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Development of Trisensory Backward Digit Span in Terms of Ages

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Abstract: In the case of the investigation of the backward digit span memory, most of the research was based on either unisensory modality (e.g., auditory or visual or tactile) or bisensory (auditory and visual) modalities or both. Very few studies investigated digit span memory using trisensory modality and how it developed across different age groups. Therefore, the present study investigated the plausibility that backward digit span (BDS) tasks of trisensory presentation developed in terms of age. 58 subjects categorised into 3 groups (group 1 aged 9-12; group 2 aged 16-18; group 3 aged 22) were individually presented with three lists of numbers with three modalities (auditory, visual and tactile) and were instructed to recall the numbers in reverse order. It was hypothesized that a gradual increase in trisensory backward digit span (TBDS) would be observed from childhood to early adulthood. However, the findings demonstrated that the mean TBDS of each group was distinct from other groups, suggesting that age played an important role in determining TBDS memory. Age, education, and physiological factors were taken into account to explain these findings.

Keywords: Memory, Backward Digit Span, Trisensory, Central Executive Function

1. Introduction

In the immediate memory span, a list of words or digits or letters is presented verbally or acoustically or both. Subjects require recalling the items (e.g., words, digits or letters) immediately after the latter are presented. The tasks turn into the memory span for digits when the number is used for participants to be repeated in the correct order. Immediate digit span devised by Jacobs (1887) and considered the most common component in test of intelligence (Wechsler, 1944) is examined mainly in two ways: Forward condition in which digits are repeated in the same order as these are presented and Backward condition, the main theme of the present study, that instructs the subjects to repeat back the digits in reverse order as these ones are presented. In this point, the backward digit span (BDS) is more challenging as compared to the Forward condition. Because BDS not only requires to rote immediate memory but also includes an additional processing component of concurrent mental operation (e.g., reordering). BDS tasks are believed to be a sensitive measure of working memory (memory that retains and utilizes information by temporarily storing and manipulating these ones). It has been widely used in neuropsychological research and clinical evaluations (e.g., Baddeley, Thomson, & Buchanan, 1975). It is a pervasively used test for measuring the memory span, because the digit span task cannot be affected by factors, such as semantics (the study of the relationship between words and the construction of the meaning), frequency of appearance in daily life and complexity etc (Jones & Macken, 2015).

Our brain receives information from the surrounding environment through different sensory organs (e.g., visual, and auditory). The more sensory organs we employ to glean information on a particular object, the more information our brain receives about that object, making our memory more enriched. We usually employ two sensory organs (e.g., visual and auditory) to learn something. More clearly, during learning, we usually see a word or an object and hear some description about that one. In this case, we come to know about that particular word or object by visual or auditory sensory organs or by both. There are a number of studies that were conducted with unisensory (employing one sensory organ [e.g., visual or auditory] to learn something) or bisensory presentation (employing two sensory organs) of BDS tasks. These studies with BDS tasks were administered focusing on different variables related to human lives (e.g., effects of age (e.g., Gregoire & Linden, 1997; Füllgrabe & Öztürk, 2022), education and culture (e.g., Ostrosky-Solis & Lozano, 2006) on BDS tasks; attention problems and executive functioning in children (Rosenthal, Riccio, Gsanger, & Jarratt, 2006) effects of noise/sound & tactile on BDS (Osman & Sullivan, 2015; Arcos, Jaeggi & Grossman, 2022) cognitive strategies employed in BDS (e.g., Hilbert, Nakagawa, Puci, Zech & Buhner, 2015). Hester, Kinsella and Ong (2004) studied forward and backward digit span performances of the subjects aged between 16-89 in which they verbally (unisensory) presented the subjects with an increasingly longer series of digits (span 2-9) in forward condition. They also verbally presented the subjects with backward digit span tasks consisting of a series of digits in which the subjects were needed to recall the digits in reverse order. These studies found that subjects with ages ranging from 16-45 scored on average 7 digits (with little fluctuations) as recall in BDS tasks. The recall began to decline after the age of 45 particularly from 55, suggesting that BDS performances remarkably varied in terms of ages. St. Clair-Thompson (2010) verbally (unisensory) presented a list of digits to 77 children (average age 7 years) and 75 adults (average age 20 years) and instructed them to recall the digits in reverse order with an aim to determine whether BDS measuresd short-term memory or working memory. His studies revealed that BDS measured working memory in children and short-term memory (that holds but does not manipulate a small amount of information in the active or readily available state for a short period of time typically 10 or 15 seconds or sometimes up to a minute) in adults. Recently, Arcos *et al.*, (2022) examined verbal memory span in 77 participants (sighted-58 & blind-19) with verbal short-term memory span tasks and forward and backward digit span tasks involving auditory, visual or tactile modalities. Their studies found that blind individuals performed better on verbal short-term memory span tasks than sighted individuals. In addition, blind individuals showed good performances in both auditory forward and backward digit span tasks. A few studies investigated working memory in the tactile modality (e.g., Papagno, Comi, Riva, Bizzi, Vernice, Casarotti, Fava & Bello, 2017; Arcos *et al.,* 2022). Hence, it is observed that most of the research focusing on backward digit span was based on either unisensory modality (e.g., auditory or visual or tactile) or bisensory (auditory and visual) modalities or both. Much of the existing memory research focusing on BDS has failed to account for measuring BDS with trisensory presentation (e.g., visual, auditory and tactile) and its effects on the advancing ages. Although TBDS was examined in people aged 45-55 in a research study conducted by Siddik, Lata and Sarker (2018), it did not do so across different age groups. Thus, the present study aims to examine the development of BDS with trisensory presentation across different age groups. In particular, it seeks to examine how trisensory backward digit span (TBDS) develops across different age groups and whether TBDS fluctuates in terms of age. In this case, experimenters showed and read out the digits to the participants. At the same time, they allowed the participants to touch each digit (made of wood) of a number. Then the participants recalled the digits in reverse order immediately after the digits were presented. We hypothesized that the present study would see a gradual increase in TBDS from childhood to early adulthood.

