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# Domain-general cognitive abilities and simultaneous interpreting skill

Brooke N. Macnamara, Adam B. Moore, Judy A. Kegl\* and Andrew R. A. Conway  
Princeton University and University of Southern Maine\*

This exploratory study examined domain-general cognitive abilities that may serve as aptitudes for interpreting skill by comparing highly skilled signed language interpreters (those considered competent in most interpreting situations) and less skilled signed language interpreters (those considered less than competent in most interpreting situations) on various measures. Specifically, the current study examined the feasibility of predicting interpreter skill level based only on a variety of cognitive abilities and personality traits. We collected data on several cognitive measures, including processing speed, psychomotor speed, cognitive control and task switching ability, fluid intelligence, working memory capacity, and mental flexibility, as well as several personality measures, including risk-taking orientation and emotion-cognition integration style, and intrinsic motivation to engage in complex cognitive tasks. Significant differences emerged between the two groups on both cognitive and personality measures suggesting that a combination of stable domain-general cognitive abilities and personality traits may be responsible for differentiating highly skilled from less skilled interpreters and may therefore be predictive of individuals' future interpreting effectiveness and skill level.

## Introduction

Simultaneous interpreting (SI) is considered an extremely complex cognitive processing task (Christoffels et al. 2003; Frauenfelder & Schriefers 1997; MacWhinney 1997). Its basic components are similar to the processes engaged during normal monolingual dialogue: listening, comprehending, communication planning, and language production. However, in normal dialogue these processes take place serially, with some overlap of comprehension and utterance planning (Garrod & Pickering 2004). What makes SI so complex is that the interpreter is simultaneously

listening, comprehending, planning, and speaking, and is doing so in two different languages with little to no control over the input rate or content. In addition, the interpreter is alternately activating and suppressing the two languages, and analyzing the speaker's goals, inferences, and subtleties while deciding how to convey the meaning in a second language and culture all in real time.

Throughout the process, the interpreter attends to the incoming message and output while holding information in memory (Cowan 2000; Macnamara 2009: 19–20; Moser 1978; Shlesinger 2003), manages the process and the demands (Christoffels et al. 2003: 202; Macnamara 2009: 18–19), analyzes and reasons (Macnamara 2009: 16; Seal 2004: 49), and makes decisions based on analyses, demands, and abilities (Macnamara 2009: 22–23; Treisman 1965: 369). These information-processing demands are not limited to linguistic tasks alone; ample psychological research has demonstrated that general cognitive abilities have substantial explanatory power across multiple content domains, including working memory capacity (e.g., Daneman & Carpenter 1980; Engle et al. 1991; Kiewra & Benton 1988; Kyllonen & Stephens 1990; Ormrod & Cochran 1988), reasoning ability (e.g., Johnson-Laird 1999: 113; Ree & Earles 1992; Sternberg 1982), and psychomotor speed (e.g., Ackerman 1988; Ownby et al. 2008). These domain-general cognitive abilities are typically assumed to be fairly innate qualities since they are present early in development (e.g., Bayliss et al. 2003; Starkey 1992) and, after adulthood, are relatively stable over time (e.g., Rund 1998: 426–428; Wichertsa et al. 2004; Waters & Caplan 2003). It is therefore reasonable to assume that not only will language and other skill learning predict interpreting performance, but individual differences in these more general cognitive abilities will predict interpreting aptitude as well.

Gerger et al. (1989) studied differences in a variety of discourse processing and verbal abilities between passing and failing interpreter students. Their results indicated that passing interpreter students had better memory for texts, comprehension, and verbal generation. Discourse-processing abilities such as those measured by Gerger et al. are mediated by working memory and more domain-general cognitive skills (Gernsbacher 1990; Just & Carpenter 1992; Kintsch 1988; Kintsch & van Dijk 1978). In other words, domain-general ability can predict performance differences in these language tasks over and above what can be explained by linguistic skill and domain-specific training alone.

Despite the plethora of evidence for the predictive power of domain-general cognitive abilities in psychological research, evidence as to the relationship between these types of measures and interpreting performance has been mixed. In a study of domain-general cognitive abilities with signed language interpreter trainees, López Gómez et al. (2007) found positive correlations between interpreting skill and short-term memory, a confidence-type personality trait, and reasoning

ability. However, other studies have shown that working interpreters demonstrate higher than average reasoning abilities, but that the degree of intelligence did not reliably differentiate the interpreters based on skill (Rudser & Strong 1986; Seal 2004). Similarly, examinations of working memory capacity of interpreters and interpreting students or non-interpreters have shown mixed results. Köpke and Nespoulous (2006) found that interpreter students had larger working memory capacity than expert interpreters, suggesting that interpreting experience is detrimental to working memory capacity while Padilla et al. (1995) and Christoffels et al. (2006) found that interpreters demonstrated higher working memory capacity than non-interpreters, suggesting that interpreting experience is beneficial to working memory capacity.

