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Inhibition and Switching in Healthy Aging: A Longitudinal Study

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Abstract

Objectives: Discrepant findings of age-related effects between cross-sectional and longitudinal studies on executive function (EF) have been described across different studies. The aim of the present study was to examine longitudinal age effects on inhibition and switching, two key subfunctions of EF, calculated from results on the Color Word Interference Test (CWIT). **Methods:** One hundred twenty-three healthy aging individuals (average age 61.4 years; 67% women) performed the CWIT up to three times, over a period of more than 6 years. Measures of inhibition, switching, and combined inhibition and switching were analyzed. A longitudinal linear mixed effects models analysis was run including basic CWIT conditions, and measures of processing speed, retest effect, gender, education, and age as predictors. **Results:** After taking all predictors into account, age added significantly to the predictive value of the longitudinal models of (i) inhibition, (ii) switching, and (iii) combined inhibition and switching. The basic CWIT conditions and the processing speed measure added to the predictive value of the models, while retest effect, gender, and education did not. **Conclusions:** The present study on middle-aged to older individuals showed age-related decline in inhibition and switching abilities. This decline was retained even when basic CWIT conditions, processing speed, attrition, gender, and education were controlled. (*JINS*, 2017, *23*, 90–97)

Keywords: Executive functions, Cognitive control, Stroop, Cognitive flexibility, Cognitive aging, Longitudinal

INTRODUCTION

Various cognitive functions are known to decline with age (Salthouse, 2012a), but there is no consensus regarding its trajectory. While cross-sectional studies indicate a linear decline from early adulthood into advanced age (Nilsson, 2012; Rönnlund, Nyberg, Bäckman, & Nilsson, 2005), longitudinal studies show relative stability until around the age of 60 years with a steeper decline thereafter (Nyberg, Lövdén, Riklund, Lindenberger, & Bäckman, 2012; Salthouse, 2009, 2010, 2012b). Furthermore, findings appear to vary depending on definitions and methods used to assess cognitive functions, the selected statistical procedure, and inclusion of information about retest effects (Goh, An, & Resnick, 2010; Rönnlund et al., 2005; Salthouse, 2012b; Van der Elst, Van Boxtel, Van Breukelen, & Jolles, 2006, 2008; Wilson et al., 2002).

Executive functions (EF), defined as "higher-level cognitive functions involved in the control and regulation of lower cognitive operations" (Stuss & Levine, 2002; p. 426), are affected as a part of normal as well as pathological aging (Diamond, 2013). This makes tests of EF popular among clinical neuropsychologists. It is, however, challenging to construct "pure" measures of the sub-functions of EF, in that performance on most EF tasks is dependent on both basic non-EF skills and the more cognitively demanding functions used to define the concept. Thus, impairment of any of these may have a negative impact on test performance (Kramer et al., 2007).

Inhibition and switching abilities are described as two key sub-functions of EF (Miyake et al., 2000). So far, there is no consensus about the effect of age on these. Both cross-sectional (Bugg, DeLosh, Davalos, & Hasker, 2007; Cepeda, Kramer, & Gonzalez de Sather, 2001; Delis, Kaplan, & Kramer, 2001; Head, Rodrigues, Kennedy, & Raz, 2008;

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Kennedy & Raz, 2009; Klein, Ponds, Houx, & Jolles, 1997; Troyer, Leach, & Strauss, 2006; Van der Elst et al., 2006; Wecker, Kramer, Hallam, & Delis, 2005; Wolf et al., 2014) and longitudinal studies (Goh et al., 2010; Kramer, Hahn, & Gopher, 1999; Van der Elst, Molenberghs, Van Boxtel, & Jolles, 2013) have demonstrated an age-related decline in the ability to inhibit irrelevant stimuli and switch between task demands.

Other studies have found performance to be stable across age, or have related observed decline to a more general slowing of information processing (Salthouse, 1996; Verhaeghen, 2011; Verhaeghen & De Meersman, 1998; Wheatley, Scialfa, Boot, Kramer, & Alexander, 2012; Zysset, Schroeter, Neumann, & von Cramon, 2007). Results from cross-sectional studies of inhibition and switching have shown varying results depending on whether basic non-EF skills are taken into account (Adólfsdóttir et al., 2014; Kramer et al., 2007; Pa et al., 2010). Additional studies of age-related changes in inhibition and switching controlling for factors that may mask or exaggerate the effect of age are thus called for.

