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Executive Functions in individuals with Intellectual Disability

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Abstract

The aim of the present study was to investigate executive functions in adults with intellectual disability, and compare them to a closely matched control group longitudinally for 5 years. In the Betula database, a group of adults with intellectual disability (ID, n=46) was defined from measures of verbal and nonverbal IQ. A control group, with two people for every person with intellectual disability (n=92), was chosen by matching on the following criterion in order of priority: IQ higher than 85, age, sex, sample, level of education, and years of education. 3 types of tasks of executive functions were included on 2 occasions, with 5 years between testing sessions: The Tower of Hanoi, executively loaded dual task versions of word recall, and verbal fluency. Adults with ID showed significant impairments on verbal fluency and on the executively loaded dual task word recall task (at encoding but not at recall). There were no group differences on the Tower of Hanoi. No significant differences between the 2 test occasions were found. The results are interpreted in terms of individuals with ID having problems with speed of accessing lexical items and difficulties with working memory-related executive control at encoding, which includes shifting between tasks. There are, however, not necessarily problems with inhibition. The dual task results additionally imply that the adults with intellectual disability were more sensitive to strategy interruptions at encoding, but that dividing attention at recall did not have such detrimental effects.

Keywords: executive functions; intellectual disability; adults; inhibition; working memory

Executive Functions in Individuals with Intellectual Disability

1. Introduction

The aim of the present study was to investigate executive functions in adults with intellectual disability, and compare them to a closely matched control group longitudinally for 5 years.

Executive functions (EFs) are processes that control and regulate thought and action. There is increasing evidence that EFs can be divided, or "fractionated", into different subcomponents. Miyake, Friedman, Emerson, Witzki, Howerter and Wager (2000) found evidence supporting the existence of three EFs subcomponents: inhibition; updating; and shifting. These subcomponents were separable but still partially correlated constructs. Other tasks that include EFs are planning, decision making, problem solving, fluency and working memory-related dual tasks (e.g. Pennington & Ozonoff, 1996).

Several studies have found evidence that EFs are related to performance on tasks closely associated with intelligence (e.g. Carpenter, Just, & Shell, 1990; Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001; Salthouse, Fristoe, McGuthry, & Hambrick, 1998). However, with the division of EFs into subcomponents this picture has become more nuanced. Friedman, Miyake, Corley, Young, DeFries and Hewitt (2006) found that updating was highly correlated with the intelligence measures, but inhibiting and shifting were not. Arffa (2007) also found that IQ was related to EFs tests of sorting, fluency and inhibition, but not to trail-making.

Maehler and Schuchardt (2009) made a distinction between learning and intelligence by including both a group with learning difficulty and normal IQ and a group with learning difficulty and low IQ. No differences were found between the two groups on EF measures, but both performed more poorly than a control group without

learning problems and normal IQ. This was interpreted as evidence for the fact that EFs are not necessarily related to intelligence, but rather to learning ability. Avila, Moscoso, Ribeiz, Arrais, Jaluul and Bottino (2009) also found differences between groups with high and low levels of education on a range of executive functions tests (digit span backwards, trail making, stroop, and verbal fluency).

There are relatively few studies of EFs in individuals with intellectual disability. However, existing evidence supports the view that such individuals may perform at their mental age (MA) level. For example, Van der Molen, Van Luit, Jongmans, and Van der Molen (2007) carried out a comprehensive assessment of EFs children with ID. They included measures of category fluency, letter fluency, dual task performance, mazes and random number generation. Children with ID performed on par with MA peers on all tasks, which for the dual task performance also was on par with chronologically aged (CA) matched peers. Similarly, in a study on the problem solving task, Tower of Hanoi, adults with ID performed on par with MA comparison groups (Numminen, Lehto, Ruoppila, 2001). Performance at the same level as MA comparison groups has also been found on executive-loaded working memory task for both adults (Numminen, Service, & Ruoppila, 2002) and children (Brown, 1974; Connors, Carr & Willis, 1998; Henry & MacLean, 2002; Henry & Winfield, 2010; Maehler & Schuchardt, 2009) with ID. Many studies have also shown below CA comparison group performance for persons with ID (e.g. Connors et al, 1998; Levén, Lyxell, Andersson, Danielsson & Rönnerberg, 2008). There is however one study that has found contradictory results. Russell, Jarrold and Henry (1996) found that children with ID performed worse than MA peers on three executive loaded working memory measures. Nevertheless, there is rather more evidence favouring the conclusion that

both children and adults with ID perform at levels commensurate with their mental age.

