Assessment of Working Memory in Normal Children and Children Who Stutter

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Abstract: The aim of this study is to assess working memory (WM) abilities in normal children and Children Who Stutter (CWS) then to compare the results in order to detect if WM deficits have a role in the development of stuttering. 30 normal children and 30 children who stutter were subjected to WM recall abilities tests and nonword repetition tasks. The WM recall tests included recall of word sets different in length and rhyming, digit span, letter sequences and picture-number test. The nonword repetition test was used to assess phonological encoding through measuring number of phonological errors produced on repeating the task, and to measure the reaction time. The children who stutter (CWS) had performed poorly on some working memory tests compared to the control group. Conclusion: Children who stutter may have diminished ability to recall nonwords and some of working memory abilities and that further investigation into this possibility may shed light on the emergence and characteristics of childhood stuttering.

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Key words: working memory; children who stutter; nonword repetition; phonological encoding, phonological errors, reaction time.

1. Introduction:

Stuttering has been described as a speech motor disorder that disrupts the timing and/or coordination between the respiratory, laryngeal, and vocal tract symptoms of speech (Van Lieshout et al., 2004). It is true that people who stutter suffer from some overt phenomena like tense movements of face, jaw and occasionally extremities; however it is also important to investigate where these phenomena came from (Kawai, 2008).

Recently working memory has been implicated in the development of stuttering. Working memory is universally recognized as neurocognitive system that provides temporary storage and processing of incoming information. Baddeley (2003) envisioned working memory as a multicomponent neurocognitive system that includes a central executive, visuospatial sketchpad and phonological loop. The phonological loop includes short term storage and rehearsal of incoming verbal information to enable comprehension. Phonological encoding during speech planning involves retrieving phonological material from storage to build articulatory plans (Levelt, 1989). Working memory is considered critical to phonological encoding (Gathercole and Baddeley, 1993) and vital to higher level cognition (Rosen and Engle, 1997).

One prominent theory which is the covert repair hypothesis of Postma and Kolk (1993) assumes that stuttering arises because inefficient or slow phonological encoding leads to an increase in covert repairs to the phonological plan, particularly when the individual is intent on speaking at a rate exceeding the compliance of the phonological encoding mechanism.

Cognitive models of speech production, such as that proposed by Levelt and colleagues (1999), provide a useful framework to consider the linguistic processes that might be deficient in stuttering. A number of studies have explored the hypothesis that retrieving semantic and/or phonological information for the purposes of linguistic encoding might be a source of deficit or delay in stuttering (Newman and Bernstein-Ratner, 2007). However these studies have produced mixed findings

The aim of this study is to assess working memory (WM) abilities in normal children and Children Who Stutter (CWS) then to compare the results in order to detect if WM deficits have a role in the development of stuttering.

2. Subjects and methods:

Subjects

Participants in this study were 30 normal children (group 1) and 30 children with stuttering (group 2). All children ages were between 5 and 13 years. The two groups were matched in age and gender. Each group was further subdivided according to children's age into 2 subgroups; A) 15 Children with ages ranging between 5 and 9 years. B) 15 Children with ages ranging between 9 and 13 years. Mean age of children who stutter (CWS) was 7.51; while the mean age of the control children was 7.93. They were all selected from the outpatient clinic, Phoniatric unit of Kasr El Aini Hospital and with following exclusion criteria: No history &/or presence of delayed language development, dyslalia, mental retardation, hearing impairment, psychological problems or neurological problems. The study was done in the period from 2008-2009.

Methods

All participants were subjected to the following protocol of assessment:

History taking and patient examination:

Including personal, perinatal, natal, post-natal developmental history and any history of childhood illness together with general, neurological, local and ENT examination.

Psychometric evaluation:

a. Stanford Binet test (4th version) (Thornidike et al., 1986). All selected participants were of average IQ (IQ≥ 85)
b. Illinois psycholinguistic test (Kirk et. al., 1969): Only 3 items were selected (psycholinguistic age, auditory sequential memory and visual sequential memory). These were selected to test other memory abilities rather than working memory.