Stroop task measures are commonly used to assess EF in both clinical and research settings (Alvarez & Emory, 2006; Lezak, Howieson, & Loring, 2004). The classical Stroop task (Stroop, 1935) includes two basic conditions of color naming and word reading. A third condition requires subjects to name the incongruent color of the ink of each printed word. Under this condition, the automatic reading response is assumed to interfer with the less automated response of naming the ink color. This interference is referred to as the *Stroop effect*.

The Color Word Interference Test (CWIT) from the Delis-Kaplan Executive Function System (D-KEFS; Delis, Kaplan, & Kramer, 2001) adds a fourth condition. Here, the subject is asked to *switch* between the more automatic task of reading the word, and the less automated task of naming the incongruent ink color (requiring *inhibition*). Due to the additional demands of task switching, this condition is assumed to be more cognitively demanding than the third condition (Delis et al., 2001). By including all four conditions, more salient measures of the EF components of inhibition and switching can be calculated by taking more basic conditions into account (Adólfsdóttir et al., 2014).

The aim of the present longitudinal study was to investigate age-related changes in such salient CWIT measures of inhibition and switching. As already reviewed in this section, age-related changes may be explained by a corresponding decline in processing speed, and retest effects may mask a true effect of age. These factors were, therefore, included as predictors together with the more basic CWIT conditions (color naming and word reading) and demographic variables (gender, education, and age) in a mixed effects statistical model, a procedure that allowed us to take into account individual differences on the outcome variables at baseline and to handle differences in time-spans between assessments, attrition, and correlation structures of individual participants. We expected age to be a significant predictor of inhibition and switching even when all these factors were taken into account.

METHODS

Participants

The participants were part of an ongoing longitudinal study on cognitive aging, brain function, and genetic markers. The study included three assessment points, where the participants took part in a neuropsychological examination. The mean interval between assessment points 1 and 2 was 3.62 years and 3.31 years between assessment points 2 and 3 (see Table 1). All assessments included the Norwegian version of the D-KEFS CWIT (Delis et al., 2001). Participants were recruited through local newspaper advertisements. All participants were native speakers of Norwegian, had completed basic obligatory education (7 years in this cohort), and were living independently in their homes during all study assessment points. A self-reported history of substance abuse, present neurologic or psychiatric disorder, head trauma, or other significant medical conditions was used as an exclusion criterion.

A total of 163 individuals participated at the first assessment point. The present study included only participants with complete data on the CWIT from at least two assessment points ($n = 130$). From this sample, five participants were excluded due to a Beck Depression Inventory score >19 (BDI-II; Beck, Steer, & Brown, 1987), one with a Mini Mental Status Examination score <25 (MMSE; Folstein, Folstein, & McHugh, 1975), and one with an IQ score <80, leaving a total of 123 participants in the final sample (see Table 1 for demographic information).

The final sample included more females than males (67%/33%), with an age range of 46 to 77 years, education between 8 and 20 years and a full-scale score on a test of intellectual function between 83 and 137. All participants gave their written informed consent to participate in the study. The Regional Committee for Medical and Health Research Ethics, Southern Norway, approved the procedure for assessment point 1, while assessment points 2 and 3 were approved by the Regional Committee for Medical and Health Research Ethics, Western Norway.

Measures and Procedures

Trained research assistants administrated a comprehensive neuropsychological test battery to all participants at each assessment point, in a quiet room. For this study, a score of intellectual function (IQ), estimated from performance on the Vocabulary and Matrix Reasoning subtests from the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999), and the Mini Mental State Evaluation (MMSE; Folstein et al., 1975) were included to select participants for the present study. Performance on the Digit Symbol Test from Wechsler Adult Intelligence Scale-Revised (Wechsler, 1981) was included to control for processing speed, as this factor is described as a main cognitive contributor to the performance on this multifaceted test (Joy, Kaplan, & Fein, 2004).