Like many other cognitive measures, EFs have been shown to be age-related (Bucur & Madden, 2010). One weakness with many of the studies above is that there is almost no evidence concerning adults with ID across the lifespan. Most of the research in this area concerns children or teenagers and is cross-sectional. Hence, the purpose of the current study was to examine EFs in an adult sample of individuals with ID and investigate possible developmental changes in EFs across a relatively long period.

Comparison groups matched for MA were not feasible given that the database we were examining only included people aged 35 years and older. Therefore, a chronological age comparison group was selected, but we were extremely careful to match individuals in the comparison group to the adults with ID on several important measures including sex, age (chronological), years of education and level of education. All matching procedures were carried out at an individual level, as previous studies have generally only used group matching procedures. It has been reported that level of education correlates with executive functions (Avila et al., 2009) and people with ID seldom continue to higher education such as university level. Therefore, controlling for education in the current study represents a considerable methodological improvement compared to previous work.

The present study uses the longitudinal Betula database (Nilsson et al., 1997; 2004) with background and cognitive measures for more than 2000 people to: (1) operationally define a group with IQ below 70; and to (2) define a control group matched on age, sex, level of education and years of education. Individual matching

was successful on most measures and participants (see method section for details) and successful matching at the group level was also obtained.

Thus, the research questions were: 1) Do adults with ID perform more poorly on executive function tasks compared to a control group matched on age, sex, level of education, and years of education? 2) Are there developmental effects on executive functions for persons with ID over a period of 5 years?

2. Method

2.1. Participants

The participants in the present study were a subsample of those in the Betula study. The Betula study is a prospective cohort study where the participants take part in extensive health and memory examinations, and interviews about social factors (Nilsson et al., 1997, 2004), the main purpose being to study the development of health and memory functions in adulthood and old age, risk factors of dementia, and premorbid memory functions.

One sample in Betula was tested the first time at T1 (Sample 1, S1). One thousand people were randomly selected from the population registry of Umeå, a city in northern Sweden with a population of about 110 000 inhabitants. The participants in S1 were 35, 40, 45, 50, 55, 60, 65, 70, 75, and 80 years of age when tested at T1 in 1988-1990. There were 100 people in each of these ten age cohorts. Participants in S1 were tested again at T2 (1993- 1995), at T3 (1998-2000), and at T4 (2003-2005). There were 716 participants still remaining in S1 at T3 and 554 S1 participants at T4. The main cause of attrition at each wave of data collection was death (about 10%). Some participants had moved from Umeå (about 2%), and some did not want to take part again or were unable to participate due to illness (2%). An additional two samples, S2 and S3, were tested for the first time at T2 (1993-1995). These

participants were independently and randomly selected from the population registry of Umeå. Participants in S2 were of the same age at T2 as S1 participants were at T1 and participants in S3 were of the same age as S1 participants were at T2. The 8 oldest age cohorts of S2 participants were called back for testing at T3. Attrition rates for those who were called back were similar to those for S1 (14%), leaving 665 S2 participants being tested at T3. In S3, 812 participants returned for testing at T3. Not only were the overall attrition rates similar for S2 and S3 as those for S1, but also the rates for the three types of attrition categories were about the same as for S1. Summing up the number of participants from S1, S2 and S3, there were a total of 2193 participants available at T3.

In the present study, a longitudinal approach with as many tests of executive functions for as many measurement times for as many participants as possible was considered ideal. At T1, there were relatively few participants in Betula, providing few participants with ID (approximately 15). Therefore, T1 was excluded. At T2 and T3, there were three tests of executive functions, but at T4 there were only 2 tests. Therefore, T4 was also excluded. This left T2 and T3 for inclusion in the present study. Test occasions T2 and T3 will in the present study be called test waves 1 and 2. Note that people with genetic syndromes, like Down syndrome, were excluded in Betula. Therefore, the intellectual disability sample that is created in the present study is likely to be a mixed sample of those with non-specific intellectual disabilities.

A measure of IQ was constructed by using a nonverbal IQ test, Block design (Wechsler, 1991), and a verbal IQ test, vocabulary (Dureman, 1960). Since none of the tests were standardized on as many people as were included in Betula, the standardized scores were not used. Instead, the measures were standardized on all

people in Betula. The measures were z-transformed, added together and then transformed again to fit the normal IQ distribution criteria (mean = 100 and SD = 15).

