Trajectories of verbal fluency and executive functions in multilingual and monolingual children and adults: A cross-sectional study

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Trajectories of verbal fluency and executive functions in multilingual and monolingual children and adults: A cross-sectional study

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Abstract

The development of verbal fluency is associated with the maturation of executive function skills, such as the ability to inhibit irrelevant information, shift between tasks and hold information in working memory. Some evidence suggests that multilinguistic upbringing may underpin disadvantages in verbal fluency and lexical retrieval, but can also afford executive function advantages beyond the language system including possible beneficial effects in older age. This study examined the relationship between verbal fluency and executive function in 324 individuals across the lifespan by assessing the developmental trajectories of English monolingual and multilingual children aged 7 to 15 years (N=154) and adults from 18 to 80 years old (N=170). The childhood data indicated patterns of improvement in verbal fluency and executive function skills as a function of age. Multilingual and monolingual children had comparable developmental trajectories in all linguistic and non-linguistic measures used in the study with the exception of planning, for which monolingual children showed a steeper improvement over the studied age range relative to multilingual children. For adults, monolinguals and multilingual participants had comparable performance on all measures with the exception of non-verbal inhibitory control and response times on the Tower of London task: monolinguals showed a steeper decline associated with age. Exploratory factor analysis indicated that verbal fluency was associated with working memory and fluid intelligence in monolingual participants but not in multilinguals. These findings raise the possibility that early acquisition of an additional language may impact on the development of the functional architecture serving high-level human cognition.

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Introduction

The ability to articulate speech fluently (verbal fluency) is crucial in typically developing children and a reliable a predictor for their academic success (Memisevic et al., 2018). A large body of research carried out with children and adults has provided evidence for an association between verbal fluency and the broader domain of executive function (e.g., Aita et al., 2019; Luo et al., 2010, Shao et al., 2014). Executive function refers to a set of vital and voluntary controlled cognitive skills that allow us to suppress irrelevant information, shift between tasks and hold and update information in working memory (e.g., Miyake et al., 2000). Executive function skills might therefore be considered the building blocks of higher-level cognitive abilities such as reasoning, problem-solving and decision-making (Diamond, 2006), supporting effective learning and knowledge acquisition.

Verbal fluency is typically assessed via administration of tasks requiring oral generation of words within defined parameters. One of those most widely employed is the Verbal Associative Fluency Test, which requires participants to spontaneously produce as many words as possible, beginning with a given letter, within one minute. Typically, the letters used are ‘F’, ‘A’ and ‘S’, so much so that this test is routinely referred to as ‘F-A-S’. Fluency is then inferred by the quantity of eligible words produced, either summed or averaged across the three manipulations. Another approach is most commonly referred to as semantic or category fluency, in which the ability to produce category exemplars is measured using the same basic procedure and scoring. Typical categories include animals, fruits/vegetables, vehicles and tools (e.g., Bright, et al., 2008). Additional constraints are minimal in both tasks (for F-A-S letter fluency, proper nouns are not allowed, and the same word with a different suffix or repetitions are not allowed in either test).

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Both letter and category fluency are considered useful measures of how well participants are able to organize lexical retrieval and apply strategic thinking (e.g., Estes, 1974; Lezak et al., 2004). Performance on these tests, therefore, is thought to rely on higher level cognitive control, although verbal fluency is more universally accepted as a 'frontal lobe' or executive function test, with category fluency impairments interpreted in the context of semantic knowledge breakdown in addition to executive deficits. Consistent with this view, Alzheimer patients tend to have greater difficulty with category fluency, implicating disproportionate temporal lobe involvement in performance on this task relative to verbal fluency (e.g., Fama et al., 1998; Monsch, et al., 1994). In neurologically healthy participants, performance is usually better on category fluency relative to letter fluency, but both are markedly sensitive to ageing and frontal lobe integrity, consistent with disproportionate age-related cortical deterioration in the frontal cortex relative to posterior regions, and to the importance of frontal regions in the creation and organization of retrieval strategies.

The literature has not provided a clear answer about which executive control mechanisms are most important for successful performance in the letter and category fluency tasks. Some authors have emphasised the role of working memory, selection and suppression (e.g., Henry & Crawford, 2004; Moss et al., 2005; Rosen & Engle, 1997; Rende et al., 2002). Indeed, to perform fluency tasks, participants must hold the instructions and their earlier responses in working memory and they must also suppress irrelevant words (e.g., words that do not start with the target letter or belong to a certain category) and repetitions. Additionally, participants often develop a strategy, which involves the ability to create clusters based on a systematic memory search (e.g., pets cluster = dog, cat; farm cluster = cow, pig; birds cluster = robin,

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pigeon). However, others have stressed the importance of switching ability (Abwender et al., 2001) and general inhibitory control (Hirshorn & Thompson-Schill, 2006), highlighting the association between verbal fluency and novel problem solving or fluid intelligence (e.g., Roca et al., 2012).

Another interesting line of research is related to the relationship between verbal fluency, executive function and multilanguage acquisition. Multilingual speakers are often found at disadvantage in tasks requiring lexical access on the assumption that they generally have a smaller vocabulary in each known language compared to monolingual speakers of those languages (e.g., Bialystok & Feng, 2011; Oller et al., 2007). However, they also have to resolve the greater selection demands associated with fluency in more than one language, and this will in turn result in slower word retrieval when compared to monolingual speakers (Gollan et al., 2005; Ivanova & Costa, 2008).

In contrast to this potential disadvantage, a large body of evidence has been reported in the last three decades for a possible bilingual advantage in executive function. In particular, children and older multilingual adults often outperform their monolingual peers in tasks of nonverbal inhibitory control, shifting and updating (see Bialystok, 2017, for a review). The reason for this executive advantage is believed to stem from the lexical disadvantage: the higher competitive demand of dealing with two or more languages in a single mind on a daily basis and for protracted period of times, may in turn strengthen frontoparietal networks functionally and structurally implicated in nonverbal cognitive control (Bialystok, 2017). This has been prompted, in part, by an increasing understanding of neuroplasticity and how specific and diverse skills and experiences may be underpinned by a core, domain general “control” network (e.g., Duncan, 2013; Voytek et al., 2010). What is less clear is whether this network can

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somehow be enhanced through a process of multilanguage acquisition and daily multilingual communication.

Neuroplasticity refers to the brain's ability to adapt in response to environmental stimulation through forming, pruning and reorganising synaptic connections (Pascual-Leone et al., 2005). Richer environments and experiences such as higher social economic status and formal education may have identifiable effects on brain structure and networks as well as measurable behavioural cognitive benefits in areas such as executive function and non-verbal intelligence (Noble et al., 2012; Kramer et al., 2004). Experimental evidence has shown that, in the bilingual brain, both languages are always active even in monolingual settings (Bialystok, 2017; Dijkstra, 2003). This joint activation requires bilinguals to pay attention to changing contexts, select and apply the appropriate language while preventing interference from the non-target language (Bialystok, 2009). Intriguingly, multilingual speakers often underperform in comparison to monolingual peers in category fluency, but not on letter fluency (Gollan et al., 2002; Rosselli et al. 2002). To the extent that letter fluency is disproportionately underpinned by frontal/executive function (in comparison to category fluency), it has therefore been argued that the use of frontal networks responsible for executive function may, in part, explain why there is typically no disadvantage for letter fluency in multilinguals (Luo et al., 2010). However, although neurological evidence supports the existence of domain general cognitive differences between language groups, the behavioural evidence for the bilingual advantage has been more controversial and the mechanism(s) that underlie the advantage reported in these studies is currently a topic of vigorous debate (see Paap et al., 2015, for a critical review).

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In the current study we explored the relationship between verbal fluency and executive function from childhood to older age using a cross-sectional design. A developmental trajectory approach in cross-sectional designs has been successfully used in studies comparing the development of typically and atypically developing children (Annaz et al., 2009; Karmiloff-Smith, et al., 2004; Thomas et al., 2001; 2009). We employed this approach, comparing performance of multilingual and English monolingual speakers from the age of 7 to the age of 80 years.

Our primary objective, therefore, was to address whether early acquisition of a second language alters the functional architecture of higher-level cognition. We also evaluate whether there are differences in these developmental trajectories that might be explained by linguistic ability (i.e., monolingual vs multilingual status). To achieve our objectives we assess performance on a range of measures of executive function and cognitive control, and determine their sensitivity to verbal fluency in monolinguals and multilinguals across the lifespan trajectory.

Methods

Participants

This project was approved by the Science and Technology Research Ethics panel at Anglia Ruskin University (FST/FREP/15/505) and was conducted in accordance with the tenets of the Declaration of Helsinki. A total of 324 individuals, all living in the UK at the time of testing, took part in this study (see Table 1 for the age breakdown and gender details). One-hundred and fifty-four (154) were typically

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developing children with age ranging from 7 to 15 years old (mean age=9.6, SD= 1.6, 72 females) and 170 were healthy adults from 18 to 80 years of age (mean age=38.6, SD=16.6, 62 males).

--- Insert Table 1 about here ---

Participant scores were extracted from a larger dataset of 536 participants who took part in a 5-year investigation of the effect of multilingualism across the lifespan. In this study, only the participants who completed the relevant tasks were included.