The Assessment protocol of Disfluency used in Phoniatric Unit, Cairo University (Shohdi, 1999): to assess disfluency and severity of stuttering.

Battery of assessment of working memory (WM):

All tasks were recorded using an audiotape (National Rx- CW30F) for documentation.

A. WM Recall Tasks:

1- Recall of short versus long word sets: to assess the efficiency of retrieval of phonological sequences of different length.
2- Recall of similar versus dissimilar word sets: to assess the efficiency of retrieval of phonological sequences with different rhyming. The word sets were presented verbally by the experimenter. Children had to remember the words in the same order in which they were presented. For a trial to be considered correct, all words in that sequence had to be remembered in the correct order. Testing continued as long as the child managed to correctly repeat at least one of the two trials at a particular list length.
3-Digit span versus letter sequences: Sequences of digits and letters graded from 3 to 10 were administered verbally provided not to be in a sequential order. Ten digits between 1 and 10 were used. Ten letters were also used (not sequential).
4- Picture-number test (Ekstrom et al., 1975): This test was used to address the visuospatial component of WM. Some modifications to the original test were done to be suitable for the examined age range. It was graded from 3 to 10 picture-number tests, it was presented visually for 60 seconds then the child was asked about the missing numbers associated with the presented pictures. The total score was given according to the maximum number of correct missing numbers recalled and associated with the correct presented pictures.

The purpose of assessment of WM recall abilities is to explore the role of verbal WM and its operations in the development of stuttering.

B. Non-Word Repetition tasks:

Non-word repetition was considered to be a phonological short term memory task, in which the phonological forms of the stimuli are unfamiliar thus requiring children to code new phonological sequences and maintain them in phonological memory. By repeating nonwords the speaker relies on the storage component of the phonological loop without the complicating effects of prior lexical knowledge (Gathercole et al., 1994). A list of 40 non-words was administered (20 bisyllabic and 20 trisyllabic non-words).

The participants were examined in a quiet setting on two sessions. Three examples of nonwords were given by the examiner and the child was asked to repeat each. Once the child appeared to be comfortable with the setting and understanding to the task, the 40 non-words were presented verbally by the examiner using the microphone of the Computerized Speech Lab. (Kay model 4300) in order to measure the reaction time using spectrographic analysis. The task was also recorded using an audiotape. Then the recording task was transcribed and analyzed for detection of (A) Phonological errors and (B) Disfluency. Reaction time (RT) was considered as the time between the end of the examiner's stimulus and the beginning of the child's response to detect if stutterers differ in their speed of phonological encoding. For the Phonological errors, the responses were scored as either correct or incorrect. All phonemes within a non-word had to be produced correctly for the response to be scored correct. Response of CWS were judged as either correct (no phonological error) or incorrect (presence of phonological error). The total number of phonological errors of the 40 non-words for all the participants was calculated. For disfluency, the response of CWS were judged as either fluent or disfluent. The number of disfluently produced responses was then calculated for each non-word and across all the task items. Disfluency was measured in order to test its relation with phonological errors on the nonwords repetition task.

Statistical Analysis:

Data was analyzed by Microsoft office 2003 (excel) and Statistical Package for Social Science (SPSS) Version 10. Parameteric data was expressed as mean and standard deviation while parametric data was expressed as number and percentage of the total. Student's t-test was used to compare between the 2 test groups. Measuring the mutual correspondence between two values was done using the Spearman correlation coefficient.

3. Results and Discussion:

Psychometric evaluation:

a. Stanford – Binet test (4th version) (Thorndike et al., 1986): There was no significant difference between controls and stutterers for all the test items except the *memory for sentences* was significantly better in controls (mean =84.53; SD= 8.42).

b. Illinois Psycholinguistic test (Kirk et al., 1969)

There was no significant difference between controls and stutterers regarding the tested items of the Illinois test.

Disfuency:

Results showed that there were 13 children with mild stuttering, 10 children with mild to moderate stuttering, 5 children with moderate stuttering and 2 children with moderate to severe stuttering.