IQ correlates with age in older people (Rönnlund and Nilsson, 2006). To make sure that this did not affect our study, three precautions were taken. First, 44 participants who had been diagnosed as demented were excluded (see Nilsson et al., 2004 for details). Second, people older than 71 years at test wave 1 (and 76 years at test wave 2) were excluded (1406 people left). The cut off was defined by calculating the mean IQ within test wave 2 and excluding age groups that had lower IQ than the mean minus one standard deviation. Third, in this new sample, an age-corrected IQ was calculated using a linear regression method (block adjusted $-.38$ per year on raw score, and vocabulary adjusted $-.07$ per year on raw score). Using this method, there were 46 people who had age-corrected IQ scores below 70 out of the total possible sample of 1406 individuals.

A control group with two persons for every person with ID was created. The first criterion was that the controls should have higher IQ than the ID group. To avoid including those with borderline IQ, an age-corrected IQ higher than 85 was thus set as the first criterion. After that, the control group was matched on the following criteria in order of priority: age; sex; sample; level of education; and years of education. The individual matching was very successful on most measures (age 100%, sex 100%, sample 97%, level of education 72%, years of education 51%). The matching was also successful at a group level, as shown in Table 1, where means and standard deviations are presented. No significant differences were found between the groups on any of the matching variables. Descriptive data for the ID group, the control group and the 1406 people that were left after exclusions (younger than 71 with no dementia) at test wave 1 are also presented in Table 1.

Insert Table 1 about here

The ID sample differed from the 1406 available people in Betula in the expected ways (IQ, level of education and years of education), but was also older (but still within one standard deviation from the mean) and contained fewer females. Since several precautions were taken to prevent the influence of age, by excluding people with dementia, excluding people over 71 years of age, and correcting the IQ measure for age, the ID sample was considered representative of the population.

2.2. Tasks

2.2.1. Tower of Hanoi: There were three vertical posts and five rings of different sizes on the last post. Rings were arranged according to size so that the largest was bottommost, the second largest next, and so on until the smallest ring was on the top. The task was to move the rings from the final post to the first one. Rings had to be arranged in the same way on the first post as they were on the final one. Rings could be moved one at a time, and a larger ring could never be placed on top of a smaller one. Participants were instructed to solve the task in as few moves and as fast as possible. Maximum allowed time was 20 minutes. Time to complete the task, number of moves and number of rule breaking moves were the three measures used from this task.

2.2.2. Verbal fluency: The task was to generate as many words as possible during one minute; separate fluency tasks were administered with different instructions. The Betula database included four verbal fluency tasks where the first was to generate words beginning with the letter A; the second to generate words with exactly five letters and beginning with the letter M. Any real words were accepted, but names of persons were not allowed. The third task was to name as many professions starting with the letter B as possible. The fourth task was to name as many

animals, starting with the letter S and with exactly five letters, as possible. The first two tasks primarily assessed maintenance and possibly updating aspects of EFs. The other two primarily assessed semantic memory and to some extent EFs. There were no tasks that assessed EFs only, but to keep the tasks as clean as possible, only the first two tasks were included in the analysis. Additional analyses that included all verbal fluency tasks gave the same general pattern of results for all four tasks, but are not presented here. The number of correct words generated in each case was scored.

2.2.3. Executive-loaded Word Recall: Materials consisted of 12 unrelated nouns in each presentation. A timer beeped every 2 sec and one noun was read each time. There were four different conditions: (1) No executive load; (2) Executive load (dual task) at encoding; (3) Executive load (dual task) at test; and (4) Executive load (dual task) both at encoding and at test. The executive-loaded conditions involved asking participants to carry out a secondary task (sorting red and black cards in two stacks according to colour), while carrying out the word recall task. The first condition without executive load is included as a baseline task since the other executive loaded dual task conditions are only executively loaded in relation to that condition. Instructions were that participants should try to remember as many nouns as possible and that they should be recalled freely in any order after the presentation. Participants were encouraged to keep to a pace of 2 sec/noun at recall. The pace of the secondary task was the same as the pace of the word recall task, i.e. 2 sec/item.