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Table 1. Demographic information for participants in the present study (n = 123)

	Assessment point 1			Assessment point 2			Assessment point 3		
	N	*M*	*SD*	*N*	*M*	*SD*	*N*	*M*	*SD*
Age (years)	122	61.04	7.56	123	64.56	7.51	100	67.03	7.29
Gender (male/female)[a]	122	40/82		123	41/82		100	32/68	
Education (years)	122	13.72	3.28						
FSIQ	119	115.87	11.78						
MMSE				122	28.93	1.02	100	29.10	1.27
BDI	121	5.82	3.85	120	5.63	4.26	98	4.73	3.63
Digit Symbol Test	122	49.06	9.94	122	47.51	11.49	100	48.07	11.80
Follow up time — assessment 1 to 2				123	3.49	0.46			
Follow up time — assessment 2 to 3							99	3.03	0.50
CWIT — Color	122	30.08	5.67	123	30.61	5.55	100	30.34	6.17
CWIT — Word	122	21.21	3.43	123	21.82	3.48	100	22.13	4.02
CWIT — Inhibition	122	56.66	14.03	123	56.35	12.96	100	56.50	13.70
CWIT — Inhibition/Switching	122	63.13	14.59	123	64.44	16.59	100	68.73	22.91

[a]Frequency
FSIQ = Full Scale Intelligence Quotient;MMSE = Mini Mental Status Examination (MMSE; Folstein, Folstein, & McHugh, 1975);
BDI-II = Beck Depression Inventory (BDI-II; Beck, Steer, & Brown, 1987);
CWIT = The D-KEFS Color Word Interference Test (Raw scores) (CWIT; Delis et al., 2001).

The CWIT (Delis et al., 2001) was used to assess inhibition and switching as well as the basic conditions controlled for in the statistical analyses. The CWIT consists of four conditions, with the first three conditions based directly on the original Stroop test (Stroop, 1935). The first condition presents 50 color patches in three different colors: red, blue, and green, and the task is to name the colors. Under the second condition, subjects are presented the written words of the same three colors, 50 times, and asked to read the words. The third condition presents the same three color words as before, printed in an incongruent ink color. The subject's task is to name the ink color of each of the 50 words, a task that is assumed to require inhibition of the more automatized response of word reading. The fourth condition requires subjects to switch between reading incongruently colored words (25 words) and naming the ink colors (25 words), depending on whether the words are printed inside a black border.

The condition aims to measure the combined ability to inhibit the reading response, and to switch between different conditions (Delis et al., 2001). Stimuli for each condition are printed on separate sheets with white backgrounds, with subjects being asked to give their responses as quickly and correctly as possible. In the present study, the outcome measure for each condition was the time spent to complete the given task (response time), recorded using a stopwatch.

Statistical Analysis

Descriptive statistical analyses were performed using SPSS 21.0.0.0, while R 2.15.3 (R Development Core Team, 2013) was used for the longitudinal analyses.

Drop out analysis

An independent *t* test was calculated to investigate whether the performance of the included participants differed from performance of those participants who dropped out between assessment points.

The longitudinal analysis

The longitudinal analysis was performed using linear mixed effects models (LMM) (Galecki & Burzykowski, 2013) with the lme4 package for R (Bates, Maechler, Bolker, & Walker, 2015). For exploratory covariate selection, we followed recommendations of West, Welch, and Galecki (2014) of using top–down model-building approach, where the initial model includes the maximum number of fixed effects, with terms eliminated backward. As argued by Mantel (1970) as well as Royston and Sauerbrei (2008), this approach is especially appropriate when predictors are intercorrelated, as was the case in our study. In each step, the effect of dropping the last remaining fixed effect from the model is tested until no predictor term remains.

The use of *p*-values and confidence intervals (CIs) for inference on model parameters from χ^2 Likelihood Ratio Tests in LMM was shown to be potentially anti-conservative (Pinheiro & Bates, 2000). Therefore, a more appropriate *F* test was used with degrees of freedom (df) approximated using the Kenward-Roger procedure as implemented in the package pbkrtest for R (Halekoh & Højsgaard, 2014). Each covariate effect is tested in three models. Applying Bonferroni correction for multiple testing, *p*-values lower than 0.05/3 = 0.0167 are reported as statistically significant

To visually examine the distribution of the residuals, we used histograms and quantile–quantile plots (Q-Q plots) that display the empirical quantiles of the residuals against the corresponding normal quantiles. R^2 is reported as per the recommendations of Nakagawa and Schielzeth (2013). Variance inflation factors (VIF) were <2 for all predictor variables, indicating no severe multicollinearity problems.