The discrepancies observed in previous research may be due to several factors. First, the limited nature of the population studied may compromise the comparability of the experimental subjects in the respective studies and/or the statistical analysis may be underpowered to detect meaningful effects. Second, differences that are found between interpreters and non-interpreters in cross-sectional designs could be due either to changes in cognitive ability as a *result* of interpreting experience or self-selection of individuals with certain cognitive abilities into the interpreting field. Third, the tasks used to measure cognitive abilities of interest are not all equally valid or reliable. Fourth, some cognitive abilities/traits will make no difference in one's future interpreting skill; some may relate to interpreting skill only up to a certain point (i.e. the first few months/years of training), while others may still correlate with interpreting performance regardless of experience or training. Finally, and perhaps most importantly, performance in complex real world interaction(s) depends on the interplay of many cognitive abilities, so that even those studies that have measured multiple abilities/traits but only analyzed first-order relationships between each measure and population type or skill level will have missed the interactive contingencies that are certain to exist.

This is a long series of challenges, and no one study can meet them all. Here, we focus centrally on the last point as a first step; through the use of tasks that have excellent psychometric validity and reliability coupled with advanced statistical analysis, we seek to assess which *combination* of general cognitive abilities and emotion-cognition interaction traits predict interpreting expertise. In the United States there is a wide variety of standards for the level of skill required for graduation and professional practice. This set of circumstances surrounding American Sign Language (ASL)-English interpreters allows us to study groups of simultaneous interpreters who have similar SI experience and training, but who vary in SI skill.

We are interested in comparing cognitive abilities of highly skilled and less skilled simultaneous interpreters to determine which combination of cognitive

abilities and personality traits predicts group membership. In other words, if highly skilled interpreters have similar cognitive abilities, which are typically assumed to be stable over time regardless of training or experience, then this combination is likely to predict who will become a highly skilled interpreter. Note: While the interpreters studied in this paper are ASL-English interpreters, we assume that cognitive processes in SI are largely similar regardless of language modality. Unless specifically noted, the authors are interpreting the measurements used in this paper as applicable to all simultaneous interpreters.

Descriptive cognitive process models illustrating the complexity of SI began to appear in the 1970s (e.g., Gerver 1976). As both cognitive psychology and SI research emerged, our understanding of the specific cognitive mechanisms engaged during SI developed (cf. e.g. Moser 1978) and today we can reasonably argue for the involvement of several key cognitive processing abilities and personality traits known to impact the constituent processes of SI. This paper specifically addresses the following cognitive processing abilities: reasoning, working memory capacity, processing speed, cognitive control, psychomotor speed, and mental flexibility.

Reasoning is essential for linguistic, environmental, and affective analysis of the source message for comprehension and prediction (Cokely 1992; Colonomos 1997, 2008; Macnamara 2009; Moser 1978) as well as planning the target message output (Cokely 1992; Colonomos 1997, 2008; Macnamara 2009).

Working memory is the simultaneous storage and processing of information in the short term, often when the information being operated upon is different than that which must be stored. Working memory capacity, one's limit of information that can be stored while simultaneously carrying out a processing task, is positively correlated with language comprehension (Daneman & Carpenter 1980) and discourse processing ability (Just & Carpenter 1992; Kintsch 1988; Kintsch & van Dijk 1978; Gernsbacher 1990), essential components of SI. In addition to language processing, working memory is also critically involved in real-time problem-solving, reasoning, and planning, as well as manipulating or transforming incoming information — all of them abilities certainly needed during SI.

Simultaneous interpreting demands that information be processed rapidly. High working memory capacity and robust reasoning ability are not useful to interpreters if they cannot process the incoming information and execute decisions at a rate faster than or consistent with the incoming information. In addition, information that is quickly processed, and no longer held in the focus of attention, allows more attentional capacity (Moser 1978).

Psychomotor speed and accuracy, or perceptual-motor coordination, allows signed language interpreters to produce the target message, when interpreting into the signed language, with precision. Psychomotor skill is also involved in physical mimicry, playing a role in learning and producing manual signs (López Gómez et

al. 2007). Psychomotor skill is assumed to be applicable only to signed language interpreters as opposed to both spoken and signed language interpreters (López Gómez et al. 2007).

During SI, the interpreter rapidly switches among subcomponents of interpreting: comprehending the source message, determining meaning equivalences, planning the production, and producing the target message (Cokely 1992; Colonomos 1997; Moser 1978). Cognitive control is engaged in order to switch among tasks and to manage task execution effectively (Monsell 2003).

Interpreting is a practice profession. Practice professions (e.g. medicine, teaching, counseling, law, and investigation) require technical knowledge and skills, but perhaps more importantly, they require assessments of ever-changing situational and human interaction factors that impact how the technical knowledge and skills should be implemented in each situation (Dean & Pollard 2005). Interpreters cannot perfectly predict the incoming message and will rarely interpret the same source message more than once. Decisions made while interpreting are adjusted for constantly changing situations as a function of this indeterminism. Interpreters rely on adaptive responses when handling the incoming message and other human interaction factors. One's capacity to adaptively coordinate actions in relation to others' actions in interpreting relies on mental flexibility, the final cognitive ability measured in this paper.

