermore, there was an interaction between language and frequency ($F(1, 23) = 30.52, p < .0001$). No other interactions approached significance. Participants were slower to name in English than in Dutch and the difference between high and low frequency words was larger when participants named in English than in Dutch.

### Table 1. Means and standard deviations (SD) for all tasks.

<table>
<thead>
<tr>
<th>Tasks</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Word retrieval</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Translation English-Dutch</td>
<td>990</td>
<td>159</td>
</tr>
<tr>
<td>Translation Dutch-English</td>
<td>951</td>
<td>170</td>
</tr>
<tr>
<td>Picture naming English</td>
<td>1151</td>
<td>171</td>
</tr>
<tr>
<td>Picture naming Dutch</td>
<td>815</td>
<td>97</td>
</tr>
<tr>
<td><strong>Memory</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reading span English</td>
<td>32.9</td>
<td>3.73</td>
</tr>
<tr>
<td>Reading span Dutch</td>
<td>33.0</td>
<td>4.01</td>
</tr>
<tr>
<td>Digit span</td>
<td>6.4</td>
<td>1.21</td>
</tr>
<tr>
<td><strong>SI performance</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SI-T (transcription)</td>
<td>18.2</td>
<td>3.91</td>
</tr>
<tr>
<td>SI-A (audio-recording)</td>
<td>2.3</td>
<td>0.86</td>
</tr>
</tbody>
</table>

*Note.* For translation and picture naming the reported averages are the reaction time for correct responses in milliseconds, for reading span the number of correctly recalled words (maximum score = 42), for digit span the number of correctly recalled series of digits, and for SI performance (SI-T and SI-A) the mean rating of the two raters (maximum score = 30, and 5 respectively).

Note that the effect of translation direction was not significant. It is often reported that forward translation, i.e., translation into the second language, is slower and more prone to errors than backward translation, into the LI (e.g., Kroll et al., 2002; Kroll & Stewart, 1994). The absolute difference in RT between forward and backward translation actually suggests the opposite pattern: translation into English was, if anything, faster. Both null results and this opposite effect have been reported before (Christoffels et al., 2003, Chapter 5; De Groot, Dannenburg, & Van Hell, 1994; De Groot & Poot, 1997; La Heij et al., 1996; Van Hell & De Groot, 1998b). De Groot and Poot (1997) tested three proficiency groups. Two groups were secondary school pupils; the highest proficiency group consisted of university students.
The former two groups were faster at forward translation; for the students the effect of translation direction was not significant. The equivalent RTs in both translation directions therefore suggest that our participants were relatively proficient in L2. Nevertheless, they were faster to name pictures in L1 (Dutch) than in L2 (English).

For the reading span task, a paired t-test showed there were no differences in performance between the Dutch and the English version ($t(1, 23) < 1, p > .10$). In other words, functional working memory capacity of our participants appears to be equally large in L1 and L2, although the absolute difference was in favor of Dutch reading span. Harrington and Sawyer (1992) similarly reported no differences between languages on a reading span task. Furthermore, this pattern matches the advanced group in the Service et al. (2002) data, even though our participants were psychology students, like their less advanced group. This may, again, be taken to indicate that these participants were quite proficient in their L2.

4.3.1 Correlational analyses

The correlations between performance on the language and memory tasks on the one hand, and the measures of simultaneous interpreting, SI-T and SI-A, on the other hand, are presented in Table 2. SI-T and SI-A correlated significantly with each other ($r = 0.86, p < .0001$), indicating that they were similar measures of SI performance. Nevertheless, the pattern of correlations between the two SI performance measures and the other tasks were somewhat different for the two measures.

Inspection of Table 2 shows that the translation task in each translation direction correlated quite highly with both interpreting measures. Also picture naming latencies correlated with interpreting performance although the correlations are somewhat stronger for picture naming in English. These results indicate that fast word retrieval is associated with better interpreting performance. In other words, some basic language skills may indeed be important for SI and fast word retrieval might be one of them.