Within the children group, 77 were English monolinguals and 77 were bilinguals/multilinguals of different linguistic backgrounds enrolled in UK primary schools. Their parents completed an online questionnaire designed to establish demographic, socio-economic and linguistic information (Filippi et al., 2020). All multilingual children started the acquisition of two or more languages with English being one of them either simultaneously from birth (N=59) or within the first 5 years of life (N=18). All monolingual children reported a basic knowledge of French or Spanish learned at school. However, they did not report daily exposure or use of foreign language, nor the ability to hold a basic conversation in a language other than English.

All multilingual children were reported to be highly proficient in both English and an additional language which they reported to use on a daily basis at home and with the extended family. Twenty-five children were reported to be exposed to a third or a fourth language, although their level of competence in these languages was considered lower.

Within the adult participants, 86 were English monolinguals with none or little exposure to a second language when at school, and 84 were multilinguals from a large

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variety of linguistic backgrounds. They also completed an online questionnaire in which biographical, socio-economic and linguistic information was provided.

They all reported to be highly proficient in English plus an additional language, which they used on a daily basis. Fifty-five individuals were raised as bilinguals since birth and 29 within early stages of their lives. Thirty-nine of them reported the knowledge of a third or a fourth language.

A list of all languages spoken by the children and the adults is reported in the online Supplementary Material, Table A1 and A2.

Socio-economic status (SES) information was calculated on the basis of parental (father and mother) highest level of education, employment (adults only) and household income. Each item was scored for academic achievement (i.e., 1=no formal/primary, 2=secondary, 3=undergraduate, 4=post-graduate, 5=doctorate), occupation, (1=unemployed, 2=part-time, 3=full-time), and a score from 1 to 6 depending on their total household income (from less than £20,000 to more than £100,000). Scores were averaged to create a composite SES score and also analysed separately

Procedure and materials

As described in the Participants section, this study is part of a larger project in which a total of 536 participants performed a total of 10 tasks (Table 2) that were split in two blocks of 5 (part A and part B), counterbalanced to ensure an equal distribution of participants who were tested starting with part A followed by part B and vice-versa. Testing was also carried out at different times of the day, with children predominantly tested in the morning and early afternoon. Overall, with this design we aimed to reduce the probability that the order of tests or other factors adversely

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influenced the results. The whole testing session lasted one hour and twenty minutes on average.

--- Insert Table 2 about here ---

The experimental battery was conducted on an ASUS laptop, mouse, standard keyboard, and a Technopro ® USB gamepad that was adapted with a red and a blue sticker attached to the buttons for the execution of the Simon task, and a green sticker for the execution of the go/no-go task. All instructions were given in English.

Ethics approval for this study was granted by the university committee. Only the children whose parents returned written informed consent were included in the sample. Children were tested in quiet room made available in three primary schools, two in London and one in the Cambridge area. Adults were tested in the testing rooms available at Anglia Ruskin University in Cambridge and at UCL - Institute of Education in London. All participants gave their written and verbal consent before starting the session.

To address the experimental questions of this study, we only included the participants who fully completed the following tasks:

Verbal fluency

Participants performed two conditions, one measuring letter (or phonemic) fluency and one measuring category (or semantic) fluency (e.g., Controlled Oral Word Association Test, COWAT, Strauss et al., 2006). For letter fluency they were instructed to say, out loud, as many words as they could think of beginning with a specific letter (i.e., F, A and S) within a time limit of 60 seconds. For semantic fluency participants were again given 60 seconds to produce words belonging to a specific category; these were 1) animals, 2) vehicles 3) fruits and vegetables and 4)

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tools. The number of words generated were summed to provide a letter fluency and a semantic fluency score (Lezak et al., 2004). Any word repetitions and category errors were excluded from data analysis.

Executive function tasks

Visual interference suppression: Simon task.

A computerised version of the Simon task (Simon & Wolf, 1963) was programmed in E-Prime version 2.0 (Schneider et al., 2007). A USB gamepad with coloured stickers (red and blue) was used to record response time and accuracy.

The task consisted of 36 trials in which either a blue star or a red star randomly appeared to the left or the right side of a white screen; each colour was presented in equal number of times to the left and to the right. A fixation cross appeared for 800 ms preceding each trial. The participants were instructed to press the left button (labelled with a red sticker) when the red star would appear on the screen and the right button (labelled with a blue sticker) for the blue star. Half of the trials were incongruent, that is, the location of the stimulus and the response button did not match (e.g., red star on the right hand side of the screen) thereby requiring participants to inhibit the conflicting spatial information and focus on the colour (i.e., conflict resolution). Congruent trials (red star on the left and blue star on the right) did not require conflict resolution. The dependent measure was the 'Simon effect' (i.e., the difference between the mean response times for congruent and incongruent trials).

Response inhibition: Go/no-go task.

All participants performed a go/no-go task called Whack-A-Mole (Petitclerc et al., 2015). They were instructed to press the green button on the USB gamepad as fast as they could when a mole popped up on the screen (go trials). They were also instructed not to press the button whey an aubergine appeared on the screen instead of a mole.

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Trials began with an open mole hole (fixation point) appearing for 500 ms in the centre of a black screen. Go and no-go stimuli were presented for 1800 ms and 1300 ms respectively, unless a response was pressed. Correct responses were visually rewarded for 200 ms with a 'WHACK!' graphic for whacking the mole and 'AWESOME!' for leaving the aubergine; 'OOPS!' was displayed for missing the mole or whacking the aubergine. The ITI was 2500 ms. following a practice block of 10 trials (3 no-go trials) participants were given the opportunity to ask questions before progressing on to the first of four blocks. Each block contained 56 trials (25% no-go) presented in a pseudorandom order.

Planning and problem solving: Tower of London.

A computerised 12 trial version of the Tower of London (Shallice, 1982), included in the free access PEBL battery (Mueller & Piper, 2014), was administered. Each problem required participants to use the computer mouse to move coloured discs (red, blue, and green) from their initial position to match their target position in the fewest possible moves. The participants were instructed to move only one disc at a time, and only the disc on the top of a stack could be moved. A move counter on the right hand side of the screen would inform them how many moves they could make and how many moves they had left. There was no time limit for each problem but all participants were advised to carefully plan their moves before they clicked on any discs. Trials ended when participants reached the move limit and the screen displayed feedback on whether or not they had successfully completed the problem.

The trials where presented in a progressively increased order of complexity consisted of four easy problems requiring 2-3 moves, four trials with problems requiring 4 moves and four trials with more difficult 5-move problems that required planning multiple sub-goals.

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Fluid intelligence: Raven's Advanced Progressive Matrices Set 1.

Participants completed Raven's Advanced Progressive Matrices Set I (Raven, 1998) consisting of 12 items of increasing complexity. Each item consisted of a 3 x 3 matrix containing eight different black and white designs that are logically related and one piece missing at the bottom right; participants were required to deduce from 8 potential pieces which piece completes the matrix. The number of correct items out of 12 was recorded. Although no time limit was given, all participants completed the task within 10 minutes.

Verbal Working memory: Digit span forwards and backwards.

All participants were administered the digit span backward and forward, subtests of the Wechsler Adult Intelligence Scale—Fourth Edition (WAIS–IV; Wechsler, 2008). They were instructed to repeat aloud a sequence of numbers produced by a native English speaker. In the forward condition, the numbers had to be repeated in the same order. In the backward condition, they had to be reversed. Trials began with 2-digit sequences (e.g., 1 – 7) that the participant verbally recalled either forwards or in reverse order. As trials progress the sequence gradually increased by one digit. Testing was interrupted when participants failed to recall the digits in two consecutive trials. Each correct response scored 1 point. The sum of correct forward and backward trials was recorded for each participant to provide an ability score.

English receptive vocabulary: British Picture Vocabulary Scale

All participants were administered the British Picture Vocabulary Scale: Third edition (BPVS-III; Dunn et al., 1997), which consists of 14 sets of words, each containing 12 items. Sets are linked with levels of complexity, starting from simple words understood by 2 – 3 year olds (e.g., ball, Set 1) to more difficult and infrequent words (e.g., lacrimation, Set 14). Panels of 4 pictures are presented for each item and the

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researcher orally say a word that is associated with only one picture. All participants started with an age-appropriate set. If two or more errors were made on the starting set then the researcher established the base set by going back a set at a time until a maximum of one error was made. Next, a ceiling set was established by presenting the participant with progressively more difficult sets until 8 or more errors were made on a set. Raw (ability) scores were calculated as the highest number on the ceiling set minus the total number of errors made during the assessment.

Design

This study had a mixed-design in which the developmental trajectories of verbal fluency and executive function were built for children and adults in both linguistic groups. Ability scores were obtained for phonological and semantic fluency (number of words produced in each condition, English receptive vocabulary (BPVS III), fluid intelligence (Raven's matrices) and working memory (digit span forward and backward). Accuracy and response time scores were calculated for the executive function tasks. *T*-tests, correlation and regression analyses were performed using SPSS version 25 for Mac. Factor Analysis was performed using the "FactorAnalyzer" package with Python (https://pypi.org/project/factor-analyzer/).