Cognitive abilities do not exist in a vacuum. This paper therefore also considers specific personality traits known to impact cognitive processing: willingness to engage in complex cognitive tasks, reward sensitivity, and risk sensitivity. We hypothesize that because SI is a complex cognitive task, certain cognitive abilities are necessary to successfully perform it. However, one's willingness to engage in such a complex cognitive task will also affect the amount of effort undertaken. Willingness to employ mental resources during the task affects performance and thus interacts with other cognitive abilities (Cacioppo & Petty 1982).

In addition to their willingness to engage in cognitive tasks, individuals vary in their motivation to engage cognitive control and make decisions based on sensitivities to the potential outcomes. To this end, individuals vary in their sensitivity to reward and risk (e.g., Gray 1982, 1987; Lopes 1987; Schneider & Lopes 1986). Individuals' sensitivity to reward motivates behavior toward subjectively positive outcomes, and increases the likelihood of decisions designed to approach desirable goals (Gray 1982).

Individuals with high risk sensitivity, on the other hand, experience anxiety when presented with potential threat, non-reward, or novelty and will structure their behavior around avoiding risk of aversive outcomes, as opposed to achieving positive outcomes (Gray 1982, 1987, 1990). Individuals with high anxiety will experience reduced working memory capacity (Eysenck 1979, 1985; Leon &

Revelle 1985; Schmader & Johns 2003; Wine 1971) and are likelier to respond more quickly to stimuli and produce more errors (Leon & Revelle 1985). SI demands that interpreters process novel, unrehearsed stimuli and adjust processing time (aka ear-voice span) based on the incoming message and interpreting abilities. An interpreter's risk sensitivity may therefore affect how she or he responds to the incoming stimuli and subsequent cognitive processing.

We have described several cognitive abilities that we believe are relevant to spoken and signed language simultaneous interpreters: reasoning, working memory capacity, processing speed, cognitive control, task switching, and mental flexibility; and one cognitive ability relevant to signed language interpreters only: psychomotor speed. We have also described personality traits that interact with cognitive abilities that we believe to be relevant to both spoken and signed language simultaneous interpreters: need for cognition, reward sensitivity, and risk sensitivity. The issue addressed in this paper is not whether these cognitive abilities and emotion-cognition interaction traits are engaged during interpreting, but whether they can predict expertise in SI and, if so, what combination of these traits best differentiates skill level.

## Method

### *Participants*

Twenty-nine ASL-English interpreters from two diverse locations in the United States participated in the study. Ages ranged from 20 to 60 ( $M=42$ ,  $SD=12$ ). Interpreting experience ranged from 6 months to 35 years ( $M=11$ ,  $SD=11$ ). Participants were not recruited on the basis of age or years of professional experience. Participants had similar interpreting training.

### *Rating*

Five raters were used to classify interpreters based on general interpreting competency. The raters were ASL-English interpreters who were familiar with the simultaneous interpreting work of the participants in a variety of settings within the prior year, and with a variety of consumers. These observations were the basis of their ratings. While participants did not undergo a standardized laboratory-based competency exam, the multiple real-life observations along with the extremely high inter-rater reliability (discussed later in this section) suggest that this method has high ecological validity. All of the raters also had previous interpreter rater/evaluation training.



Competency was defined as performing well in skill-based aspects of the interpreting process including comprehension, language production,<sup>1</sup> message equivalence, and the ability to perform flexibly along the interpreting-transliterating continuum depending on the appropriateness to the situation. Transliterating, retaining the word order and syntax of the source language while producing target language words, is preferred by some Deaf persons and may be understood to various degrees by others. Many signed language interpreters provide transliterating services even when interpreting service is necessary for monolingual ASL-using Deaf individuals. Therefore, some of the participants who work competently in many situations as transliterators were not placed in the highly skilled group if they did not exhibit competence to interpret into sign following ASL grammar.<sup>2</sup> Interpreters were not rated on ethical behavior, maturity, attitude toward consumers or colleagues, or other professional behavior.

The raters scored the interpreters on a three-point scale as (1) highly skilled, (2) somewhat skilled, and (3) less skilled. The two raters for the first location had very high inter-rater reliability, Cronbach's  $\alpha = .978$ . Rater 1-1 was not familiar with two participants' interpreting skill and Rater 2-1 was not familiar with two other participants' interpreting skill. Because the inter-rater reliability was highly correlated between the two raters, the rating from the familiar rater was accepted. The three raters for the second location also had very high inter-rater reliability, Cronbach's  $\alpha = .958$ . While the first two raters at the second location had very high inter-rater reliability, Rater 1-2 and Rater 2-2 Cronbach's  $\alpha = .935$ , both raters were unfamiliar with one participant's interpreting skill. A third rater was secured who was familiar with the skill level of the participant in question. The third rater demonstrated high inter-rater reliability with both the other raters, Cronbach's  $\alpha = .935$  and 1.0, respectively. The third rater's rating of the participant in question was accepted.