Reading span English correlated significantly with interpreting performance as assessed by SI-T, but not as assessed by SI-A. The correlation of reading span Dutch and SI-

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3 To support the idea that the lack of a difference between translation directions and between Dutch and English reading span was due to the relatively high L2 proficiency of our participants, we performed an additional analysis. The difference between forward and backward translation and the difference between English and Dutch reading span (i.e., the language effect) was calculated and correlated to the mean (passive and active) self-assessed proficiency in English. The correlation with the language effect in translation was significant ($r = -.51, p < .05$), indicating that a higher English proficiency was indeed associated with a smaller language effect. Similarly, the correlation of proficiency with the language effect in working memory was in the expected direction, albeit not significantly ($r = -.29, p > .10$). Higher proficiency is associated to a smaller difference between English and Dutch reading span, albeit not significantly so. Note that there was an extremely small range of proficiency scores (between 5 and 7 on a 7-point scale). The homogeneity of the participant group in this respect limited the power of this analysis.
T showed a trend towards significance, but again, no significant relation is found with SI-A. For the digit span task the correlation with both interpreting performance measures was significant. These data give some indication that a larger or more efficient working memory is associated with better interpreting performance, and that also passive recall is associated with SI performance.

Table 2. Correlation between the performance on all tasks and two measures of performance on the interpreting task, SI-T and SI-A.

<table>
<thead>
<tr>
<th>Task</th>
<th>SI-T</th>
<th>SI-A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Translation English-Dutch</td>
<td>-.62***</td>
<td>-.37*</td>
</tr>
<tr>
<td>Translation Dutch-English</td>
<td>-.66***</td>
<td>-.54**</td>
</tr>
<tr>
<td>Picture naming English</td>
<td>-.62***</td>
<td>-.57**</td>
</tr>
<tr>
<td>Picture naming Dutch</td>
<td>-.41*</td>
<td>-.44*</td>
</tr>
<tr>
<td>Reading span English</td>
<td>.44*</td>
<td>.03</td>
</tr>
<tr>
<td>Reading span Dutch</td>
<td>.30◊</td>
<td>.24</td>
</tr>
<tr>
<td>Digit span</td>
<td>.35*</td>
<td>.38*</td>
</tr>
</tbody>
</table>

Note. * $p < .05$, ** $p < .01$, *** $p < .001$, ◊ $0.1 < p < .05$, one-tailed Z-test. Note that negative correlations are expected for the translation and picture naming tasks because better performance is associated with shorter reaction times, and higher scores on the SI measures.

It thus seems that it is indeed possible to identify basic subskills that are relevant for SI performance. Better SI performance is associated with faster reaction times on word retrieval tasks. There is also some evidence that working memory is relevant, especially when considering SI-T. It is not clear why there are differences between the two measures of SI performance. The correlations were in general lower for SI-A. This might be because of the lower inter-rater reliability for SI-A ($\rho = 0.80$) than for SI-T ($\rho = 0.91$). Another difference between these measures is that they are based on different aspects of the output. SI-T is based on the transcription of the output, whereas SI-A is based on the audio-records. The latter measure may be influenced more by aspects unrelated to how well the meaning of the input is preserved in the interpretations, such as interruptions in speech and type and clarity of voice. Further analysis is performed on SI performance according to SI-T because for this measure the inter-rater reliability was highest.

4.3.2 Graphical models analysis

In order to gain more understanding of the relation between the different variables in this study, we performed a graphical models analysis. This is a multivariate analysis that uses
graphs to represent models and enables a representation of associations between variables (Edwards, 2000). The analysis is similar to path analysis. Graphical modeling is based on the partial correlations between the variables. The procedure considers each of the individual edges (links between the variables) and subsequently removes those edges that are not required, i.e., for which the partial correlation does not differ significantly from zero. It is possible that variables become completely isolated, indicating that there is no association with any of the other variables. Graphical modeling is aimed at obtaining a model of associations that is as simple as possible and still describes the data well. With this analysis the relative importance of the associations between each of the tasks and SI can be assessed.

The analysis was performed with the MIM software package (Edwards, 2000). Using F-tests for stepwise backward testing on individual edges (starts from the full model with all edges present, by deleting edges) we obtained the model graphically presented in Figure 1. This model fits the data well, $\chi^2(21) = 14.117, p = 0.86$. Note that a model fits the data if the Chi-square test is not significant. The model was stable in the sense that two other model selection procedures yielded the same model: stepwise forward testing (starts from a model without any edges, by including necessary edges) and the Edwards-Havránek-search algorithm (Edwards, 2000). An analysis of the residuals indicated that the assumption of conditional multivariate normality was satisfied. It is important to emphasize that the model selection was in no way restricted by any a priori assumptions on the relations between the variables in this study.

