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# A bilingual disadvantage in metacognitive processing

Tomas Folke [a,*,1], Julia Ouzia [b,*,1], Peter Bright [b], Benedetto De Martino [a], Roberto Filippi [b,c]

[a] University of Cambridge, Department of Psychology, Downing Street, Cambridge CB2 3EB, United Kingdom
[b] Anglia Ruskin University, Department of Psychology, East Road, Cambridge CB1 1PT, United Kingdom
[c] Developmental Neurocognition Lab, Birkbeck, University of London, Malet Street, London WC1E 7HX, United Kingdom

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ABSTRACT

Recent research indicating that bilingualism is associated with enhanced executive function suggests that this enhancement may operate within a broader spectrum of cognitive abilities than previously thought (e.g., Stocco & Prat, 2014). In this study, we focus on metacognition or the ability to evaluate one's own cognitive performance (Flavell, 1979). Over the course of two experiments, we presented young healthy adult monolinguals and bilinguals with a perceptual two-alternative-forced-choice task followed by confidence judgements. Results from both experiments indicated that bilingual participants showed a disadvantage in metacognitive efficiency, determined through the calculation of Mratio (Maniscalco & Lau, 2014). Our findings provide novel insight into the potential differences in bilingual and monolingual cognition, which may indicate a bilingual disadvantage. Results are discussed with reference to the balance of advantages versus disadvantages associated with multilanguage learning.



## 1. Introduction

### 1.1. Bilingual cognition

Previous research has found bilingual children and adults to outperform their monolingual peers on tasks requiring the inhibition of irrelevant information (e.g., Bialystok, Craik, Klein, & Viswanathan, 2004; Martin-Rhee & Bialystok, 2008), shifting from one set of information to another (e.g., Bialystok, 1999; Bialystok & Martin, 2004), as well as updating information in working memory on tasks with high processing demands (Bialystok et al., 2004; Carlson & Meltzoff, 2008). The bilingual advantage in executive function has been associated with a range of bilingual experiences, cross-culturally, and across the lifespan (Bialystok & Viswanathan, 2009; Bialystok et al., 2004) consistent with claims that both languages of bilingual individuals are concurrently active at all times, even in unilingual contexts (Dijkstra, Timmermans, & Schriefers, 2000; Dijkstra & Van Heuven, 1998, 2002; Van Hell & Dijkstra, 2002). Therefore, for a bilingual speaker, active suppression of the non-target language may be required (Green, 1986, 1998; though note the alternative explanation of semantic facilitation discussed in Costa, 2005; Costa & Caramazza, 1999; Mahon, Costa, Peterson, Vargas, & Caramazza, 2007) as well as shifting mechanisms (Green & Abutalebi, 2013). As a result of this continuing inhibitory demand, bilingualism is thought to 'train the brain' and enhance executive function beyond the domain of language (Abutalebi & Green, 2007; Hernandez, Bates, & Avila, 1996; Mechelli et al., 2004; Stocco, Yamasaki, Natalenko, & Prat, 2014).

Recently, the 'bilingual advantage hypothesis' has been challenged by reports of no significant group differences or methodological issues (Paap & Greenberg, 2013; Paap, Johnson, & Sawi, 2014; Paap, Sawi, Dalibar, Darrow, & Johnson, 2014) including bias towards the publication of confirmatory findings (de Bruin, Treccani, & Della Sala, 2015). According to the work of Paap and colleagues, as well as others (e.g., Duñabeitia et al., 2014; Gathercole et al., 2014; Morton & Harper, 2007), there are no empirical grounds to believe that bilingualism is associated with enhanced executive function.

Broader approaches to bilingual cognition have provided important insights. For example, recent research suggests that bilingualism is associated with advantages in monitoring visual conflict (Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009; Costa, Hernández, & Sebastián-Gallés, 2008), speed of rule-based learning (Stocco & Prat, 2014), Theory of Mind (Rubio-Fernández & Glucksberg, 2012), exercising perceptual-level rather than response-level inhibition (Blumenfeld & Marian, 2014), adjusting

* Corresponding authors at: University of Cambridge, Department of Psychology, Brain Decision Modeling Laboratory, Downing Street, Cambridge CB2 3EB, United Kingdom (T. Folke). Anglia Ruskin University, Department of Psychology, Faculty of Science & Technology, East Road, Cambridge CB1 1PT, United Kingdom (J. Ouzia).

*E-mail addresses:* tomas.folke@gmail.com (T. Folke), jouzia@gmail.com (J. Ouzia).

[1] The first two authors share first authorship. Placement on the manuscript was determined by alphabetical order.

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proactive and reactive control (Morales, Gómez-Ariza, & Bajo, 2013), and controlling verbal interference during speech comprehension (Filippi, Leech, Thomas, Green, & Dick, 2012; Filippi et al., 2015). Overall, it appears that research successfully demonstrates a bilingual advantage using paradigms that require the use of multiple components of executive functioning, rather than inhibitory control in particular.

One area of interest that has not, to date, received attention in the literature is whether metacognitive processes are affected through the development of additional linguistic skills (i.e., second or multiple language learning). Past bilingualism research has addressed metalinguistic awareness as well as metacognitive reading strategies in children (García, Jiménez, & Pearson, 1998). However, to our knowledge there have been no attempts reported in the literature to evaluate general metacognitive abilities in bilingual individuals.