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CWIT variables

Raw scores from CWIT conditions 3 and 4 (inhibition and inhibition/switching) were log-transformed and used as outcome variables in the LMM models (Baayen & Milin, 2010). To isolate the additional cognitive demands of inhibition and switching, we included the basic CWIT conditions used to calculate the primary CWIT contrast measure according to the D-KEFS manual (Delis et al., 2001), and to generate salient measures of inhibition and switching as described in previous papers from our research group (Adólfsdóttir et al., 2014; Halleland, Haavik, & Lundervold, 2012). The conditions included are listed in Table 2 for each of the outcome variables. Additional factors controlled for were processing speed, retest effect, gender, and education (see below), all known to affect cognitive function (Van der Elst et al., 2006, 2008).

Retest effect

The method recommended by Ferrer, Salthouse, Stewart, and Schwartz (2004) was used to evaluate the effect of retest. This method uses a binary dummy variable coding for the retest status of a measure. The variable was coded as “retest” when a given task was completed a second or third time. It is thus assumed that practice effects mainly occur between the baseline and first follow-up testing, without any additional effects from the third time. This approach was used in a longitudinal study of cognitive abilities and olfaction (Finkel, Reynolds, Larsson, Gatz, & Pedersen, 2011; Wehling, Wollschläger, Nordin, & Lundervold, 2016) as well as in a longitudinal study of age and gender effects on episodic memory (Lundervold, Wollschläger, & Wehling, 2014).

Predictors

When modeling the possible longitudinal effect of age, separate models were made for each of the three executive function processes: inhibition, switching, and combined inhibition/switching. The full model for each outcome variable included the basic condition(s) needed to calculate primary contrast measures (Delis et al., 2001), measures of general processing speed and retest effect, and the effects of gender, education, and age. By including a random intercept effect for individual subjects, our models also take into account the heterogeneity in individual performance for the outcome variables at baseline (see models in Table 2).

RESULTS

Dropout and Test–Retest Reliability

An independent Bonferroni corrected *t* test analysis of CWIT raw scores showed no statistically significant differences between participants who dropped out between assessment points, and those included in the present study (see Appendix A).

Table 2. Statistical models for the a) inhibition, b) inhibition/switching and c) switching process

Model	Effects tested	F	ndf	ddf	*p*	Estimate	*SE*	t
a) Inhibition								
1	Age effect	13.00	1	173.00	***<.001***	0.00606	0.00165	3.7
2	Effect of education	4.78	1	121.50	*.03*	−0.00880	0.00396	−2.2
3	Gender effect	0.78	1	123.41	*.38*	0.02498	0.02829	0.9
4	Retest effect	0.74	1	225.35	*.39*	−0.00967	0.01114	−0.9
5	Processing speed	16.10	1	306.80	***<.001***	−0.00419	0.00103	−4.1
6	Effect of color naming	84.50	1	284.30	***<.001***	0.01780	0.00191	9.3
b) Inhibition/Switching								
1	Age effect	10.60	1	160.80	***<.002***	0.00720	0.00216	3.3
2	Effect of education	0.71	1	126.73	*.40*	−0.00442	0.00518	−0.9
3	Gender effect	1.10	1	123.80	*.30*	−0.03861	0.03604	−1.1
4	Retest effect	0.13	1	226.19	*.72*	0.00578	0.01614	0.4
5	Processing speed	23.00	1	277.00	***<.001***	−0.00677	0.00139	−4.9
6	Effect of color naming and *word reading*	19.90	2	307.00	***<.001***	0.01271	0.00389	3.3
	Effect of *color naming* and word reading					0.00991	0.00290	3.4
c) Switching								
1	Age effect	6.42	1	154.55	***.0165***	0.00526	0.00204	2.6
2	Effect of education	0.28	1	121.12	*.60*	−0.00250	0.00466	−0.5
3	Gender effect	1.22	1	122.29	*.27*	−0.03650	0.03247	−1.1
4	Retest effect	1.16	1	224.54	*.28*	0.01734	0.01830	1.1
5	Processing speed	20.20	1	276.00	***<.001***	−0.00584	0.01601	−4.6
6	Effect of inhibition	75.20	1	250.60	***<.001***	0.00868	0.00099	8.8

Note. ndf = numerator degrees of freedom; ddf = denominator degrees of freedom based on Kenward-Roger approximation. Bonferroni-corrected alpha level = 0.05/3 = 0.0167.