2.3. Design

The design of the analysis was a 2x2 split plot design. The within group variable was test wave (1 or 2) and the between group variable was group (ID group or control group). The design was repeated for all nine measures of executive function.

3. Results and Discussion

The α -level was set to .05 and then corrected for the total number of analyses carried out (dividing by 9, $\alpha_{\text{corrected}} = .006$). Means, standard deviation and t -values on group differences for all measures relating to test wave 1 can be seen in Table 2 and relating to test wave 2 in Table 3.

Insert Tables 2 and 3 about here

In the nine ANOVAs, there were significant main effects of test wave only for word recall with distracter at both encoding and test, $F(1, 133) = 6.94, p < .001, r = .22$, and no significant interaction effects between test wave and group. However, there were main effects of group for both fluency measures, $F(1, 136) = 67.3, p < .001, r = .58$ for words beginning with letter A and $F(1, 135) = 70.7, p < .001, r = .59$ for words with 5 letters beginning with M respectively. There were also main effects for two of the three executive-loaded word recall conditions, $F(1, 133) = 16.6, p < .001, r = .33$ for executive load at encoding and $F(1, 133) = 15.6, p < .001, r = .32$ for executive load at both encoding and test. In both cases an executive load at *encoding* led to weaker word recall performance among individuals with ID. Note that no group difference was found for the word recall baseline condition without executive load. This means that the differences found for the two executively loaded conditions were due to the added dual task constraints and not an initial difference on the baseline task. All other main effects were not significant.

This means that, overall, there were only one significant effect of test wave and it had a small effect size. Differences between groups were found for fluency and executive-loaded word recall (with dual task at encoding) with medium to large effect sizes, but not on the Tower of Hanoi.

4. General Discussion

The current study examined EFs over a period of 5 years in adults with ID, comparing them to a very closely matched comparison group. This comparison group was matched not only for age, but for gender, level of education and number of years of education. The results showed that adults with ID had a selective impairment in some areas of EFs, including verbal fluency and executive-loaded word recall. However, there were no deficits with respect to performance on the Tower of Hanoi, suggesting that adults with ID do not have difficulties in the area of non-verbal planning. In addition, only one significant difference were noted between the two test waves and it had a small effect size, implying that performance on a range of EFs is stable in adults with ID over a period of five years. Numminen, Lehto and Ruoppila (2001) found ToH performance of adults with ID to be equal to MA matched controls. However, those with ID violated the rules of the ToH more often, and needed more trials to solve the ToH problems than the MA comparison group. In the present study, no overall difference between the ID and comparison groups were found on three separate measures, but at test wave 2, there was a significant difference for number of incorrect moves on the *t*-test.

Therefore, there may be subtle indications of difficulties on this task in the sample of adults with ID. Tower of Hanoi is a complex task that most probably involves many aspects of EFs. To solve ToH the most efficient way, a goal-recursion strategy can be used, making the ToH mainly a planning task with high loads on working memory (Carpenter, Just, & Shell, 1990). However, studies have shown that a perceptual strategy, which involves simply making a next move that will bring the current state perceptually closer to the goal state, is less demanding and may be used more frequently (Goel & Grafman, 1995). Miyake, Friedman, Emerson, Witzki, Howerter and Wager (2000) supported this notion and showed that ToH performance

was most closely related to inhibition, and less so to updating and shifting. Applying this reasoning to our results would imply that adults with ID do not necessarily have problems with inhibition.

There was a significant impairment in verbal fluency in the adults with ID, compared to the comparison group. This is consistent with previous findings reporting MA-level verbal fluency performance in teenagers with ID, but deficits in relation to chronological age (Van der Molen, Van Luit, Jongmans & Van der Molen, 2007). Verbal fluency was measured with two tasks that assessed maintenance and possibly updating aspects of EF. The tasks also have a semantic memory component since they were verbal tasks. However, precautions were made to keep the tasks as clean as possible in relation to EFs by only including the two verbal fluency tasks with the least semantic memory demands. The verbal fluency findings imply that adults with ID are less able to search and retrieve lexical items based on phonotactic and/or semantic rules.

For executive-loaded word recall, the adults with ID showed poorer performance than the comparison group, only when the executive load was imposed at *encoding*. This suggests that individuals with ID have problems with executive control during dual task performance at the encoding stage, rather than at the retrieval stage. These results are not directly comparable with previous research on executive-loaded working memory (e.g. Henry & MacLean, 2002; Henry & Winfield, 2010; Mähler & Schuchardt, 2009) as the tasks were somewhat different (here, executive load was imposed using a secondary task; in previous research, executive load was imposed by requiring concurrent processing and storage). However, previous findings with children and teenagers have found reasonably consistent evidence for impairments in relation to chronological age, which would be consistent with the current findings.