The correlation between severity of stuttering and reaction time of both bisyllabic and trisyllabic nonwords showed a highly significant +ve correlation (r value=0.825 and 0.827 respectively) (Figure 1 & 2).

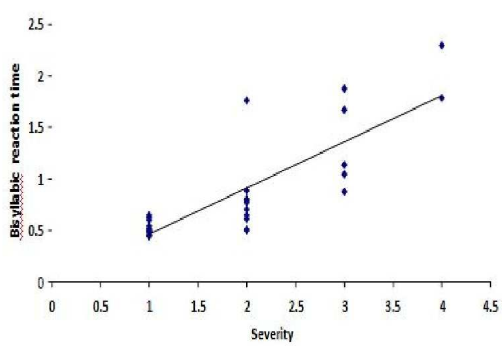

Figure (1): The correlation between severity of stuttering and reaction time of bisyllabic nonwords.

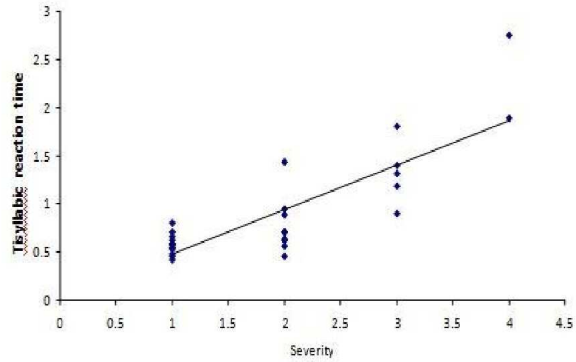

Figure (2): The correlation between severity of stuttering and reaction time of trisyllabic nonwords.

Battery of assessment of Working Memory (WM): A-Working Memory Recall Tasks (Figure 3):

There was no significant difference between the controls and the stutterers in all parameters of the working memory recall tasks except the digit Span (mean=5.93; SD=1.41) and Picture-Number test (mean=5.27; SD=1.01) in which the controls had a better recall score than stutterers.

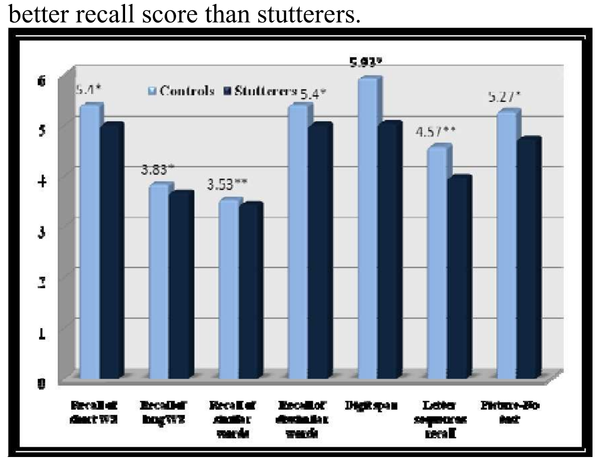

Figure (3): Recall parameters in controls and stutterers.

WS: word sets, *=significant, **=highly significant

The correlation between age and recall of short word sets, long word sets, dissimilar words, digit span and picture number tests among controls showed a significant +ve correlation while the correlation between the age and recall of similar words and letter sequences showed a highly significant +ve correlation also among controls (Table 1).

Correlation between age and recall of similar words and digit span among stutterers showed a significant +ve correlation while the correlation between the age and recall of short word sets, long word sets, dissimilar word sets, letter sequences and picture- number tests showed a highly significant +ve correlation (Table 1).