Results

Children

Independent *t*-tests showed that age did not statistically differ between monolingual and multilingual groups, $t(152) = -.68$, $p = .50$. Analyses of socio-economic status, that is, scores of parental education (father and mother), and family income, analysed both separately and together through an averaged individual index, showed that the two groups had comparable SES (father education = $t(152) = 1.40$, $p = .17$, mother

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education= $t(152)$ =.37, p = .71, family income= $t(152)$ =1.19, p = .24, and individual averaged index=$t(152)$ =.02, p = .98).

There were no significant gender differences in verbal fluency skills (p=.74 for letter fluency and p=.95 for category fluency). Independent t-tests and Bayes factors indicated that English monolinguals and multilinguals were comparable across all verbal and non-verbal measures (Table 3).

--- Insert Table 3 about here ---

Correlations between verbal fluency and executive function

Pearson correlation analysis showed that both semantic and phonological fluency were significantly correlated (at p<.001) with measures of inhibitory control (go task reaction time), accuracy in planning (Tower of London), fluid intelligence (Raven's matrices), working memory (digit span) and receptive vocabulary (BPVS). The correlations with measures of inhibitory control accuracy (no-go trials), shifting and updating (Simon task) and response time for planning (Tower of London) were not significant (p>.05 in all cases). All correlations are reported in the Supplementary Material, Table B1. Stepwise linear regressions were also computed in which semantic and phonological fluency were regressed on digit span, Simon, go/no-go and Tower of London measures. For prediction of semantic fluency, three variables were entered: forwards digit span (explaining 18% of the variance), go task reaction time (an additional 8%) and no-go trial accuracy (an additional 3%). The best fit model for phonological fluency was virtually identical, with the same variables and ordering (explaining 19%, +5%, and +5%, respectively). All other variables were excluded as meaningful predictors using the standard inclusion criterion of p=.05.

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The role of development and multilingualism for linguistic and non-linguistic skills

Regression analyses checked for outliers with Cook's distance (Cook, 1977) were performed to explore the developmental trajectories of verbal and nonverbal abilities. They revealed that age was a reliable predictor of best performance in both linguistic groups in measures of verbal fluency, receptive vocabulary, fluid intelligence, working memory and response time in inhibitory control ($p \leq .001$). Age was a significant predictor of accuracy in the executive function planning task (Tower of London), for the monolingual group ($p < .001$), but not for the multilingual groups ($p = .38$). For both groups, age was not a reliable predictor for time of planning the first move and for completing the task in the Tower of London, and for inhibitory control accuracy ($p > .10$). Finally, there was a trend in the relationship between age and the Simon effect in monolinguals ($p = .07$) whilst this relationship was just significant in multilinguals ($p = .04$).

Fisher r-to-z analysis for comparison between correlation coefficients for the monolingual and the multilingual group indicated that the children's developmental trajectories were largely comparable. However, the trajectory of accuracy for planning/reasoning in resolving the Tower of London task significantly differed between the two groups ($p = .009$) indicating that age predicts best performance more closely in monolinguals in comparison to multilinguals (Figure 1).

All results, including Fisher r-to-z analyses, are reported in the Supplementary Material, Table C1.

--- Insert Figure 1 about here ---

The relationship between verbal fluency and executive function across development in children

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All verbal and nonverbal measures with the addition of the variable *age* were factor-analysed across all groups with both varimax (orthogonal) and promax (oblique) rotations. Considering that the variables were highly correlated we opted to report the promax rotation which may offer more valid factor loadings (Corner, 2009). However, the varimax rotation results are also available in the Supplementary Material, Table D, for comparison purposes.

The Bartlett sphericity ($p<.001$) and Kaiser-Meyer-Olkin (KMO=.80) measures verified the sampling adequacy for the analysis.

The analyses yielded four factors with Eigenvalues ≥ 1, explaining on average 54.0% of the variance for the entire set of variables. Figure 2, 3 and 4, illustrate the factor loadings, which are also reported in the Supplementary Material, Table E.

Examination of the factor loadings in the whole children population, i.e., monolinguals and multilinguals collapsed, shows a strong fluency construct (Factor 1), largely independent from age and all measures of working memory and executive function. Factor 2 is strongly dominated by age but also reflects response time and vocabulary knowledge. Factor 3 appears to reflect an underpinning executive planning /working memory construct which is independent from response inhibition (Factor 4).

The comparison between monolingual and multilingual children, although presenting some moderate differences in loading distributions, generally confirms an emergent fluency construct in both groups (Factor 1 in monolinguals, Factor 2 in bilinguals). Nevertheless, only in monolinguals is there reliable evidence of co-involvement of working memory and fluid intelligence within this fluency factor. In bilingual children fluid intelligence, working memory and executive planning ability dominated one factor (in this case, Factor 3), consistent with an underpinning fluid ability/psychometric *g* construct operating in this group. In monolingual children,

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stimulus/response conflict monitoring and executive planning ability emerged as distinct constructs (Factors 3 and 4, respectively), with only the former emerging as Go/No Go accuracy performance (Factor 4) in bilinguals.

--- *Insert Figure 2 about here* ---

--- *Insert Figure 3 about here* ---

--- *Insert Figure 4 about here* ---

Adults

Independent *t*-tests showed that age difference between the two groups was not statistically significant, $t(168) = -.62$, $p = .54$. Analyses of socio-economic status, that is, scores of parental education (father and mother), occupation and family income, analysed both separately and together through an averaged individual index, showed that the two groups had comparable SES (father education = $t(168) = .009$, $p = .99$, mother education= $t(168) = .99$, $p = .32$, occupation= $t(168) = .52$, $p = .61$, family income= $t(168) = .15$, $p = .88$, and individual averaged Index= $t(168) = 1.66$, $p = .10$) Male participants showed better verbal fluency performance than females with 50.2 mean words produced for phonological fluency (females = 43.2) and a mean of 75.8 for semantic fluency (females = 71.6). The difference was highly significant for letter fluency skills (p=.002) but not for semantic fluency (p=.08). Independent *t*-tests and Bayes factors indicated that English monolinguals and multilinguals performed comparably on measures of fluid intelligence and working memory but monolinguals showed significantly better performance on verbal fluency, English vocabulary knowledge, inhibitory control and planning response times (Table 4).

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Correlations between verbal fluency and executive function

Pearson's correlation analysis showed that phonological fluency was significantly correlated with measures of executive function (Simon task, p=.01), working memory and receptive vocabulary (p<.001). Semantic fluency was significantly correlated with fluid intelligence (p=.01), working memory and receptive vocabulary (p<.001), but not with executive function and inhibitory control measures (p>.10).

There was a statistical trend in the correlation between semantic fluency and accuracy in performing the Tower of London task (p=.07). All correlations are reported in the Supplementary Material, Table B2. Stepwise linear regressions were also computed in which semantic and phonological fluency were regressed on digit span, Simon, go/no-go and Tower of London measures. For prediction of semantic fluency, only forwards digit span was included, explaining 16% of the variance. The best fit model for phonological fluency included forwards digit span (18%) and the Simon effect (explaining an additional 4% of the variance). All other variables were excluded as meaningful predictors in both models using the standard inclusion criterion of p=.05.

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The role of age and multilingualism for linguistic and non-linguistic skills

Regression analyses checked for outliers with Cook's distance (Cook, 1977) were performed to explore the developmental trajectories of verbal and nonverbal abilities. They revealed that age was a reliable predictor of best performance for phonological fluency in both linguistic groups (monolinguals p=.003; multilinguals p=.001). However, for semantic fluency, monolinguals' performance was not significantly associated to age (p=.37), whereas for multilinguals age was still a significant predictor of best performance (p=.04).

For both groups, age was a significant predictor of performance in English receptive vocabulary ($p \leq .001$), Simon effect (monolinguals p=.004; multilinguals p=.002) and Go/No-go task response time (monolinguals p<.001; multilinguals p=.006).

For other measures, age played a different role in the two linguistic groups. For monolinguals, age was a significant predictor of performance in response time for planning (Tower of London first move, p=.05; Tower of London response time for completing a trial, p=.003), and there was a statistical trend for measures of fluid intelligence and working memory (p=.06). For multilinguals age was not a significant predictor of working memory (p=.83) and response time for planning (p>.40) but it predicted performance in fluid intelligence (p=.001). In both groups, age was not significant in measures of accuracy in inhibitory control and planning (p>.20).

Fisher r-to-z analysis for comparison between correlation coefficients for the monolingual and the multilingual group indicated a statistical trend for response time in the Go/No-go task (p=.05). As shown in Figure 5C, monolingual speakers showed a longer response time than multilinguals as they aged. There was a statistical trend in the trajectories of response time for planning (p=.06). Figures 5D and E, show that monolingual speakers were faster than multilinguals at a younger age, but they

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performed increasingly similarly in older age. The multilinguals' performance did not appear to decline with ageing and remained stable across the lifespan.

All other comparisons were non-significant (p>.10). Regression analysis results, including Fisher r-to-z analyses, are reported in the Supplementary Material, Table C2.

--- Insert Figure 5 ---

The relationship between verbal fluency and executive function across development in adults

Exploratory factor analysis with promax rotation was conducted with both linguistic groups collapsed and then separately for monolingual and multilingual adults. The Bartlett sphericity (p<.001) and Kaiser-Meyer-Olkin (KMO=.6) measures verified the sampling adequacy for the analysis.