Since there were only two cases in which a rater rated a participant as somewhat skilled (the only two in which raters differed), and since inter-rater reliability was extremely high, the rating of the other rater was accepted. For the first instance in the first location, the participant was rated by one rater as in-between the two skill groups and by the second rater as less skilled — and was placed in the less skilled group. For the second case in the second location, one rater rated the participant as in-between the two skill groups. The other two raters rated the

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1. Language skills were rated as an aspect of interpreting skills. Language ability is strongly correlated with interpreting ability (e.g., Padilla et al. 1995).

2. Interestingly, not exhibiting competence to interpret into sign following ASL grammar is not necessarily a language ineptitude. Many transliterators can produce accurate ASL in conversation, but not while interpreting, suggesting a cognitive or emotion-cognition interaction trait may be responsible for this discrepancy.

participant as less skilled and the participant was placed in the less skilled group. Due to the generally dichotomous ratings, as participants were generally rated as either highly skilled or less skilled and the few instances of *somewhat skilled* ratings were the only ones not agreed upon, the middle group was removed and the two groups were termed *highly skilled* and *less skilled*. There were no instances of polar classifications (one rater placing a participant in the less skilled group and another placing the same participant in the highly skilled group).

The highly skilled group consisted of 15 interpreters and the less skilled group consisted of 14 interpreters. There were no significant differences between the two groups in age (highly skilled group  $M = 42$ ,  $SD = 13$ ; less skilled group  $M = 42$ ,  $SD = 10$ ) or years of professional interpreting experience (highly skilled group  $M = 12$ ,  $SD = 11$ , less skilled group  $M = 10$ ,  $SD = 10$ ), both  $F_s < 1$ .

At first, the lack of correlation between years of experience and rated skill appears counter-intuitive. Expertise research assumes that experts, individuals who consistently perform superiorly to the majority of practitioners, have accumulated over ten years of domain-specific experience (e.g., Chi et al. 1988; Hoffman 1992; Simon & Chase 1973). Experience alone, however, does not necessarily make an expert (Ericsson et al. 1993) since it is not a good predictor of proficiency (Ericsson et al. 1993; McDaniel et al. 1988). This appears especially true for professions and skills that require adaptation based on human interaction factors, which have the lowest correlations between proficiency and years of experience after the first couple of years.<sup>3</sup> (For review see Ericsson et al. 1993.)

### Measurements

Seven cognitive ability measurements and three emotion-cognition interaction measurements (specific personality dimensions) were administered to participants. (See Table 1 for a summary of the measurements.) The seven cognitive ability measurements were the Raven's Advanced Progressive Matrices (Raven 1962), Connections Tests (Salthouse et al. 2000), Letter Comparison (Salthouse & Babcock 1991), Pattern Comparison (Salthouse & Babcock 1991), Symmetry Span task (Unsworth et al. 2005) and a computerized version of the Wisconsin Card Sorting Test (Grant & Berg 1948). The emotion-cognition interaction measurements were the Behavioral Inhibition System/Behavioral Approach System (BIS/BAS) scales (Carver & White 1994) and the Need for Cognition scale (Cacioppo & Petty 1982). All measurements used in this study are psychometrically sound and are common measurements for their respective abilities/traits.

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3. If the interpreter had less than two years of experience, the raters were asked to rate skill relative to experience.

**Table 1.** Measurements

Task	Ability/Trait Measured
	<i>Cognitive abilities</i>
Ravens	fluid intelligence; reasoning
Symmetry Span	working memory capacity
Letter Comparison	cognitive processing speed
Pattern Comparison	cognitive processing speed
Connections A	psychomotor speed
Connections B	psychomotor speed; cognitive control; task switching
WCST	mental flexibility
	<i>Emotion-cognition interaction (personality) traits</i>
Need for Cognition scale	willingness to engage in complex cognitive tasks
BAS scale	sensitivity to reward
BIS scale	sensitivity to risk

*Note.* Ravens = Ravens Advanced Progressive Matrices. WCST = Wisconsin Card Sorting Test. BAS = Behavioral Approach System. BIS = Behavioral Inhibition System.

### *Cognitive Ability Measurements*

#### *Raven's Advance Progressive Matrices*

Raven's Advanced Progressive Matrices (referred to simply as "Ravens" in this paper) is a multiple-choice abstract reasoning test designed to measure general fluid intelligence and reasoning in above-average intelligence individuals. Problems consist of a 3 X 3 matrix where each element is a pattern that shares some features with adjacent elements. The lower right element is missing, and participants are asked to choose which of the available choices best completes the pattern. Participants had ten minutes to complete as many of the 18 increasingly difficult matrices as possible. (We used the odd problems only. Previous research has shown the odd-even split-half corrected reliability coefficient is .96 [Burke 1972:253].) Individuals who score high on the Ravens are better able to educe meaning in abstract patterns, think clearly, and reason than those who score low on the test.