Table (1): The correlation between age and WM recall tasks in controls and stutterers

	Control age (r value)	Significance	Stutterers age (r value)	Significance
Recall of short word sets	**0.397**	**S**	**0.501**	**HS**
Recall of long word sets	**0.366**	**S**	**0.591**	**HS**
Recall of similar words	**0.517**	**HS**	**0.378**	**S**
Recall of dissimilar words	**0.397**	**S**	**0.501**	**HS**
Digit span	**0.401**	**S**	**0.382**	**S**
Letter sequences recall	**0.492**	**HS**	**0.513**	**HS**

WM: working memory, HS: highly significant, S=significant

Both controls and stutterers showed a highly significant better recall of short (controls: mean = 5.40; SD = 1.19, stutterers: mean = 5.00; SD = 1.08) than long word sets (controls = 3.83; SD= 0.83 and stutterers= 3.67; SD= 0.66), dissimilar (controls: mean = 5.40; SD= 1.19 and stutterers: mean= 5.00; SD= 1.08) than similar word sets (Controls: mean=3.53; SD=0.73 and stutterers: mean=3.43; SD=0.73), Digit span (controls: mean= 5.93; SD= 1.41and stutterers: mean =5.03; SD=1.27) versus Letter-sequences (Controls: mean=4.57; SD=1.33 and stutterers: mean=3.97; SD= 1.10).

B) Nonword Repetition Tasks:

Phonological Errors (PEs):

Stutterers had a highly significant more phonological errors compared to the controls in both bisyllabic and trisyllabic nonwords repetition task.

There were a highly significant more number of phonological errors in trisyllabic nonwords than in bisyllabic nonwords in both the controls and the stutterers.

Table (2): Number of phonological errors in bisyllabic nonwords and trisyllabic nonwords between controls and stutterers.

		Controls	Stutterers	P VALUE
Phonological errors	**Bisyllabic nonword**	4	32	0.000002**
	Trisyllabic nonword	35	61	0.006**
	P VALUE	0.000**	0.002**	

** = highly significant p value (≤0.01)

There was no significant difference in the number of phonological errors in bisyllabic nonwords between controls (subgroup A, aged 5-9 y) and controls (subgroup B, 9-13y). While control subgroup A showed a highly significant more number of phonological errors than control subgroup B in trisyllabic nonwords.

Stutterers (subgroup A, aged 5-9 y) had a highly significant more number of phonological errors than stutterers (subgroup B, aged 9-13 y) in both bisyllabic and trisyllabic nonwords.

Disfluency:

There was no significant difference in the number of disfluencies between bisyllabic and trisyllabic nonwords in the stutterers (p=0.292).

Stutterers subgroup A had a highly significant more number of disfluencies in both bisyllabic and trisyllabic nonwords compared to stutterers subgroup B (p=0.002 and 0.000 respectively).

There was no significant difference between the number of phonological errors and the number of disfluencies in stutterers in both bisyllabic and trisyllabic nonwords (p=0.155 and 0.436 respectively).

Nonwords Reaction Time (RT) (Table 3)

There was a highly significant longer reaction time in the stutterers than the controls for both the bisyllabic and trisyllabic nonwords repetition tasks (mean of bisyllabic RT in control group=0.56; SD=0.12; mean of bisyllabic RT in stuttering group=0.85; SD=0.51) and (mean of trisyllabic RT in control group=0.58; SD= 0.14; mean of trisyllabic RT in stutterers=0.88; SD= 0.53).

Neither the controls nor the stutterers showed significant difference between reaction time for both bisyllabic and trisyllabic nonwords repetition task.

Table (3): Reaction time of bisyllabic and trisyllabic nonwords in controls and stutterers

		Controls		Stutterers		P VALUE
		Mean	SD	Mean	SD	
Non-word repetition	Mean BRT	0.56	0.12	0.85	0.51	0.005**
	Mean TRT	0.58	0.14	0.88	0.53	0.006**
	P value	0.504	0.841			

(SD=Standard deviation; BRT= Bisyllabic Reaction Time; TRT= Trisyllabic Reaction Time)
** = highly significant p value (≤0.01)

3. Discussion:

Psychometric evaluation:

Stanford-Binet test:

Testing different memory abilities showed no significant difference between controls and stutterers except for memory for sentences as controls showed a slightly better performance and that may be explained by the fact that sentences are more complex than words and convey more grammatical complexity which can increase the mental load on stuttering memory recall abilities.