The analyses performed with both groups collapsed and separate for monolingual and multilingual adults, yielded four factors with Eigenvalues ≥ 1, explaining on average 45.50% of the variance for the entire set of variables. Figure 6, 7 and 8, illustrate the factor loadings, which are also reported in the Supplementary Material, Table F.

--- Insert Figure 6 about here ---

--- Insert Figure 7 about here ---

--- Insert Figure 8 about here ---

With all adults entered into the analysis, four factors were identified, which we interpret based on the assumption that variable loadings above 0.4 are stable (e.g., Field, 2013). Factor 1 is dominated by verbal fluency and digit span performance, and therefore appears to reflect *controlled lexical access*.

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Factor 2 is best represented by visuospatial planning ability (Tower of London accuracy scores), nonverbal abstract reasoning (Raven's matrices scores) and stimulus/response conflict processing (Simon cost). We therefore consider the underpinning construct to be *nonverbal fluid intelligence/psychometric g*. Factor 3 is virtually entirely characterised by *vocabulary knowledge* (BPVS). Factor 4, disproportionately represented by performance on the Go/No Go task appears to reflect response inhibition.

As in the analysis of children, notable differences in the loadings emerged when language groups (monolinguals/multilinguals) were analysed separately (Figures 7 and 8). In multilinguals, Factor 1 is disproportionately associated with fluency performance with more evidence for co-dependence on verbal short-term/working memory in monolinguals (again consistent with monolingual children). Consistent with the full group analysis, in multilinguals Factor 2 was dominated by visuospatial planning ability, nonverbal abstract reasoning and stimulus/response conflict monitoring ability, therefore indicative of an underpinning fluid intelligence/psychometric *g* construct. In monolinguals there was little or no evidence for a shared construct underlying these abilities. Instead, visuospatial planning and stimulus/response conflict monitoring emerged as distinct constructs (Factors 3 and 4, respectively). Notably, in our monolingual group, Raven's matrices scores showed low and unstable loadings across all emergent factors.

Overall, factor analysis in children and adults has shown that i. verbal fluency appears to be largely independent of measures of working memory, fluid intelligence and executive function in bilinguals, but is more integrated with working memory and fluid intelligence in monolinguals; and ii. executive planning ability and fluid intelligence dominate the same factor in bilinguals but not in monolinguals. If these

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differences in the patterns of variable loadings occurred only in the children or the adult participants they should be regarded as holding limited intrinsic value, but the consistency in the patterns across both sets of data indicate that the differences in the characteristics of these emergent factors may warrant further consideration.

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Discussion

This study investigated the developmental trajectories of verbal fluency and executive function in a sample of 324 participants, 154 children from 7 to 15 years old and 170 adults from 18 to 80 years old. Half of the total sample was made of bilingual speakers who started to acquire a second language in addition to English from early stages of life. The other half was made of English monolingual participants. We sought to identify which component of executive function is more associated with verbal fluency skills. Additionally, possible effects of multi-language experiences in the development of linguistic and non-linguistic skills were explored by comparing the performance of the English monolingual and multilingual groups. Semantic and phonological fluency were measured according to the standard procedure requiring oral elicitation of words belonging to specific semantic categories or beginning with a given letter. Executive function was measured through a set of tasks, including the Simon task a Go/No-go task (Whack-the-mole), and the Tower of London task. Each task targeted specific components of executive function, i.e., shifting, updating, inhibitory control and planning. Measures of short-term and working memory (digit span forward and backward), fluid intelligence (Raven's matrices) and receptive vocabulary (BPVS) were also acquired. Biographical and socio-economic status information were collected through administration of an online questionnaire. Results showed that age was a significant predictor of best linguistic and non-linguistic performance across the whole sample. Multiple regression of fluency measures on our measures of working memory, executive planning and response inhibition showed limited evidence for a meaningful relationship between phonological or category fluency and executive function. In both age groups, forwards digit span was robustly identified as the best predictor variable, which is

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typically assumed to be a straightforward measure of short-term memory (unlike backwards digit span, which requires online manipulation of data held in short-term/working memory). Multilingual and monolingual children had comparable trajectories in all measures with the exception of planning skills (Tower of London) where multilingual children did not seem to improve their performance across development as steadily as the monolinguals. In all other measures, neither linguistic disadvantages nor executive function advantages were observed in the multilingual sample.

Similar results were obtained in the adult sample. However, as opposed to children, adult multilingual participants demonstrated a different trajectory in reaction time in inhibitory control (on the Go/No go task). In comparison to monolingual speakers, a slower deterioration in response time over the age distribution was observed on this measure in the bilingual group. This result offers some evidence that managing two or more languages in a single mind may confer possible benefits in the ageing population and in a specific cognitive skill: inhibitory control.

Factor Analysis was performed for both groups in order to explore the relationship between verbal fluency, age, vocabulary knowledge and non-verbal measures of IQ and executive function. Common patterns were observed. First, verbal fluency appears to be largely independent from executive function measures across the whole sample. However, when monolinguals and multilinguals were compared separately, some significant differences also emerged. Children and adult English monolinguals' verbal fluency performance were associated with measures of fluid intelligence, working memory, vocabulary knowledge, executive function and age. In multilingual children and adults verbal fluency remained largely independent from all others non-verbal measures. We offer a tentative interpretation in the following section.

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Empirical and theoretical considerations

Overall, the results indicate similar performance levels in both monolingual and multilingual participants on our tests of verbal and nonverbal ability. The developmental trajectories in children and adults also show similar patterns. Considering that the multilingual participants were all learners of English and another language from early stages of life and were all living in the UK at the time of testing, it is perhaps not surprising that their knowledge of English was like native monolingual speakers when performing the verbal fluency task. The children's developmental trajectories for all non-verbal measures were comparable with the exception of the cognitive planning component measured with the Tower of London task. Here, monolingual children outperformed multilingual peers. This finding is consistent with evidence that the visuo-spatial planning and problem-solving demands operating in the Tower of London may be served by cognitive mechanisms distinct from those serving verbal working memory performance and non-verbal inhibitory control (e.g., D'Antuono et al., 2017; Kaller et al., 2011; Zook et al., 2004). To the extent that performance on the Tower of London reflects goal-directed planning proficiency, these results indicate that multilingual acquisition during childhood might have negative consequences in this domain but render other aspects of executive functioning unaffected. In earlier work we have reported a bilingual disadvantage in metacognitive processing evidenced by disproportionately lower confidence in test performance (Folke et al., 2016) and while purely speculative, we raise the possibility that reduced confidence might, in part, manifest in poorer actual performance on complex measures of goal-directed strategic planning such as the Tower of London.

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With regard to the adults, again monolinguals and multilingual participants had comparable performance on all measures with the exception of non-verbal inhibitory control measured with the go/no-go task and response time on Tower of London trials, on which monolinguals showed a trend towards steeper decline with age. While these findings may infer slower age-related cognitive deterioration associated with multilingualism, we caution against accepting this inference on the basis of this statistically marginal observation.

Other studies provide less equivocal results (e.g., Bialystok et al., 2004), offering the interpretation that lifelong multilingualism may protect the brain from the effect of ageing (e.g., Craik et al. 2010). These findings have generated a heated debate in the field. Some authors argue that positive results may be task-dependent (e.g., Paap et al., 2013, 2015) and a recent large-scale meta-analysis of 152 studies on adults found no systematic evidence for a bilingual advantage in inhibitory control (or any other cognitive ability) after controlling for publication bias (Lehtonen et al., 2018). Consistent with this review, recent research from our lab did not find any significant difference between monolingual and bilingual elderly participants with classical measures of executive function such as the Simon task and the Tower of London (Papageorgiou et al., 2018) and our current finding, based on evidence from a single test, should therefore be interpreted in the context of this increasing weight of pooled evidence against the existence of a straightforward multilingual advantage in any aspect of cognitive control.

Intriguingly we observed disparity between monolinguals and multilinguals in the patterns of interdependency among our variables revealed via exploratory factor analysis. Furthermore, these differences in the patterns of intercorrelation generally held in both the child and adult groups. Most notably, evidence that verbal fluency,

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working memory and nonverbal fluid intelligence share a common underpinning construct was observed in monolinguals but not in multilinguals. In both multilingual children and adults a strong fluency factor emerged, on which other variables associated with working memory, executive function and fluid intelligence showed only low or marginal loadings. Our analysis also revealed that while fluid intelligence, working memory and executive planning ability dominated the same factor in bilinguals, this was not the case in monolinguals – an observation that was again observed in both child and adult groups.

These findings raise the possibility that early acquisition of an additional language may impact on the development of the functional architecture serving high level human cognition. In earlier work we have published evidence that the whole-brain network topology underpinning the control of interference during language processing may show divergence in response to multilanguage (vs single language) acquisition (Filippi et al., 2011; 2020) and, in this context, it is plausible that *functional* adaptation and qualitative specialization of cognitive subsystems responsible for selective attention, working memory and control may develop. Such a perspective is consistent with the adaptive coding model of neural function (Duncan, 2001) in which neurons are hypothesized to adapt their properties in direct response to ongoing goal-relevant demands. In the current context, the claim is that the networks responsible for controlling language and thought in the multilingual brain must adaptively tune themselves to a more diverse range of inputs than is the case in the monolingual brain, and this leads to differences in the functional selectivity and adaptability of the latent variables serving bilingual cognition.