#### *Symmetry Span*

Symmetry Span is one of several "complex span tasks" that measure working memory capacity by measuring item recall in the face of interference. Complex span tasks are commonly used to measure working memory capacity. Participants are tasked with performing the processing components of the task as well as retaining as many of the memoranda as possible. In symmetry span, participants make judgments about the symmetry of abstract figures along the vertical axis that are

interleaved with the presentation of a colored square on a 4 X 4 grid. Participants are tasked with remembering the position of the colored squares. After the 3–7 symmetry decision and colored square presentation trials, participants recall the position of the 3–7 colored squares in sequence. Individuals who score high on symmetry span have higher working memory capacity than those who score low on the task.

### *Letter Comparison*

The Letter Comparison task assesses cognitive processing speed by measuring perceptual and decision-making speed through comparison of orthographic patterns. Participants are presented with 8½ X 11-inch pages with pairs of non-lexical letter strings. Participants must compare the two items in the pair and mark whether they are the same or different. They complete as many pairs as possible in 30 seconds (per page). Two pages with different figures/letters are presented for each condition. Scores are calculated based on the number of correct decisions minus the number of uncorrected errors.

### *Pattern Comparison*

The Pattern Comparison task is exactly the same as the Letter Comparison task except for the actual stimuli. Instead of non-lexical letter strings, Pattern Comparison uses abstract visual figures.

### *Connections Test A*

Connections A measures psychomotor speed with two conditions: numbers and letters. Participants are presented with 8½ X 11-inch pages with numbers or letters in circles. Participants connect the numbers or letters in sequence with a pen. The numbers or letters are not presented on the page in sequence, but a sequential letter or number is always adjacent (in any direction) to the former letter or number. Participants are allowed 20 seconds per page. Scores are based on the quantity of accurate connections minus the number of uncorrected errors, and reflect psychomotor speed ability.

### *Connections B*

Connections B measures cognitive control, task switching, and psychomotor speed. Participants are presented with materials similar to those in Connections A, but must connect numbers *and* letters in alternating sequence. Connections B has two conditions: numbers-letters in which the sequence begins with a number (i.e. 1 ⇒ A ⇒ 2 ⇒ B ⇒ 3 ⇒ C, etc.) and letters-numbers in which the sequence begins with a letter (i.e. A ⇒ 1 ⇒ B ⇒ 2 ⇒ C ⇒ 3, etc.). Scoring and time allowances for Connections A and B are the same. Individuals who score high on

Connections B exhibit more robust and faster task switching abilities, more efficacious cognitive control, and faster psychomotor speed than those who score low on Connections B.

### *Wisconsin Card Sorting Test*

The Wisconsin Card Sorting Test (WCST) measures set-shifting and mental flexibility. Set-shifting is the ability to adapt to changes and to shift among different sets of rules. Participants view the images of four decks of cards face-up on the screen and are asked to sort new cards into one of the four piles based on either the color, the number, or the shape of the symbol(s) on the card. Participants are not informed of the correct sorting rule, but are informed after each decision whether the sort choice was correct or incorrect. They must then infer the sorting rule from the feedback provided. Without warning, the rule will be changed during this task and the participants must discard the old rule and infer a new one based on the relevant symbol dimension. Individuals who score high on the WCST (based on percentage of correct sorts) are more able to flexibly adapt to changing reinforcement than those who score low on the test.

### *Emotion-Cognition Interaction Measurements*

#### *BAS*

The BAS scale measures reward sensitivity, drive, and fun-seeking traits. BAS reflects approach orientation, as when the goal is to move toward something desired. Individuals who score high on the BAS scale are more sensitive to positive rewards and personal enjoyment, and are more likely to actively pursue activities that yield such rewards than are those who score low on the scale. The BAS scale is an individual differences assessment. Participants respond on paper to a series of statements with a Likert-type scale, choosing whether each statement is “very true for me”, “somewhat true for me”, “somewhat false for me”, or “very false for me.”

#### *BIS*

The BIS scale measures risk-taking sensitivity and anxiety surrounding aversive stimuli and novelty. It is interleaved with the BAS scale.<sup>4</sup> Participants respond to BIS scale statements exactly as they respond to BAS scale statements.

### *Need for Cognition Scale*

The Need for Cognition scale measures an individual’s intrinsic motivation to engage in complex, cognitively demanding tasks. Participants respond on paper to a

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4. BIS sensitivity and BAS sensitivity are orthogonal.

series of statements with a Likert-type scale, choosing whether in their view each statement is “completely true”, “mostly true”, “mostly false”, or “completely false.”

### *Procedure*

Everyone was tested individually for approximately one hour and ten minutes and was paid for participation. Participants were administered the tasks in the following order: (1) BIS/BAS scales, (2) Need for Cognition scale, (3) Letter Comparison, (4) Pattern Comparison, (5) Connections Tests (A and B alternated, the standard procedure for administering the Connections Tests), (6) the Ravens, (7) Symmetry Span, and (8) the Wisconsin Card Sorting Test.

## **Results and discussion**

### *Univariate analyses*

Prior to statistical analysis, all measurement scores were examined for accuracy of data entry, missing values, and normality of distribution. Missing values occurred for two subjects for the questionnaires (BIS/BAS scales and the Need for Cognition scale) and one subject for the WCST (due to timing issues during data collection.) The values were not replaced. There were no univariate outliers and all distributions were normal. (See Table 2 for descriptive statistics.)