Illinois Test:

There was no significant difference between controls and stutterers in visual as well as auditory sequential memories.

Severity of stuttering:

Correlation between severity of stuttering and reaction time in both bisyllabic and trisyllabic nonwords showed a significantly +ve correlation. This means that with increase in the severity of stuttering, the time needed for encoding and phonological processing increases.

Working memory recall tests:

The present study showed no significant difference between controls and stutterers in various recall tasks, however the stutterers showed poorer performance in picture- number test than controls and that could be explained that this task put more pressure and demands on their mental and recall abilities due to time pressure during the task.

There was a highly significant ability to recall short word sets than recall of long word sets in both stutterers and controls. This can be attributed to the fact that short words have less articulatory duration and less phonological complexity and that short articulatory duration allows rapidly spoken words to be rehearsed more frequently. Words that are rehearsed more frequently are less likely to decay before an entire sequence of them can be recalled (Baddeley, 1986). And it could also be explained by what Caplen et al., 1992 had hypothesized that the word-length effect stems from speech planning rather than overt or covert articulation and that speech planning are influenced by the phonological complexity of words, as indexed by number of phonemes and syllables. Comparing the results of recall of dissimilar words versus recall of similar words, both controls and stutterers showed better performance in recall of dissimilar words than recall of similar words. Typically, sequences of phonologically similar words are remembered less well than sequences of dissimilar words (Schweickert et al., 1990).The phonological similarity effect supports the phonological loop model's assumption that verbal information is represented in a modality-specific phonological store rather than in another type of storage system. Comparing the results of digit span versus letter-sequence tests in both controls and stutterers, it was clear that both groups had better performance in digit span than in recall of letter sequences. This could be explained by the fact that children especially the younger ones are more familiar with digits than with letters.

A correlation between age and various recall parameters in both control and stuttering groups showed a significant +ve correlation in both groups. Some researchers showed that brain maturation increases with increase in age. Structural neuroimaging studies show that regions of parietal and especially frontal cortex undergo changes well into adolescence and early adulthood. These studies suggest that the brain systems underlying WM and thus WM undergo changes well into adolescence and regions are activated when children and adults retain information in WM**.** Behaviorally, WM undergoes substantial growth over the course of development. For example, counting and listening span increase from 7 to 13 years of age (Siegel and Ryan, 1989), and digit span increases from 4-5 items at 4-5 years of age to 5-7 items at 14-15 years of age (Conklin et al.,2007).

Non-Word Repetition Task:

Phonological errors (PEs)

The number of phonological errors in controls was lower than stutterers. This could be attributed to the poor rehearsal and storage abilities of children with stuttering. The findings of the present study goes with the Covert Repair Hypothesis assumption that building a phonological output representation, is realized through the association of phonemes with slots in a metrically defined frame. Normally, if a slot in the frame needs to be filled, the phoneme that has the highest activation level at the critical time point is selected. In a person who stutters, however, activation spreading is slow. This means that when a specific slot needs to be filled, it is likely that competition among candidate phonemes has not settled. Consequently, a misselection may occur. Many such misselections are pre-articulatory detected and repaired, which yield interruptions and restarts in overt speech, if one couldn't do these covert repairs, the overt phonological errors would be produced.

Both controls and stutterers also produced more errors in trisyllabic than bisyllabic nonwords. The more the length of the nonwords, the more difficulty in encoding, rehearsal and storage. Present findings are also similar to those reported by Montgomery (1995), in children with specific language impairment (SLI). He found that children with SLI performed significantly worse than language-matched typically developing peers on three syllable non-words. At the 3 syllables, the CWS showed more difficulty with the task, as do many children with SLI.

On comparing the result of the number of phonological errors in bisyllabic and trisyllabic nonwords between the two control age subgroups, it was found that no significant differences between both groups as regards number of phonological errors in bisyllabic nonwords, but it showed that group (A) aged between 5-9 years produced more errors in trisyllabic nonwords than group (B) aged between 9-13 years. As regards the two stutterers' age subgroups, group (A) showed more errors than group (B) in both bisyllabic and trisyllabic nonwords. These results suggest that phonological ability of children improves when they grow older.