![Figure 1](image-url). Graphical model of associations between SI performance and other tasks (RS = reading span; TL = translation task; PN = picture naming task).
From the graphical model we can make the following observations. First of all, there are only direct edges to SI performance from reading span English and translation Dutch-English. In other words, these two variables are the most relevant to SI because they have a direct effect on SI performance. Any influence of the remaining variables is mediated by reading span English or translation Dutch-English. Note that the absence of, for example, an edge between picture naming English or Dutch and SI performance means that picture naming in both languages is not directly associated to SI performance. In other words, although the ordinary correlation between picture naming and SI is significant (see Table 2), picture naming does not uniquely explain part of the variance in SI performance.

In the introduction, transcoding and meaning-based interpretation were discussed. The model emerging from the data indicates that transcoding may be a relatively important strategy for untrained SI. This is suggested by the fact that an edge between translation and SI exists, but not between picture naming and SI.

Second, a highly interesting result is that the model consists of two separate paths of tasks that are connected directly only to SI performance: On the one hand, the two working memory tasks are associated, on the other hand, translation, picture naming, and digit span are associated. This means that we obtained evidence that different, (conditionally) independent subskills in SI exist, in the sense that working memory and translation each have an independent relation to SI performance.

Furthermore, in the model the Dutch and English versions of each task are linked directly to each other. Thus, only one version of each task (i.e., reading span English, translation Dutch-English, picture naming English) is associated to other tasks, whereas the other language version (i.e., reading span Dutch, translation English-Dutch, picture naming Dutch) is connected in the model only through their counterpart. This was to be expected because the task may be assumed to capture the same underlying processes in the two languages. Therefore, one would not expect separate association between, for example, both English-Dutch and Dutch-English translation with SI, because these tasks mainly explain the same variance. It is not completely clear why it is translation into English and not translation into Dutch that is directly linked to SI (which took place into Dutch). Although speculative, possibly the requirement to generate responses in L2 captures more of the restraints of processing in L2 that are relevant to SI than production in L1. However, one should take into account that the correlation between Dutch-English and English-Dutch translation is high ($r = .77, p < .05$), suggesting that, to a large extent, both tasks measure the same underlying skill. Moreover, Dutch-English translation is more easily selected in the model as the translation direction with a direct edge to SI, because this task's correlation with SI is slightly higher than the correlation of English-Dutch translation with SI (i.e., -.66 and -.62, see Table 1).

Finally, it is noteworthy that in the model digit span has no direct relation to SI performance. Apparently short-term memory capacity, at least in the native language, is not as relevant to SI as working memory is. Although this latter conclusion may not be surprising, perhaps it can be considered unexpected that digit span is associated with
translation rather than with the working memory tasks. It this context it is worth mentioning that the correlations between digit span and word translation into Dutch \((r = -0.59)\) and into English \((r = -0.50)\) were higher than the correlation between digit span and reading span Dutch \((r = 0.41)\) and English \((r = 0.22)\), and that all correlations, except for the correlation with reading span English reached significance. One suggestion concerning short-term memory may shed some light on why this pattern emerged. The digit span gives an indication of the capacity of the individual’s phonological loop component. This slave-system of the working memory system is specialized for the retention of verbal material over short periods of time (e.g., Baddeley, 1986; Gathercole & Baddeley, 1993). Baddeley, Gathercole and Papagno (1998) argued that the primary function of the phonological loop is that of a language learning device (see also e.g., Ellis & Sinclair, 1996). It is found that vocabulary knowledge is strongly associated with digit span performance in children and with the learning of novel words in adults (e.g., Baddeley, Gathercole et al., 1998). Of the tasks in the present study, conceivably especially word translation skill is related to individual differences in foreign vocabulary acquisition ability. The relevance of the phonological loop in the acquisition of vocabulary may thus hint to why in our model the digit span task is associated with the translation task rather than the reading span task.

### 4.4 General discussion

Using correlational analysis and graphical modeling we were able to show that it is possible to identify subskills in the complex task of SI. We found evidence that lexical retrieval and working memory are associated to SI performance.

The graphical model showed direct links from SI performance to reading span English and to translation into English. This indicates that of the subskills we studied, the efficiency of working memory and retrieval of translation equivalents are the most relevant subskills in SI. Interestingly, there are two (conditionally) independent paths, namely working memory and word translation skills, to SI performance. This means that these subskills separately contribute to SI performance.