Why would such group differences in the latent variables explaining performance across our tasks emerge in the absence of group differences in levels of performance?

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The Inhibitory Control Model (ICM; Green, 1986, 1998) and its expansion, the Adaptive Control Hypothesis (ACH; Green & Abutalebi, 2013) propose that inhibition is the key mechanism for bilingual language processing: in order to produce one language, bilinguals must inhibit the non-target language. The ACH provides the most detailed account of the bilingual language selection processes. According to this model there are eight different control processes: 1) goal maintenance, 2) conflict monitoring 3) interference suppression, 4) salient cue detection, 5) selective response inhibition, 6) task disengagement, 7) task engagement, and 8) opportunistic planning that are recruited differently in relation to the specific linguistic context in use.

The ACH also describes three different interactional contexts: 1) single language, 2) dual language, and 3) dense code-switching. A single-language context operates when languages are used separately (e.g., L1 at home, L2 at work). A dual-language context operates when both languages are mixed (e.g., interactions in which one speaker uses L1 and the other L2). The dense-code switching context occurs when interactions are not only mixed but speakers also "play" with their languages with frequent switches within a single sentence or by creating novel words (e.g., merging two languages in a single word).

For each one of these contexts the ACH makes distinctive predictions in terms of control process demands. For example, in the context of single or dual-language, goal maintenance and interference control processes are required, presenting overall increasing demand on the speaker's cognitive system. On the contrary, in the dense-code switching, the speaker does not need such a high level of control: both languages can be uttered freely in the same interaction.

Our observation that verbal fluency performance is relatively independent from performance on standard measures of working memory and fluid intelligence in

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multilinguals might be considered consistent with the ACH because the task is performed in a single language context (English), and this model proposes that it is only in a dual-language context (i.e., neither single-language nor dense language switching contexts) that significant recruitment of inhibitory control mechanisms will occur in the bilingual mind. Furthermore, given the model prediction that it is only under dual-language contexts that a bilingual advantage is conferred (for a discussion see Kalamala et al., 2020), the lack of performance differences between our monolingual and bilingual groups across all our tasks (all presented in English) can also be accommodated. Thus, if we assume that all our multilingual participants are frequent (or dense) language switchers and they habitually use both languages in their daily interactions at work and with friends and family, the interpretation seems consistent with the ACH's prediction that active control processes should not required to monitor the currently active language.

We acknowledge the potential limitations of this study that are associated with drawing inferences on lifespan developmental trajectories on the basis of data which are necessarily cross-sectional. However, we also acknowledge that this approach has been successfully demonstrated in previous research (Annaz et al., 2009; Karmiloff-Smith et al., 2004; Thomas et al., 2001; 2009). We therefore encourage further work aimed at understanding how second language learning may alter unity and diversity in the functional organization and network topology of high level cognitive processes across the lifespan, and recommend that such efforts avoid unnecessary focus on the question of whether there is a genuine bilingual cognitive *advantage*.

In conclusion, our findings suggest that the brain may adapt functionally in response to the demands associated with multilanguage acquisition, encouraging convergence and divergence in the functional specificity of the cognitive latent variables revealed

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in patterns of covariation at the behavioural level. It therefore follows that functional mechanisms serving cognitive control may differ between multilinguals and bilinguals but, as the present findings suggest, these differences may not manifest in a performance advantage.

Supplementary Material

The Supplementary Material is available at: qjep.sagepub.com

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Figure Captions

Figure 1. Developmental trajectories of monolingual and multilingual children for accuracy in performing the Tower of London task, measuring planning/reasoning.

Figure 2. Loadings for all children with promax rotation

Figure 3. Loadings for monolingual children with promax rotation

Figure 4. Loadings for multilingual children with promax rotation

Figure 5. Developmental trajectories of monolingual and multilingual adults for phonological and semantic fluency (A and B), inhibitory control (C), accuracy and reaction time in performing the Tower of London task (D and E), and English receptive vocabulary (F).

Figure 6. Loadings for all adults with promax rotation

Figure 7. Loadings for monolingual adults with promax rotation

Figure 8. Loadings for multilingual adults with promax rotation

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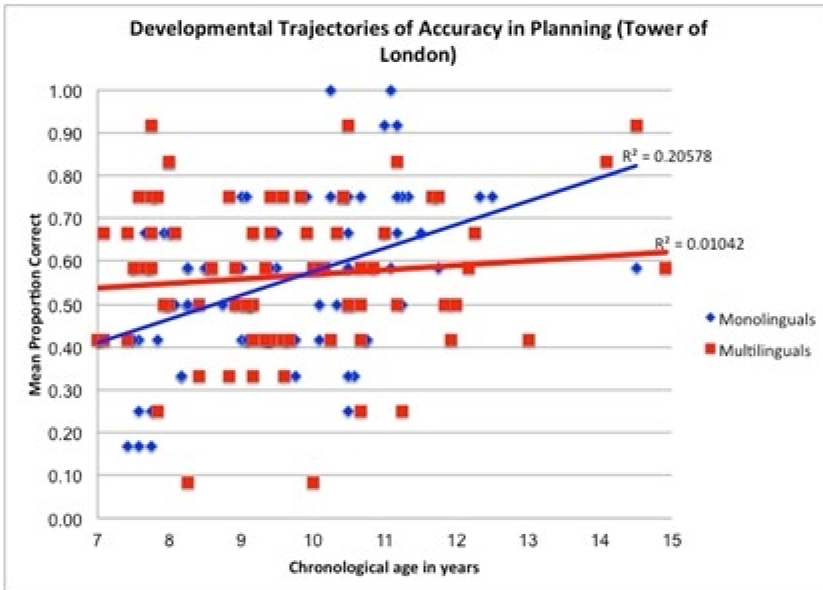

Figure 1. Developmental trajectories of monolingual and multilingual children for accuracy in performing the Tower of London task, measuring planning/reasoning.

146x104mm (72 x 72 DPI)

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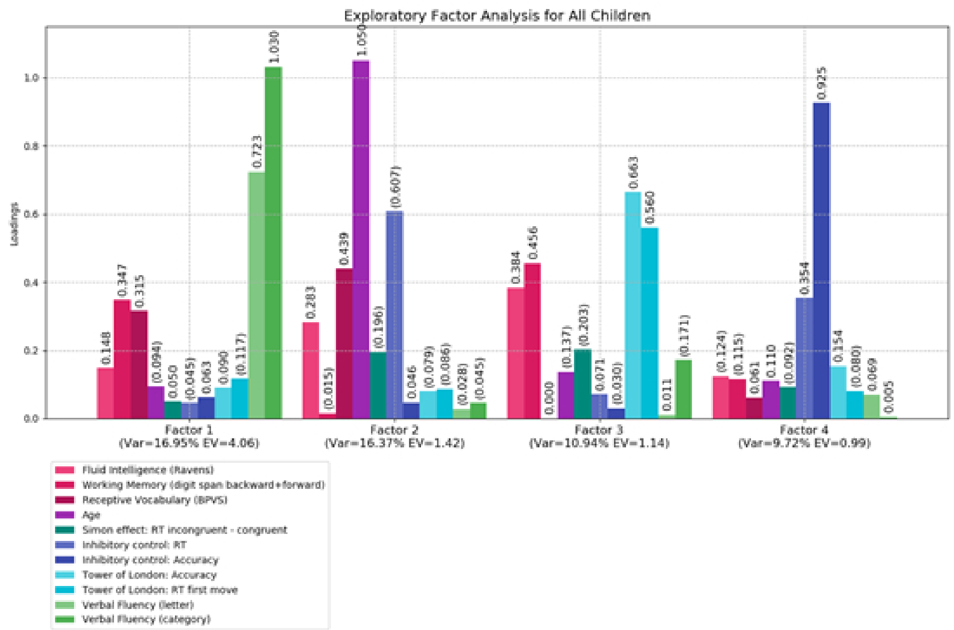

Figure 2. Loadings for all children with promax rotation

374x240mm (39 x 39 DPI)

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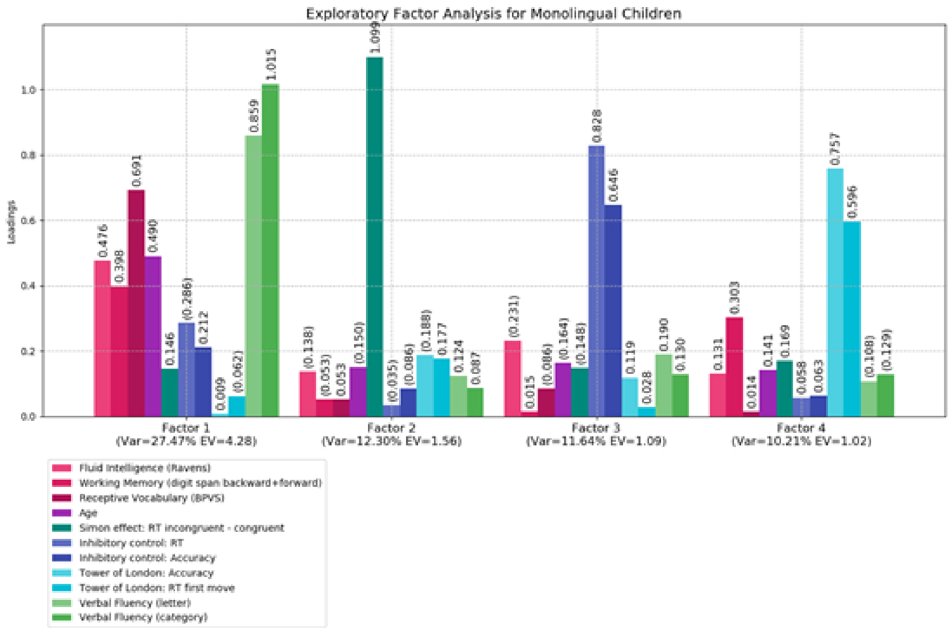