One-way analyses of variance (ANOVAs) were conducted for each of the measurements prior to multivariate analyses. The ANOVAs revealed that

**Table 2.** Descriptive statistics ( $N=29$ )

Measurements	Less skilled ( $n=14$ )		Highly skilled ( $n=15$ )	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
BIS	23.15	3.76	20.46	2.21
BAS	13.61	1.53	13.46	1.84
Need for Cognition	66.54	11.50	69.46	8.81
Connections A	28.63	5.78	33.65	6.04
Connections B	14.02	5.53	18.09	3.36
Pattern Comparison	.62	.13	.72	.14
Letter Comparison	.51	.10	.56	.10
Ravens	8.00	2.77	8.67	3.09
Symmetry Span	.54	.18	.61	.10
WCST	68.85	12.12	76.92	9.06

Table 3. Cohen's *d* effect sizes

Measurement	Effect Size <i>d</i>	Relative size	% Standing	% of Non-overlap
Connections B	.93	> Large	82	51.6
BIS	.92	> Large	82 (LS)	51.6
Connections A	.88	> Large	82	51.6
WCST	.79	Large	79	47.4
Pattern Comparison	.77	Large	79	47.4
Letter Comparison	.52	Medium	69	33.0
Symmetry Span	.50	Medium	69	33.0
Need for Cognition	.30	> Small	62	21.3
Ravens	.24	Small	58	14.7
BAS	.09	< Small	54 (LS)	7.7

Note. "% Standing" indicates the average percentile standing of the highly skilled interpreters relative to the less skilled interpreters (highly skilled interpreters scoring higher than less skilled interpreters) unless otherwise noted as "(LS)", in which case the less skilled interpreters scored higher than the highly skilled interpreters and the "% Standing" then refers to the average percentile standing of the less skilled interpreters relative to the highly skilled interpreter. "Relative size" is based on common interpretations of the magnitude of the effect size. "Percent of non-overlap" refers to the percent of the distributions of the two groups that do not overlap and is a way to view how different the two groups are. Relative size, percentile standing, and percent of non-overlap are based on *d* rounded to the tenth decimal.

Connections A scores,  $F(1, 27) = 5.170$ ,  $p = .031$ ,  $\eta^2 = .161$  and Connections B scores,  $F(1, 27) = 5.844$ ,  $p = .023$ ,  $\eta^2 = .178$  were significantly different between the two groups with highly skilled interpreters scoring higher. ANOVAs also revealed that BIS scores,  $F(1, 24) = 3.733$ ,  $p = .065$ ,  $\eta^2 = .135$ ; Pattern Comparison scores,  $F(1, 27) = 3.642$ ,  $p = .067$ ,  $\eta^2 = .119$ ; and WCST scores,  $F(1, 27) = 3.194$ ,  $p = .085$ ,  $\eta^2 = .106$  were marginally significant with highly skilled interpreters scoring higher for Pattern Comparison and WCST and scoring lower on the BIS scale. No other measurements were significant ( $ps > .10$ ).

The results of the ANOVAs suggest that faster psychomotor speed (Connections A), stronger cognitive control and task switching (Connections B), increased willingness to take risks (less inhibition surrounding risk-taking) (BIS), faster cognitive processing speed (Pattern Comparison), and more mental flexibility (WCST), are important for differentiating highly skilled and less skilled interpreters. To further explore effect sizes of the ten measurements, Cohen's *d*s were calculated (see Table 3). Cohen's *d* is a ratio: it is the difference between two group means relative to the pooled standard deviation of the two groups. Thus, a Cohen's *d* of 1.0 means that one group is an entire standard deviation greater than the other.

The Cohen's *d* effect sizes corroborate the ANOVAs by demonstrating that the five predictors which the ANOVAs revealed as significant and marginally

significant have the largest effect sizes. While being partially redundant, exhibiting all the effect sizes regardless of an arbitrary  $p < .05$  cut-off reveals the range of effects and can provide insight as to which measurements are the most appropriate to use for future studies and which ones may be the most fruitful in further analyses. Specifically, the five measurements with the largest effect sizes are likely to reveal significant effects in a future higher-powered study and in multivariate analyses of the current data, which we turn to next.

### *Multivariate analyses*

ANOVAs reveal differences between groups along a single dimension without taking into account other factors. Analyzing complex data sets in this manner can cause researchers to miss effects from contributing factors working in tandem with the variables being parceled out for univariate analysis. Discriminant function analysis reveals the best linear *combination* of predictors that differentiate two groups. Discriminant function analysis is similar to binary logistic regression, but is more powerful and efficient (Tabachnick & Fidell 2007: 441) and provides more accurate classifications and hypothesis testing as long as statistical assumptions are held (Grimm & Yarnold 1995: 241).