Disfluency

Comparing the number of disfluencies between bisyllabic and trisyllabic nonwords in stuttering group, there was no significant fluctuation in fluency as nonwords increased in length. Thus, it would appear that even though CWS had greater difficulty (i.e., producing PEs) in the two and three syllable nonwords than their normally fluent peers, these difficulties did not manifest themselves in children's fluency. And thus, the poor performance of CWS in nonwords repetition task as regards the phonological errors was not related to speech production difficulties (speech disfluencies) but the results cannot be considered conclusive as the majority of the CWS were of mild and moderate degrees of severity. However, the finding is consistent with both Hakim and Ratner (2004) and Anderson et al (2006) that revealed no significant fluctuation in fluency as nonwords increased in length. On contrary, an older literature on stuttering in adults has documented that disfluencies should increase with increasing word length (Soderberg, 1966 and Wingate, 1967).

Comparing the number of disfluencies of bisyllabic and trisyllabic nonwords between the two stutterers' age subgroups, there was highly significant difference as group (A) produced more disfluencies than group (B) in both bisyllabic and trisyllabic nonwords. However there is no evidence that disfluency increases in young age.

Comparing the number of disfluencies and number of phonological errors in bisyllabic and trisyllabic nonwords in stutterers, no significant difference was found .The results were in accordance with Wolk et al (2000) who indicated that frequency of disfluency on syllables with phonological errors was similar to those produced without errors. According to them, it may have been predicted that more disfluency would occur during instances of phonological errors. One explanation for the results is that the two disorders (stuttering and disordered phonology) may indeed be separate entities. Although stuttering and phonological errors may co-occur in the same child, they may not interact in the same syllable.

Reaction Times (RTs)

Comparing the results of reaction time of bisyllabic and trisyllabic nonwords between the controls and the stutterers, it was found that the stutterers had longer reaction time in both bisyllabic and trisyllabic nonwords than the control group, although, that only fluent productions were selected to measure the reaction time. And that led us to the prediction that children who stutter may take more time for phonological encoding than normal children. These results were in agreement with the results of the study by Kolk et al (1991) who suggested that individuals who stutter may demonstrate impairment in their phonological encoding mechanisms. This assumption leads to the prediction that the activation of target phonemes is somewhat delayed for people who stutter, resulting in a relatively long period of time when target phonemes are in competition with other phonemes. But the results did not match with the results of Bakhtiar et al (2008) who found no significant difference between the two groups regarding reaction time in both bisyllabic and trisylabic nonwords. They assumed that the defect might be in the other parts of linguistic processing but not phonological ones.

The comparison of reaction time between bisyllabic and trisyllabic nonwords in both controls and stutterers showed insignificant difference. Lack of significance may be attributed to the small sample size and the difference could be significant with more increase in nonwords syllabic length. The result of the present study is in agreement with the results of Bakhtiar et al (2008).

The present study showed no difference between controls and stutterers in recall tasks, except picture-number test. This could be explained by that their prior lexical knowledge about the words and the semantic content of these words facilitated their recall.

The results of this study are in agreement with the Covert Repair Hypothesis in that the children with stuttering produced more phonological errors than normal children and they had longer reaction time. This may support the assumption of the Covert Repair Hypothesis of the presence of a phonological encoding deficit and that leads to the prediction that the activation of target phonemes is somewhat delayed for people who stutter, resulting in a relatively long period of time when target phonemes are in competition with other phonemes. The Covert Repair Hypothesis assumed that when disfluency is suppressed, overt speech errors should increase in frequency and the more overt stuttering, the less phonological errors should be observable; however, this was not proved in this study. The relation between disfluencies and phonological errors is still query waiting for further investigation.

4. Conclusion:

In accordance with several studies, it was found that performance of CWS on phonological memory tasks lag to some degree behind that of normal children. Further research in this area may shed light on the emergence and characteristics of childhood stuttering and that can lead to new approaches for the management of stuttering.

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