Figure 3. Loadings for monolingual children with promax rotation

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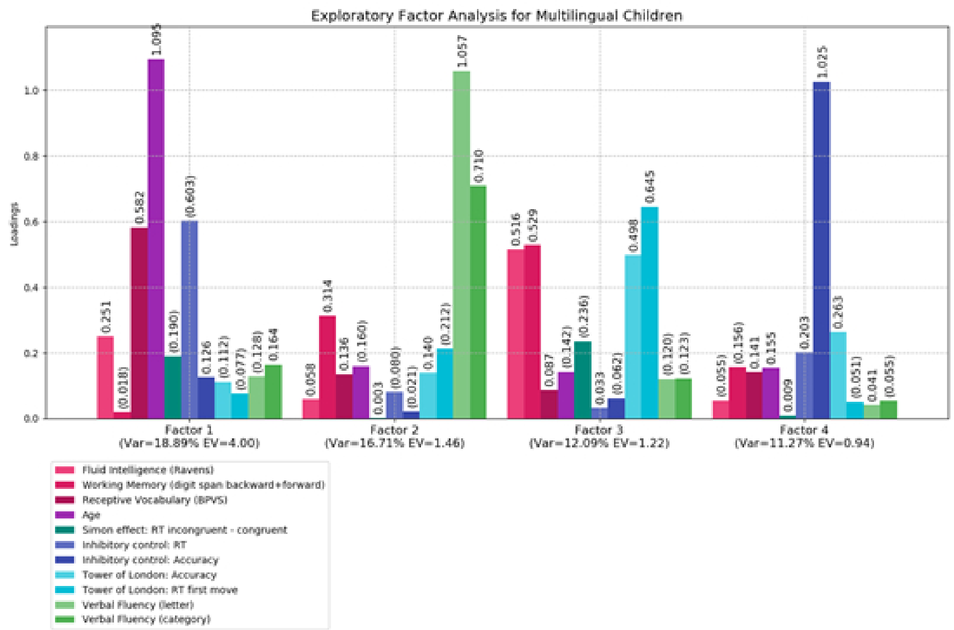

Figure 4. Loadings for multilingual children with promax rotation

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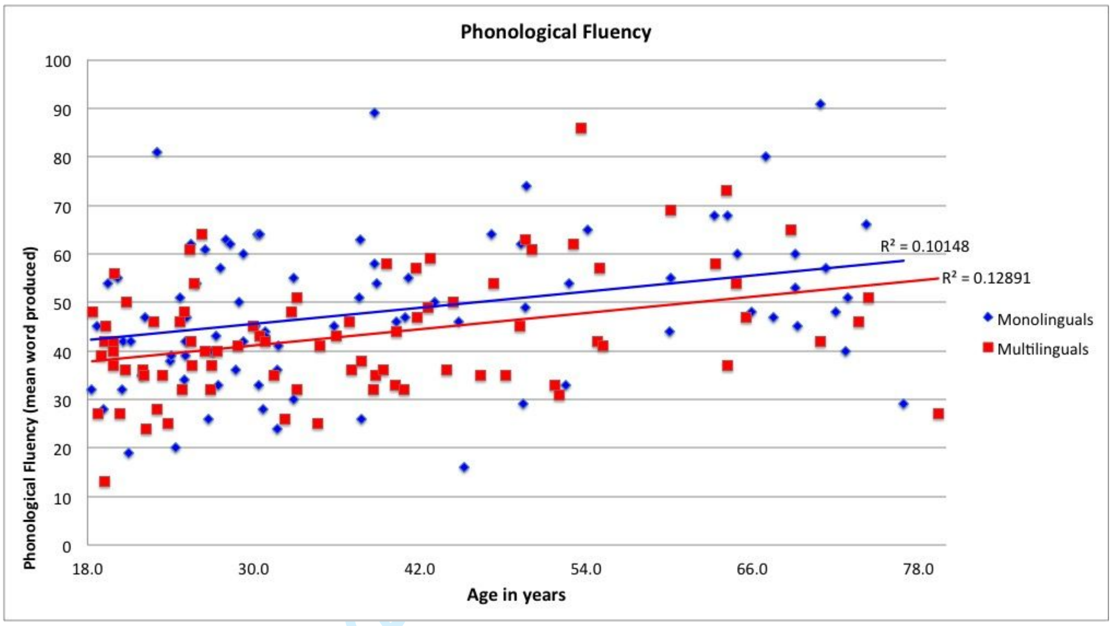
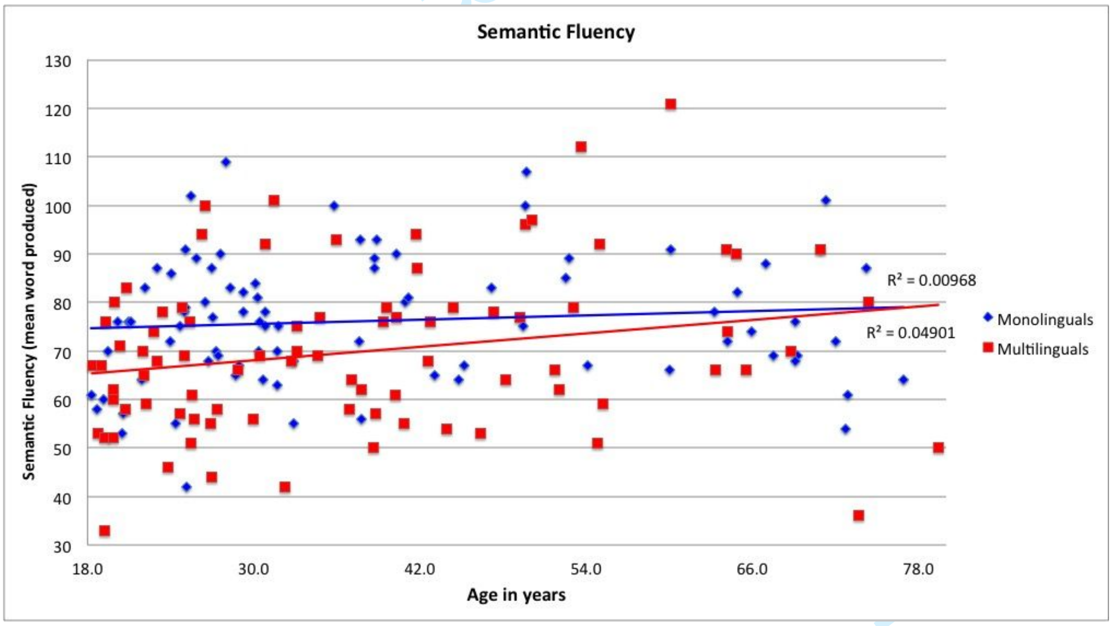