Prior to analysis, the cases were analyzed for multivariate outliers. Mahalanobis distance indicated two (one from each skill-level group) multivariate outliers ( $z$ -scores  $> 3.0$ ). The two outliers were removed. Cases with missing values were also removed when measurements with the missing values were entered into the analyses in keeping with the requirement for discriminant function analysis. With the removal of the two multivariate outliers as well as cases with missing values, and with no more predictors (number of measurements entered into the analysis) than cases in the smallest group, the statistical assumptions underlying discriminant function analysis were met, leaving 89 percent of the cases available for analysis.

Discriminant function analysis creates statistical models in order to predict group membership from a set of predictors (also known as classifiers). Various combinations of predictors were evaluated. A successful statistical model was revealed, Wilks' Lambda = .551,  $\chi^2(5) = 11.616$ ,  $p = .040$ , correctly classified cases = 83.3% (see Table 4). As predicted, the measurements with the largest effect sizes created the significant discriminant function model: Connections A, BIS, Connections B, Pattern Comparison, and WCST.

Structure coefficients are the correlations of each classifier to the discriminant functions (similar to factor loadings in factor analysis). The structure coefficients are used to assign meaningful labels to the discriminant functions. The structure matrix revealed the following coefficients: Connections B = .659, Connections A = .506, WCST = .370, Pattern Comparison = .352, and BIS = -.193. Since the highly



**Table 4.** Discriminant Function Analysis classification results

<b>Count</b>			
<b>Actual Group</b>	<b>Predicted Group Membership</b>		<b>Correct Classifications</b>
	<b>Highly skilled</b>	<b>Less skilled</b>	
Highly skilled	10	3	10/13
Less skilled	1	10	10/11
Total			20/24
<b>Percentage</b>			
<b>Actual Group</b>	<b>Predicted Group Membership</b>		<b>Correct Classifications</b>
	<b>Highly skilled</b>	<b>Less skilled</b>	
Highly skilled	76.9	23.1	76.9
Less skilled	9.1	90.9	90.9
Total			83.3

skilled group served as the reference group, positive coefficients indicate the positive correlation of scores from the highly skilled group to the discriminant functions while negative coefficients indicate the negative correlation of scores from the highly skilled group to the discriminant functions. In other words, the higher an individual scored on Connections B, Connections A, WCST, and Pattern Comparison and the lower the score on BIS, the more the scores correlated to the discriminant functions and the likelier the model was to predict that the individual belonged in the highly skilled group. The following discriminant function labels were created from the result of the structure coefficient matrix: task switching ability (Connections B), psychomotor speed (Connections A), mental flexibility (WCST), cognitive processing speed (Pattern Comparison), and aversion to risk (BIS).

The standardized canonical discriminant function coefficients indicate the unique contribution of each classifier to the discriminant functions and are used to determine the relative importance of the classifiers in predicting group membership (similar to beta weights in multiple regression). Mental flexibility (.634) is the most important predictor relative to the other entered classifiers followed by cognitive processing speed (.612), aversion to risk (-.520), task switching ability (.513) and, substantially less important, psychomotor speed (.220). See Table 5 for a summary of the coefficients.

To further establish the validity of the classification, a permutation test was conducted. This examines the possibility that the discriminant function solution does not capture something fundamentally different between these groups, but is simply a brute-force mathematical solution for separating cases into groups,

**Table 5.** Structure Coefficients and Standardized Canonical Discriminant Function Coefficients

Measurement	SC	Label	Importance (SCDFC)
WCST	.370	Mental Flexibility	.634
Pattern Comparison	.352	Cognitive Processing Speed	.612
BIS	-.193	Sensitivity to Risk	-.520
Connections B	.659	Task Switching Ability	.513
Connections A	.506	Psychomotor Speed	.220

*Note.* SC = Structure Coefficient, Label = the structure coefficients' corresponding factor labels, SCDFC = Standardized Canonical Discriminant Function Coefficients. The SCDFCs indicate relative importance. Wilks' Lambda = .551,  $\chi^2(5) = 11.616$ ,  $p = .040$ .

regardless of what those groups might be. Put differently, the permutation test assumes that discriminant function analysis will find a solution predicting group membership for any arbitrary groups. To carry out this test, group membership is randomly reassigned for all the cases and the discriminant function analysis re-conducted with the original predictors. If this produces a statistically significant classification, then the original result is undermined and the discriminant function analysis has not captured true empirical differences between these groups. However, if the discriminant function analysis is unable to produce a significant classification of the permuted data, then the original result does reflect true differences between these groups in the indicated abilities. Discriminant function analysis was performed using the same five predictors with the cases now randomly assigned to the less skilled group and the highly skilled group. The results were not significant, Wilks' Lambda = .744,  $\chi^2(5) = 5.766$ ,  $p = .330$ , indicating that the original discriminant function analysis model was, in fact, tracking true and important differences between highly skilled interpreters and those of lower skill level.