The relation between picture naming and SI was mediated by translation; there is no direct effect of picture naming on SI. It seems that, given knowledge about translation performance, individual differences in the efficiency of the processes underlying picture naming performance are not relevant to SI performance. Regarding memory skills, the English version of the reading span task had a direct effect on SI performance, which suggests that working memory capacity in L2 may be more important in constraining processing in SI than capacity in L1, even though average performance on the reading span did not differ for L1 and L2. Secondly, L1 digit span does not seem to capture any short-term memory requirements in SI on top of reading span. The implication of our model is that if we want to predict (L2 into L1) SI performance on the basis of the set of tasks included in this study, we would only need L2 working memory capacity and translation (into L2). The
other tasks do not give any additional information on SI performance. This conclusion is important if we want to use these tasks in a practical setting, for example, to select or train SI students (note that we cannot be sure that our results generalize to L1-L2 interpreting since we only assessed interpretation into L1).

Given the complexity of the SI task, it is noteworthy that all our participants were able to produce at least some output when performing the task. It is likely that on a professional level SI requires particular skills or talents that not everyone possesses to the same degree. However, at a more modest level SI seems to be within reach of reasonably proficient bilinguals untrained in SI, a fact that should be taken into account by current theories on (multilingual) language processing and memory.

Since the participants in this study were untrained in SI we cannot be certain that our findings generalize to professional interpreters. In fact, Neubert (1997) even claimed that untrained, or ‘natural’, translation is distinctly different from professional translation and interpreting. On the other hand, Harris and Sherwood (1978) stated that translation in general is an innate skill and that all bilinguals are able to translate within limits set by their proficiency (see also Malakoff & Hakuta, 1991; Malakoff, 1992). That interpreting skills may come about naturally is suggested by the fact that immigrant children often serve as interpreters for older members of their family (Harris & Sherwood, 1978). Although the literature does not provide a solid base on which to decide whether or not processing by professional interpreters is unique and differs from that of novices in this task, one study, reported by Dillinger (1994), suggests that at least comprehension processes in SI may be qualitatively the same for professionals and novices. The advantage of using, as we did, novices as participants is that this way the role of subskills is assessed without ‘contamination’ of the idiosyncratic strategies that interpreters may have developed (e.g., Shlesinger, 1994).

A final consideration is that our results might be explained by an underlying factor of general language proficiency in English. In other words, one might ask whether differences in general language proficiency generate the individual differences on both SI and the other tasks. The fact that in the model L1 tasks are not directly associated to SI but mediated by L2 may indicate that this is the case. Note, however, that language proficiency is a very general, multi-dimensional concept that involves pronunciation, grammar, vocabulary knowledge, and pragmatics, which can all be mastered at different levels by the L2 user. If one argues that word translation efficiency and English working memory capacity are different aspects of English language proficiency, we have at least still shown that these specific subskills are relevant.

However, there are in fact two findings that argue against the idea that global proficiency differences induce individual differences in performance on all tasks used in this study, including SI. First, the correlational analysis showed that L1 tasks also correlate significantly with SI performance, suggesting that the subskills are also relevant to SI if they are measured in the L1. Moreover, in the graphical model two independent paths are associated with SI performance. That the working memory tasks were separated from the
other tasks means that functional memory capacity in English and translation retrieval skills independently contributed to SI performance. This is a strong indication that not (only) individual differences in general English proficiency fuel the differences in performance on SI.

In future research it will be interesting to assess the role of different aspects of language proficiency and to include bilinguals of different proficiency levels to disentangle the relation between language proficiency and SI performance. It is also important to try to generalize our findings by including professional interpreters as participants. We have shown that efficient word translation and memory skills are important for SI by untrained bilinguals. Of course, other subskills may be relevant too. For example, interpreters have to speak in the target language only, while they are listening source language, which means that both languages have to be activated. It would, therefore, be interesting to assess whether individuals differ in the ability to control multiple languages without apparent interference from one language to another, and whether this ability is indeed related to SI. Also, in SI it would be useful if spoken language comprehension proceeds exceptionally fast. The ability to quickly comprehend discourse and to resolve lexical and other types of input ambiguities may be another relevant subskill in SI (e.g., Christoffels & De Groot, in press, Chapter 2; Gernsbacher & Shlesinger, 1997).