A



B

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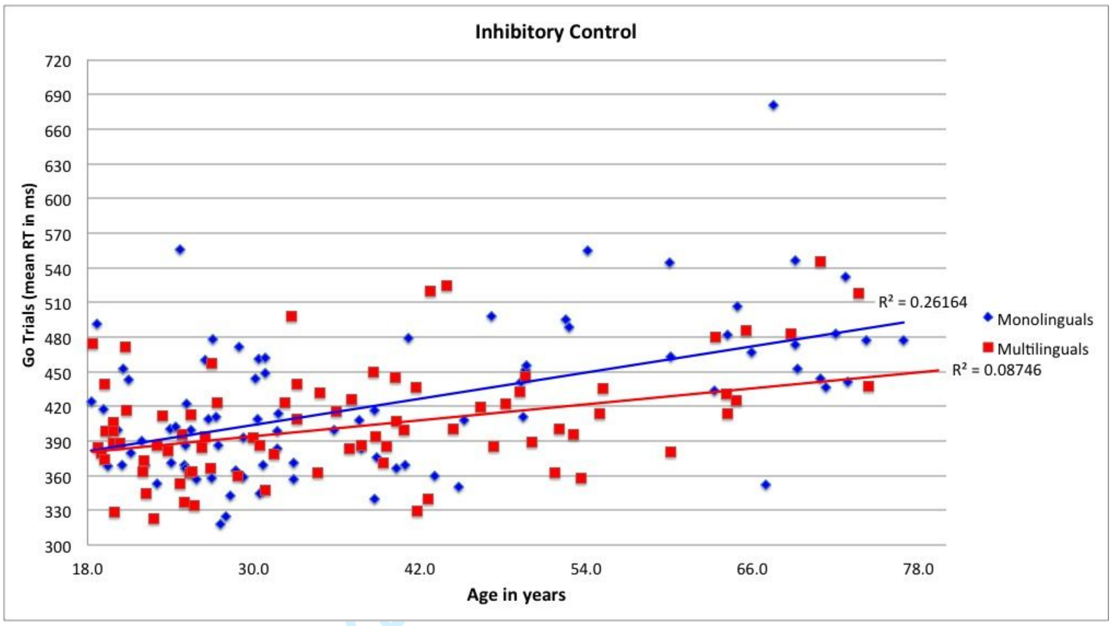
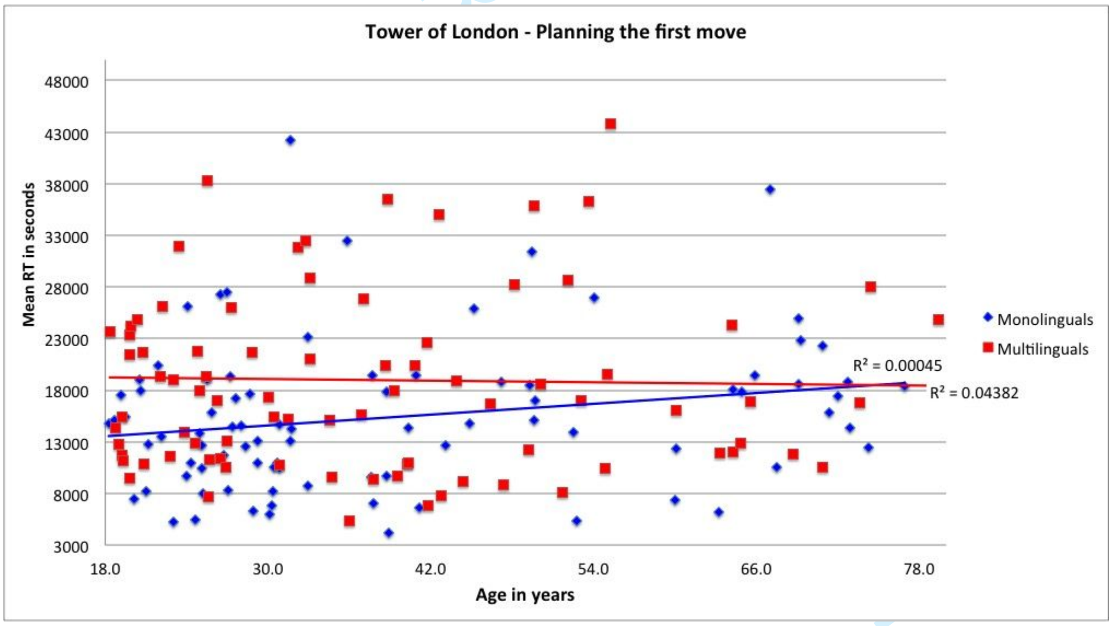


C



D

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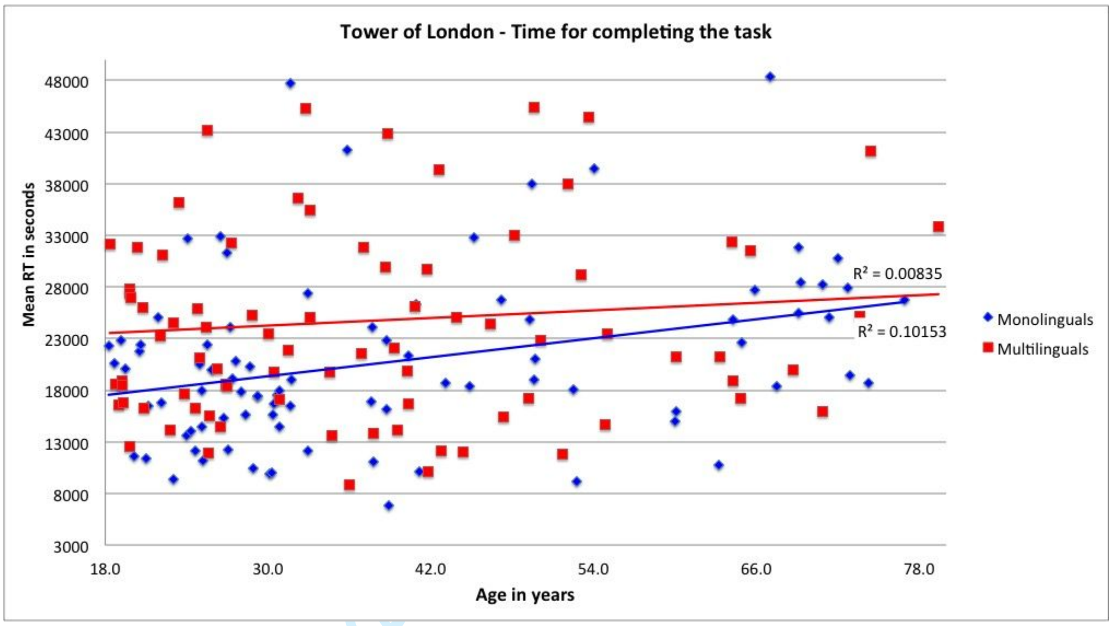
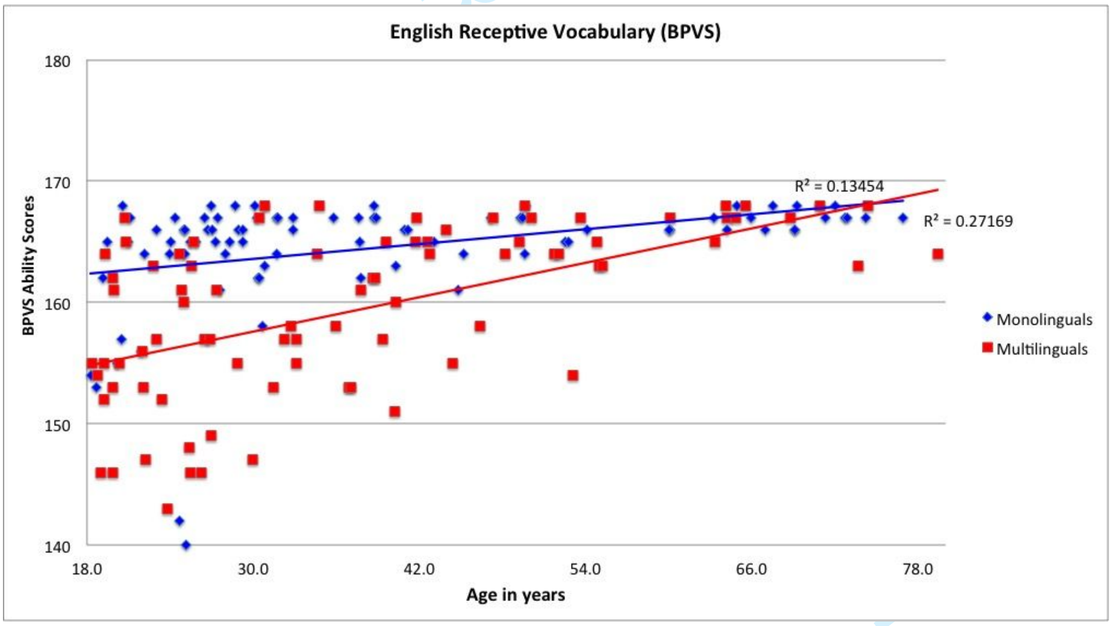


E



F

Figure 5. Developmental trajectories of monolingual and multilingual adults for phonological and semantic fluency (A and B), inhibitory control (C), accuracy and reaction time in performing the Tower of London task (D and E), and English receptive vocabulary (F).

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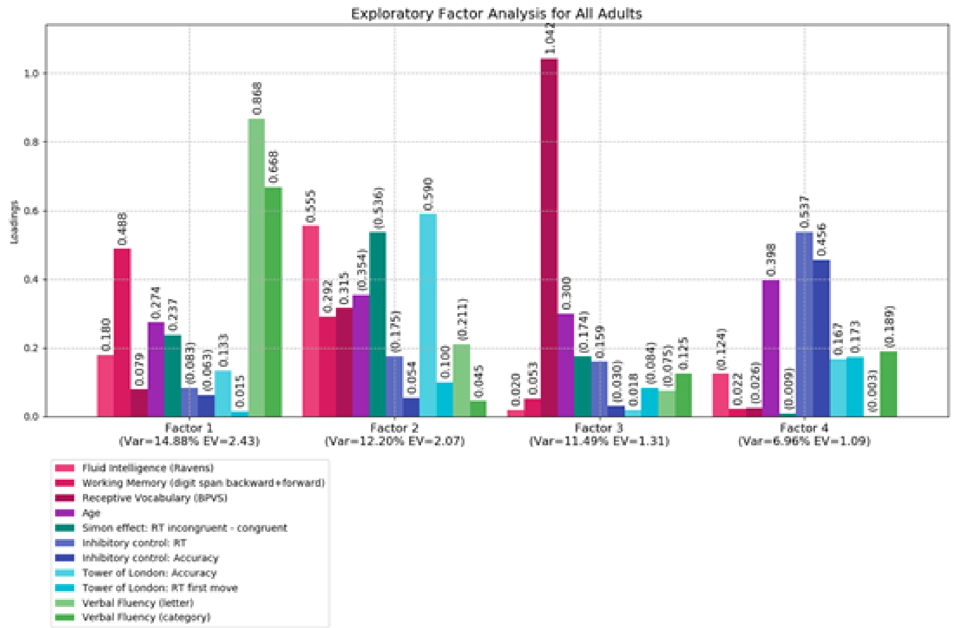