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Longitudinal Analysis

The longitudinal analysis revealed that age added statistically significantly to the predictive accuracy of the full models for each of the three EF variables (inhibition, switching, and combined inhibition / switching) (Table 2), after controlling for the basic CWIT conditions, processing speed, retest effect, gender, and education. Additionally, the basic CWIT conditions and processing speed added significantly to the predictive accuracy of the models for all the EF variables, while the effects of retest, gender, and education were non-significant (Table 2). The model for inhibition predicted that for each year passed, the log inhibition score increases by 0.0061 units, that is, the raw response time for males increased by a factor of $e^{0.0061} = 1.0061$, or by 0.61% per year. The model for the combined inhibition/switching score predicted that for each additional year, the log inhibition/switching score would increase by 0.0072 units, corresponding to a year-on-year response time increase for males by a factor of $e^{0.0072} = 1.0072$, or 0.72%. The model for switching score predicted that for each additional year, the log switching score increased by 0.0053 units, corresponding to a raw response time increase factor of $e^{0.0053} = 1.0053$, or a 0.53% per year for males.

As stated above, the differences between females and males were marginal, with a year-on-year increase in females of 0.62%, 0.70% and 0.51%, respectively. The marginal R^2 as defined by Nakagawa and Schielzeth (2013) indicated that the amount of variation explained was 79% for the inhibition model, 69% for the switching model, and 70% for the full model for combined inhibition and switching (conditional $R^2 = 0.43\%$, 0.36%, and 0.29%, respectively). The importance of using linear mixed models to account for the clustered error variance due to non-independence of observations from the same subject was demonstrated by estimated intraclass correlation coefficients between 0.49 and 0.68. A visual inspection of Q-Q plots and histograms showed acceptable distribution of the residuals for all models.

DISCUSSION

The present study investigated age-related cognitive changes in the EF sub-functions of inhibition and switching, derived from the CWIT, while controlling for basic CWIT conditions, a measure of processing speed, and measures of retest effects, gender, and education. Age, the basic CWIT conditions, and the processing speed measure added significantly to the explained variance of the inhibition, switching, and the combined inhibition/switching measures, while the retest effects, gender, and education failed to contribute.

The present findings support studies demonstrating longitudinal age-related decline in EF (Goh et al., 2010; Van der Elst et al., 2013). Results from previous cross-sectional studies (Adólfsdóttir et al., 2014; Halleland et al., 2012), where different components of EF subtests were parsed out, showed that a considerable variance in inhibition and/or switching performance was left unexplained. We, therefore, added two measures expected to improve these predictions: measures of processing speed and the effect of retest.

Processing speed is known to affect performance on all Stroop conditions (Joy et al., 2004), but its influence may be different on the basic conditions of color naming and word reading than on the more cognitively demanding conditions assessing inhibition and switching. We, therefore, added a processing speed measure with a high load on cognitive capacity, the Digit Symbol Test (Lezak et al., 2004). Although the current results showed that this measure added to the predictive accuracy of the statistical models for all our selected EF measures, the association between progressing age and a decline in inhibition and switching was left statistically significant.

By this, the results seem to contradict Salthouse's Processing Speed theory (Salthouse, 1996). The theory states that increased age is associated with a reduction in processing speed, which in turn influences higher order cognitive functions, including EF. Salthouse (1996) argues that EF measures do not uniquely contribute to age-related cognitive decline when this general slowing is accounted for. Our results rather lend some support to the Inhibitory Deficit Theory by Hasher and Zacks (1988): an age-related decline in performance on the inhibition and the inhibition/switching measures was retained even after a rigorous control of basic test conditions and processing speed.

The concept of inhibition is, however, complex and embraces different types (Friedman & Miyake, 2004; Nigg, 2000). This was not taken into account in the present study. When calculating a measure of switching, we only controlled for one aspect of inhibition, that is, inhibition of a prepotent response. Other aspects of inhibition that may be intrinsic to the switching process were thus left unexplored (Friedman & Miyake, 2004; Kiesel et al., 2010; Koch, Gade, Schuch, & Philipp, 2010).