### 1.2. Metacognition

Metacognition is the ability to evaluate one's own cognitive processes, or, more informally, to have 'thoughts about thoughts' (Fernandez-Duque, Baird, & Posner, 2000; Flavell, 1979; Fleming, Ryu, Golfinos, & Blackmon, 2014). On a theoretical level, this is often modelled as a two-level system, with an object level, first order process, and a meta level, second order process (Nelson & Narens, 1994). An important aspect of metacognition is the ability to get a subjective sense of one's cognitive performance (Grimaldi, Lau, & Basso, 2015; Peirce & Jastrow, 1885). For example, when we identify a familiar-looking face on a crowded street we might feel more or less certain that we did see an old friend (or just someone that looked like them). In this case, the face categorisation would be the first order process and our sense of confidence in the categorisation would reflect a second order process, evaluating the fidelity of the first order process. In many cases, subjective confidence judgements are thought to result from imperfect readouts of the uncertainty associated with the first-order decisions (Meyniel, Sigman, & Mainen, 2015).

In experimental psychology, metacognitive performance is often assessed by comparing confidence judgements in relation to an objective measure of task performance, such as error rate (e.g., De Martino, Fleming, Garrett, & Dolan, 2013; Schwartz & Díaz, 2014; Yeung & Summerfield, 2014). When evaluating metacognitive performance three terms are of central importance: accuracy, bias, and efficiency (Maniscalco & Lau, 2012, 2014). Metacognitive accuracy is the extent to which confidence can be used to discriminate between correct trials and error trials (Galvin, Podd, Drga, & Whitmore, 2003). For example, if a participant is shown a set of pictures and has to evaluate whether they have seen them before, good metacognitive accuracy would result in their confidence judgements being consistently higher when they are correct, compared to when they are wrong. Metacognitive accuracy appears to be domain-general in healthy people, in the sense that people have similar metacognitive accuracy across tasks that require different first order abilities (McCurdy et al., 2013; Song et al., 2011; Veenman, Elshout, & Meijer, 1997). However, note that dissociations have been found between metacognition relating to memory and metacognition relating to visual discrimination in patients with brain lesions (Fleming et al., 2014).

In order to gain a complete picture of metacognitive performance one must also account for metacognitive bias. Metacognitive bias refers to the tendency to generally report high- or low confidence, regardless of the quality of the available information, or the accuracy of the first order judgement. For example, people tend to be overconfident in certain memory tasks (i.e., overestimating how often they are correct), whilst still being able to discriminate between correct and incorrect performance (for a review see Hoffrage, 2004). Metacognitive efficiency is a signal theoretic concept that refers to how good a person's metacognitive accuracy is given their first order accuracy. Intuitively, this is straightforward: imagine two people, Susan and John, performing a memory test. Susan produces fewer errors and therefore has better first order accuracy than John. Nevertheless, both participants report high confidence for 80% of the correctly remembered items and report high confidence for 40% of the items when they were wrong. This means that they both demonstrated the same level of metacognitive accuracy, because their confidence judgements were equally good at discriminating between correct and incorrect trials. However, in a sense John is metacognitively superior to Susan, because even though his first order decision process is worse, he still shows equally accurate confidence judgements. In our experiment we controlled for first order performance to get a pure measure of metacognitive efficiency in two ways. First, we used an adaptive staircase procedure to ensure a similar first-order accuracy for the experimental task across all participants. Second, we controlled for differences in first order performance mathematically.

Historically, metacognitive accuracy was computed by correlating confidence with first order performance within each participant (Kornell, Son, & Terrace, 2007; Nelson, 1984). However, this approach has been criticised for its inability to distinguish metacognitive accuracy from metacognitive bias (Masson & Rotello, 2009). This problem has recently been addressed by Maniscalco and Lau (2012, 2014), who applied signal detection theory (SDT) to metacognition, thus providing separate measures for bias and sensitivity. Below follows a non-technical introduction to the SDT framework in relation to first and second order performance, to help the interested reader appreciate how metacognitive efficiency is quantified (for a more in-depth, technical treatment, see Maniscalco & Lau, 2014).

One of the easiest ways to measure first-order performance in a two-alternative discrimination task is simply to compare the proportion of hits to the proportion of false alarms. Hits and false alarms are two of four possible outcomes that can occur within this context: (1) a hit is correctly indicating when a target is present; (2) a miss is failing to indicate when a target is present; (3) a false alarm is indicating that a target is present when it is not; and (4) a correct rejection is indicating that a target is absent when it is. We can calculate the hit rate for the full experiment by dividing the number of hits by the total number of trials when the target was present, and the false alarm rate by dividing the number of false alarms by the total number of trials when the target was absent. (Note that hit rate + miss rate = 1 and false alarm rate + correct rejection rate = 1, so the other two measures are superfluous). The higher the hit rate relative to the false alarm rate, the better the participant's first order performance. This can be visualised by plotting hit rates on the *y*-axis and false alarm rates on the *x*-axis.

Now say that we want to determine the participant's discriminatory ability independent of their response bias (i.e., their tendency to prefer one response over the other). One way to do this would be to change the relative rewards offered for hits versus correct rejections and plot different hit rates and false alarm rates for these different incentive structures. Such a plot is called a Receiver Operating Characteristic (ROC) curve. The strength of the SDT framework is that, from a single hit ratio-false alarm ratio pairing, it can estimate ROC curves that closely match ROC curves estimated from multiple pairings (Green & Swets, 1966). Therefore, SDT allows us to separate response bias from discriminatory ability without having to vary the incentive structures of the responses.

SDT assumes that each response is the result of two factors, the strength of evidence on that trial and the response criterion. In the example below, evidence can be ranked from "target is definitely absent" to "target is definitely present" (see the *x*-axis in Fig. 1). For each trial of a given difficulty, the strength of evidence is drawn