Figure 6. Loadings for all adults with promax rotation

374x240mm (39 x 39 DPI)

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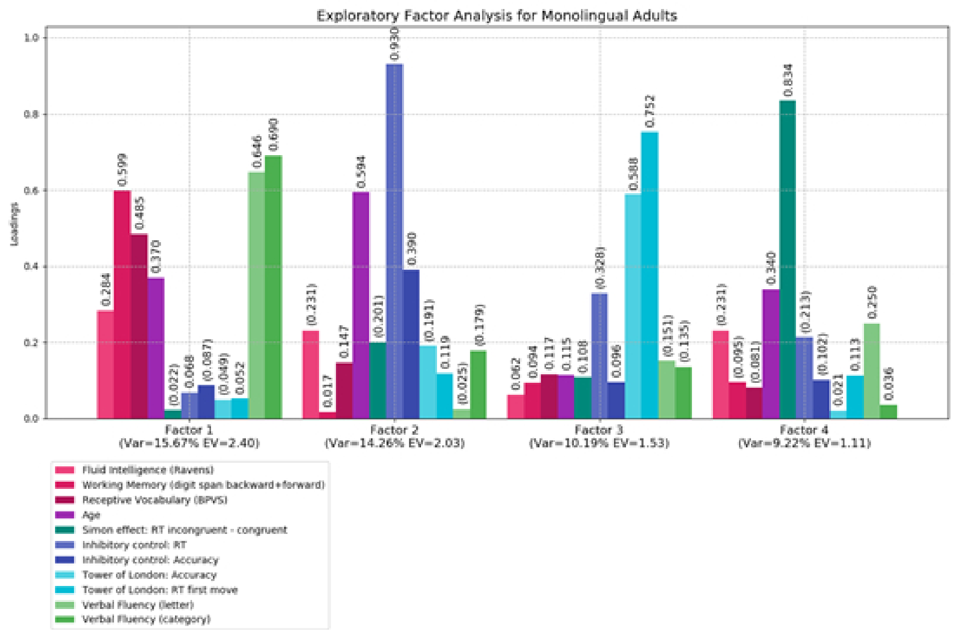

Figure 7. Loadings for monolingual adults with promax rotation

374x240mm (39 x 39 DPI)

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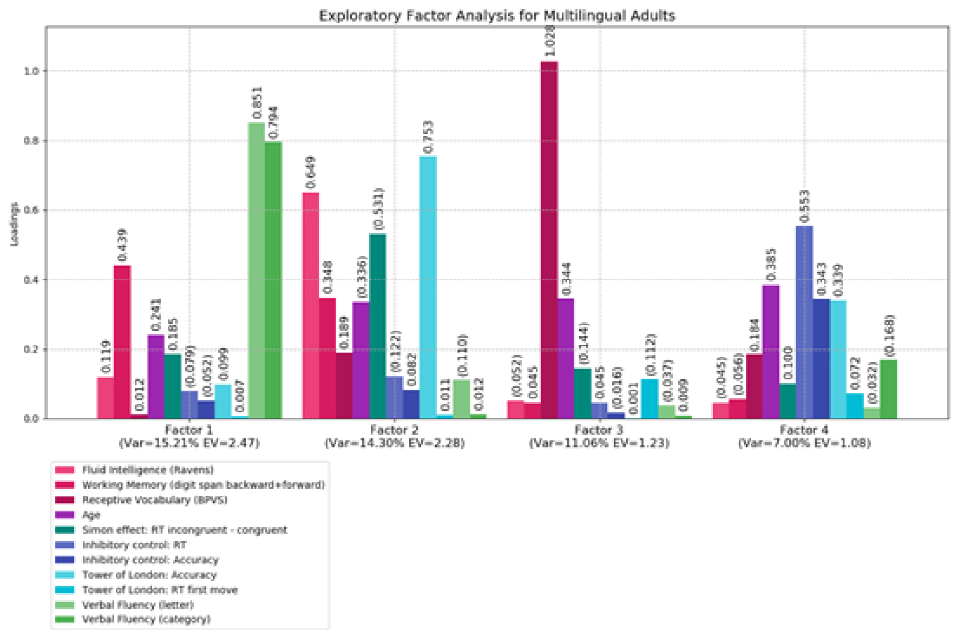

Figure 8. Loadings for multilingual adults with promax rotation

374x240mm (39 x 39 DPI)

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Table 1: Total number of participants divided by age group (in years), linguistic group and gender.

Age Group	Monolinguals Males	Monolinguals Females	Monolinguals Mean age	Multilinguals Males	Multilinguals Females	Multilinguals Mean age	***Tot. Monol.***	***Tot. Mult.***
7-15	39	38	9.5(1.5)	43	34	9.7(1.7)	*77*	*77*
18-80	36	50	39.4(17.4)	26	58	37.8(16.0)	*86*	*84*

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Table 2. The test battery used in the project "An investigation of multilinguistic experience across the lifespan".

Part A
Ping task
Verbal Fluency*
Sentence Interpretation task
Simon task*
Whack-the-mole task*
Part B
Metacognition task
Raven's Progressive Matrices*
Tower of London*
BPVS III*
Digit span (BW+FW)*

* Tasks used in the current study

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Table 3. Means and standard deviations (in brackets) of children's performance in all verbal and nonverbal measures with statistical comparisons between monolingual and multilingual children. Bayes factor shows the likelihood of the null over the alternative hypothesis.

Experimental measures	All	Monolinguals	Multilinguals	*p*	BF_{01}
Raven's *(mean ability score)*	6.7 (2.6)	6.9 (2.5)	6.5 (2.6)	*p=.32*	*4.95*
BPVS *(mean ability score)*	132 (19)	135 (17)	130 (21)	*p=.12**	*2.43*
Digit Span Forward *(mean ability score)*	8.4 (1.7)	8.4 (1.6)	8.5 (1.9)	*p=.72*	*7.48*
Digit Span Backward *(mean ability score)*	5.3 (1.9)	5.3 (1.8)	5.3 (2.1)	*p=.90*	*7.91*
Verbal fluency *letter (mean ability score)*	25.0 (9.8)	23.8 (8.6)	26.16 (10.9)	*p=.15*	*2.92*
Verbal fluency *category (mean ability score)*	45.0 (12.9)	46.1 (12.3)	43.9 (13.4)	*p=.29*	*4.59*
Simon effect (*RT incongruent - congruent in ms)*	67.0 (48.1)	68.4 (50.7)	65.7 (45.7)	*p=.74*	*7.54*
Go/No-go task *accuracy*	82% (11)	82% (11)	82% (12)	*p=.83*	*7.96*
Go/No-go task *reaction time* **(***ms)*	517 (79.5)	526 (74)	509 (84)	*p=.18*	*3.36*
Tower of London *accuracy*	56% (18)	55% (18)	56% (18)	*p=.63*	*7.12*
Tower of London *RT first move (secs)*	13 (9)	12 (7)	14 (10)	*p=.21*	*3.77*
Tower of London *RT (secs)*	21 (10)	20 (10)	22 (11)	p=.26	4.28

** Where equal variance was not assumed the corrected p value was used.*

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Table 4. Means and standard deviations (in brackets) of adults' performance in all verbal and nonverbal measures with statistical comparisons between monolinguals and multilinguals. Bayes factor shows the likelihood of the null over the alternative hypothesis. Statistically significant results are in bold and trends are underlined.

Experimental measures	All	Monolinguals	Multilinguals	*p*	BF_{01}
Raven's *(mean ability score)*	9.5 (2.1)	9.7 (2.0)	9.3 (2.3)	*p=.29*	*4.81*
BPVS *(mean ability score)*	162 (6.6)	165 (4.8)	159 (7.2)	***p<.001***	*0.00*
Digit Span Forward *(mean ability score)*	11.5 (2.4)	11.4 (2.3)	10.7 (2.4)	*p=.13*	*2.68*
Digit Span Backward *(mean ability score)*	8.2 (2.3)	8.2 (2.6)	8.3 (2.3)	*p=.65*	*7.57*
Verbal fluency *letter (mean ability score)*	45.7 (14.0)	48.2 (15.1)	43.3 (12.4)	***p=.02***	*0.69*
Verbal fluency *category (mean ability score)*	73.1 (15.2)	76.2 (13.0)	69.8 (16.6)	***p=.006***	*0.22*
Simon effect (*RT incongruent - congruent in ms)*	54.4 (46.0)	51.2 (47.0)	57.7 (45.0)	*p=.36*	*5.54*
Go/No-go task *accuracy*	89.6% (8)	89.5% (9)	89.7% (8)	*p=.91*	*7.96*
Go/No-go task *reaction time* **(***ms***)**	412 (63)	422 (64)	403 (62)	*p=.06*	*0.22*
Tower of London *accuracy*	77% (17)	79% (13)	76% (20)	*p=.30*	*5.01*
Tower of London *RT first move (secs)*	17 (9)	15 (7)	19 (10)	***p=.008***	*0.28*
Tower of London *RT (secs)*	23 (10)	21 (8)	25 (11)	***p*=.008**	0.28

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