Dual tasks involve, by definition, shifting attention between two tasks. The results above are interpreted such that individuals with ID have problems with shifting at encoding but not necessarily at test.

There were very few significant effects of test wave: only in the case of executive-loaded word recall (with dual task at both encoding and test) was there a significant decrease in performance over time. Similarly, there were no significant interaction effects between test wave and group, implying that age-related changes in EFs (or not as the case may be) are similar in those with and without ID. However, it may be the case that the 5 years that elapsed between the two test waves reported here, represents too short a time-frame for age to have a substantial effect on the EFs of adults with ID.

5. Conclusions

The present study has investigated executive functions in adults with intellectual disability, and compared them to a closely matched control group longitudinally for 5 years in the Betula database. The individual matching was based on sex, age (chronological), years of education and level of education. This is a substantial methodological improvement compared to previous studies in this area. A selective impairment on EFs was found for individuals with ID compared to the controls. Lower performance was found on fluency tasks and word recall with executive load (dual task) at encoding; but not on word recall with executive load at test or Tower of Hanoi problem solving. Compared to previous results, the lower performance results are a replication, but the lack of group difference on some EFs tasks is a novel finding. The results were interpreted such that individuals with ID have problems with speed of accessing lexical items and working memory related executive control at

encoding, which includes shifting between tasks. There were not, however, necessarily problems with inhibition.

There was only one significant decline (with a small effect size) in EFs between the two testing occasions, implying that significant changes in EF did not occur in adults with ID (or controls) over the five-year period of this study.

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Table 1

Means and standard deviations on age, IQ, years of education and percent females for the intellectual disability group (ID), the controls and all people under the age of 71 years at test wave 1.

Test	All people under 71 years at test wave 1		ID		Controls	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
n	1406		46		92	
Age at test wave 1	54.0	10.1	63.2	8.1	63.2	8.0
IQ	100	15	62.8	5.7	99.2	8.2
Years of education	11.2	4.0	7.0	1.5	7.8	2.7
% females	52.5		45.7		45.7	

Table 2

Means and standard deviations for the executive functions measures at test wave 1.

Test	ID		Controls		<i>t</i> -test	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>t</i>	<i>p</i>
ToH seconds to complete	492	278	398	243	2.04	ns
ToH number of moves	75.7	38.1	67.0	30.8	1.44	ns
ToH number of incorrect moves	2.52	2.55	2.10	7.08	.39	ns
Fluency A	6.59	3.07	11.73	4.16	7.43	***
Fluency M5	3.22	1.70	7.24	3.18	7.93	***
Word recall no executive load	2.32	.93	2.57	1.08	1.30	ns
Word Recall. executive load at encoding	2.41	1.00	2.87	.85	2.78	*
Word Recall. executive load at test	2.34	1.03	2.37	1.12	0.14	ns
Word Recall. executive load at encoding and test	2.30	.98	2.72	1.00	2.32	ns

* $p < .05/9 = .006$ one-tailed

*** $p < .001/9 = .0001$ one-tailed

Table 3

Means and standard deviations for the executive functions measures at test wave 2.

Test	ID		Controls		<i>t</i> -test	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>t</i>	<i>p</i>
ToH seconds to complete	422	189	381	210	1.11	ns
ToH number of moves	68.9	25.4	65.6	26.9	.69	ns
ToH number of incorrect moves	2.07	2.03	1.08	1.58	3.15	*
Fluency A	6.41	3.40	11.12	3.68	7.26	***
Fluency M5	3.20	1.73	6.40	3.01	6.68	***
Word recall no executive load	2.35	1.12	2.51	1.08	.80	ns
Word Recall. executive load at encoding	2.28	.98	2.71	.82	2.72	*
Word Recall. executive load at test	2.00	1.12	2.33	1.03	1.72	ns
Word Recall. executive load at encoding and test	1.96	1.01	2.54	.96	3.30	**

* $p < .05/9 = .006$ one-tailed

** $p < .01/9 = .001$ one-tailed

*** $p < .001/9 = .0001$ one-tailed