### *Discussion*

The results from the ANOVAs, effect sizes, and discriminant function analysis clearly and strongly suggest that highly skilled interpreters are more mentally flexible, have faster cognitive processing speed, are less anxious about risks, are faster and more accurate when task switching, and have faster psychomotor speed than less skilled interpreters, regardless of the fact that both groups have the same amount of professional experience. Additionally, results from the multivariate analysis indicate that mental flexibility and cognitive processing speed are the most important predictors closely followed by willingness to take risks and task switching ability and, to some extent, psychomotor speed. These five predictors

were all significant and relatively powerful individual predictors, and together were the only combination of predictors to significantly and successfully predict group membership. The convergence of all the analytical results supports the hypothesis that certain domain-general cognitive abilities and emotional-cognitive interaction traits are strongly related to simultaneous interpreting performance.

Additionally, two other measures, Letter Comparison and Symmetry Span, exhibited medium effect sizes, but were not statistically significant predictors, given the current sample size. These results, however, imply that variations of the tasks measuring the same or similar constructs may contribute significantly in a future study with higher power. (A variant of Letter Comparison, Pattern Comparison, already provided significant statistical results in the current study.)

The medium effect size demonstrated by Symmetry Span suggests that working memory capacity differences may be predictive of interpreter skill level, but further studies should explore various tools that better capture the processing and storage capacities needed during simultaneous interpreting. Oberauer (2004) defines three distinct types of working memory capacity measurements that load onto a single working memory factor. They are (1) tasks that measure storage of briefly presented material concurrent with interfering processing, (2) formation of new structures and relationships, and (3) some executive functioning, such as updating. Symmetry Span primarily taps the first factor. SI, on the other hand, engages complex and simultaneous storage and processing demands along with concurrent and continuous context-based restructuring. Therefore, future studies utilizing working memory measures of updating and restructuring ability are likely to prove more auspicious when assessing variation among interpreters or students of interpreting than the measurement used in the current study. Indeed, the current results identify several psychological constructs for which multiple measures have been developed. In future work with substantially larger sample sizes a factor-analytic or structural equation modeling approach would potentially provide much greater resolution on the issue of exactly which abilities and traits combine, and in what fashion, to predict SI performance. Furthermore, such techniques are naturally suited to address issues of causality, provided that the relevant longitudinal data are available.

## General discussion and future directions

As depicted in Table 4, by using a combination of domain-general cognitive abilities and personality traits, the current study was able to correctly classify 76.9% of the highly skilled interpreters and 90.9% of the less skilled interpreters, for an overall cross-validated accuracy of 83.3%. Among the several constructs tested,

mental flexibility, cognitive processing speed, task switching ability, psychomotor speed, and aversion to risk appear to be important in differentiating interpreters with a high level of SI skill from those with a low level of SI skill.

Because this study was unbiased by years of experience or age and because the cognitive constructs measured are generally stable, the results beg the question as to whether these traits and abilities may be reliable predictors of future interpreting skill levels prior to experience or training. Specifically, our results suggest that, particularly in combination, high levels of mental flexibility, cognitive processing and psychomotor speed, task switching ability, a low level of risk sensitivity, and possibly working memory capacity increase the likelihood that one will be a highly skilled interpreter.

As mentioned above, other cognitive mechanisms are likely to be crucial during the learning process that may be less relevant to differences in levels of performance after extensive experience. For example, individuals with low fluid intelligence or little willingness to engage in complex cognitive tasks may be less likely to complete an interpreter training program and so were not included here. Fluid intelligence and willingness to engage in complex cognition may therefore be predictive constructs for successful interpreting during the learning phase. Measures predictive of learning *and* performance should therefore be administered in any future longitudinal study.

The constructs measured in this study are unlikely to be the only abilities and traits predictive of interpreting learning and skill. Further studies are needed to explore other aptitudes such as executive functions (e.g. planning, updating, and selection and inhibition of irrelevant stimuli); social interaction abilities (e.g. boundary balancing, attitude, and ethical reasoning); meta-cognitive abilities (e.g. performance monitoring, internal-state monitoring, audience monitoring, and speaker meaning, speaker goal-state, and speaker-state monitoring); and learning ability (e.g. second language learning aptitude, general knowledge learning aptitude [crystallized intelligence], and skill acquisition aptitude). This complex constellation of candidate predictors reinforces the appeal of a structural equation modeling (SEM) approach for both larger sample cross-sectional follow-up studies as well as longitudinal investigations. SEM techniques would reduce the dimensionality of the predictive problem to a few central psychological constructs that could potentially explain the trajectory of learning as well as 'ultimate' performance after experience.

The relatively high predictive success rate of the current analysis coupled with the general stability of the identified measures over time suggest that domain-general cognitive abilities may also be good predictors of interpreting skill before one has received interpreter training. Further research is needed to evaluate this possibility. However, pending the results of such a study, one can envision the

development of an aptitude test that includes the measurement of abilities and traits that takes advantage of the readily available methods of measuring the abilities and traits identified here. If there is an extension from the current post-training classification to pre-training identification of those individuals most likely to succeed as interpreters, then such an aptitude battery could potentially further enhance the predictive power of admission tests, increasing the likelihood that each accepted student later becomes a highly skilled interpreter.

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