Inclusion of information about retest effects, which is commonly ignored in research on cognitive aging (Salthouse & Tucker-Drob, 2008), is another strength of the present study. Comparing performance on a test at baseline with performance in a retest situation may mask age-related decline if the two effects are not separated in longitudinal studies: the effect of practice may inflate the scores obtained on the second assessment point (Ferrer, Salthouse, McArdle, Stewart, & Schwartz, 2005; Ferrer et al., 2004). Inclusion of the retest effect as a control variable should, therefore, be imperative in longitudinal studies. The lack of retest effect in our study was thus a bit surprising. It may reflect that older adults are less prone to practice effects than younger adults (Calamia, Markon & Tranel, 2012; Salthouse, 2010; Salthouse & Tucker-Drob, 2008). However, this is contradicted by results from previous studies showing retest effects on verbal memory function (Lundervold et al., 2014) and odor identification (Wehling et al., 2016). From this, effects on performance from prior experience seem not to be uniform across cognitive domains.

The lack of retest effects may also be explained by its close link to processing speed: when repeating a task, much of the

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gain is due to faster response time. The retest effect of the Digit Symbol Test, used to assess processing speed, may thus have disguised a retest effect on the outcome variable. This conclusion is supported by the retest effect on the Digit Symbol Test documented in a recent study on olfaction (Wehling et al., 2016). Finally, our coding of a retest effect from the first to the second assessment may also be relevant. Although this first effect may be strong, effects of subsequent practice cannot be excluded.

Higher education has previously been linked to superior performance (Van der Elst et al., 2006, 2008). The present study showed no effect of education and no effect of gender on the selected EF measures. Although these results are in line with findings by Troyer et al. (2013), we assume that the high estimated IQ in the present sample may have contributed to these findings. With a high IQ, the effects of education and gender on cognitive function may have been partly outweighed.

STRENGHS AND LIMITATIONS

The main strengths of the present study are related to its longitudinal design, inclusion of relevant control variables, and the use of a statistical procedure correcting for attrition and measurement intervals, and taking individual differences at baseline into account when modeling age-related change (cfr. Salthouse & Soubelet, 2014). Previous studies including an age to time interaction term have revealed a steeper age-related effect for older than younger individuals (Van der Elst et al., 2013), with the steepest decline from the age of 60 (Nyberg et al., 2012). The narrow age band in the present study restricted such an analysis. On the other hand, the significant findings even within this age band emphasize the strength of the age effect on the measures of inhibition and switching included in the present study.

Differences between methods used to assess EF represent a general challenge to interpretation of results from studies of inhibition and switching. The present results are based on performance on a paper-and-pencil task, with switching between two qualitatively different tasks: one highly automated (word reading) and the other requiring inhibition of this automated response in favor of naming the color of the ink. However, inhibition and switching can be assessed by a range of tests, for example, other tests within the D-KEFS battery, and by computer based tests yielding more fine-tuned reaction time measures (Westerhausen, Kompus, & Hugdahl, 2011). Still, we expect that the frequent use of the D-KEFS version of the Stroop task in current clinical and research practice will make our results of interest to a large audience.

The Digit Symbol Test is a multifaceted test used to control for processing speed in the present study. Although the processing speed component is described as a main cognitive contributor to the performance on the test (Joy et al., 2004), we cannot rule out the influence from other cognitive and motor aspects of the test measure.

The use of only one measure of processing speed and one subtest assessing EF should also be listed as a limitation. The time frame of the neuropsychological examination did, however, not allow inclusion of a larger number of tests. A more extensive examination could have enabled a more extensive investigation of factors influencing the multifaceted concepts of inhibition and switching.

The mean Full Scale Intelligence Quotient in our study was higher than average, which may restrict the generalizability of our findings. In that our statistical procedure takes into account individual differences, we still believe that our findings can be used to reflect cognitive function in middle aged and older adults.

Both reaction time and errors are assessed from performance on the CWIT. The current study did not explore the effect of age on errors. A focus on reaction time measures was inspired by Starns and Ratcliff (2010), showing that older individuals tend to respond slower rather than making errors.

CONCLUSION

The present longitudinal study confirmed age-related changes in the inhibition and switching components of EF in middle-aged and older adults. The main contribution of the present study was to show that this effect remained statistically significant even after controlling for basic CWIT conditions, measures of processing speed, retest effects, gender, and years of education. Given that the measures included in the current study are commonly used in both clinical and research settings, we believe that this knowledge is potentially of great importance to the accurate assessment of EF in this age group.

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Supplementary material

To view supplementary material for this article, please visit https://doi.org/10.1017/S1355617716000898

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