Touch is considered the foundation of human cognition (Perez, 2019). Baby starts to receive its first experiences with the surrounding environment through touch. Thus, tactile learning or learning through touch plays an important role in a child's growth in cognitive and language abilities along with other ones (e.g., physical abilities, social and emotional development). Humans utilize tactile sense organs to gather multiple information on objects around themselves and develop reciprocal bonds. Hatfield (1994) demonstrated that positive touch (e.g., affection, touch for learning) facilitated children and adults to enhance learning and language processing and to improve problem-solving abilities. More importantly, children acquiring tactile learning obtain the potential to have better motor skills, and learning development in the future that contribute to their future academic successes. Heled, Rotberg, Yavich & Hoofien (2021) reported that tactile modality was a valid tool for assessing working memory that was measured by backward digit span and other memory-related tasks. Considering the advantages of touch sense, we have decided to employ this sense organ (touch) along with other sense organs (e.g., visual and auditory) in BDS tasks.

2. Methods

2.1 Subjects

58 students (male 30 and female 28) aged between 9 and 22 were purposively selected and used as subjects in the present study. They were from different socio-economic and education levels. In detail, 20 subjects aged between 9-12 (group 1) belonged to the fourth and fifth grades while 30 subjects aged between 16-18 (group 2)

did to the eleventh and twelfth grades. The remaining 8 subjects aged 22 (group 3) were studying in the fourth year (honors). Spontaneous participation was observed among them. All the participants were Bangladeshi by birth and living in Bangladesh during the experiment. The participants were informed of the purpose of the study.

2.2 Apparatus

Three sets of stimuli (lists of numbers) were used in three phases. Each list of numbers contained ten numbers and the list of digits made of wood began at length three and was expanded to length 12. To facilitate the subjects to recall the digits in reverse order, paper and pen were provided. A stopwatch was used to maintain time management in accomplishing the experimental tasks.

2.3 Procedures

Subjects were individually tested in a room, where three lists of numbers were presented with three modalities (auditory, visual and tactile) one after another with five-minute intervals among each of the lists. Sequences of digits were constructed randomly and were presented at the rate of one per second. More clearly, a number (e.g., 472) securing the first position of List 1 was shown and read out to the subjects. The subjects, at the same time (during the visual and auditory mode of presentation), were allowed to touch each digit (made of wood) of a number (e.g., 472). Then the next number (e.g., 4329) securing the second position in the same list and including one more digit was presented in a similar manner to that of the first instance (e.g., 472). In such a manner, 10 numbers from the list 1 were presented to the subjects. After a five-minute interval, 10 numbers from the list 2 were presented. The list 3 faced the same experimental procedures as that of list 1 and list 2. Subjects were instructed to recall as many digits from the lists as they could remember in reverse order as these ones were presented. For instance, if a number 472 was presented, subjects needed to recall this number in reverse order (e.g., 274). Written responses from the subjects were received after each number on the list was presented. Subjects' correct and incorrect responses were marked with a tick (√) and cross (x) symbols respectively. The performances of the subjects were assessed by the method recommended by Woodworth and Schlosberg (1954). As per the method, if, for example, a subject correctly recalls all the lists up to and including four digits, a basal value of four is allotted. If above that value, the subject correctly scores twice with five-digit lists, twice with six and once with seven, not at all eight and none further, his total BDS will be 4+(2+2+1)/3 (basal value + additional correct responses/3)=5.67, since equal credit is given for each correct recall above the basal level.

3. Results

Group 1 aged between 9-12, group 2 aged between 16-18 and Group 3 aged 22 secured a mean TBDS of 3.98, 5.38 and 5.41 respectively, revealing that TBDS increased in terms of age. We tested the statistical significance differences of TBDS among groups. A one-way analysis of variance (ANOVA) demonstrated significant differences (F, [6.290], p<.003) in TBDS among groups with respect to age level. To find out which group shares significant differences with which group, a post hoc ANOVA was administered. The most noticeable significant differences appeared between subjects aged 9-12 and 16-18 (p<.05). Sex differences in TBDS were also found within a group, although they did not appear remarkably. For example, in group 1 aged between 9-12, 20 students, among which 10 male and 10 female participated in TBDS experiments, in which they showed a mean TBDS of 4.23 and 3.73 respectively..

Table 1. TBDS analyzed by one-way analysis of variance (ANOVA)

	Sum of squares	*df*	Mean square	F	Significance
Between groups	26.130	2	13.065	6.290	.003
Within groups	114.245	55	2.077		
Total	140.375	57	15.142		

Table 2. A post hoc analysis that showed a significant difference between the groups of 9-11 and 16-18

Post hoc analysis Multiple Comparisons						
(I) Educational qualification	(J) Educational qualification	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound
Primary	**Higher Secondary**	-1.40600(*)	.41605	**.004**	-2.4082	-.4038
	Hons 4th year	-1.43450	.60292	.054	-2.8868	.0178
Higher Secondary	Primary	1.40600(*)	.41605	**.004**	.4038	2.4082
	Hons 4th year	-.02850	.57349	.999	-1.4099	1.3529
Hons 4th year	Primary	1.43450	.60292	.054	-.0178	2.8868
	Higher Secondary	.02850	.57349	.999	-1.3529	1.4099

* The mean difference is significant at the .05 level.

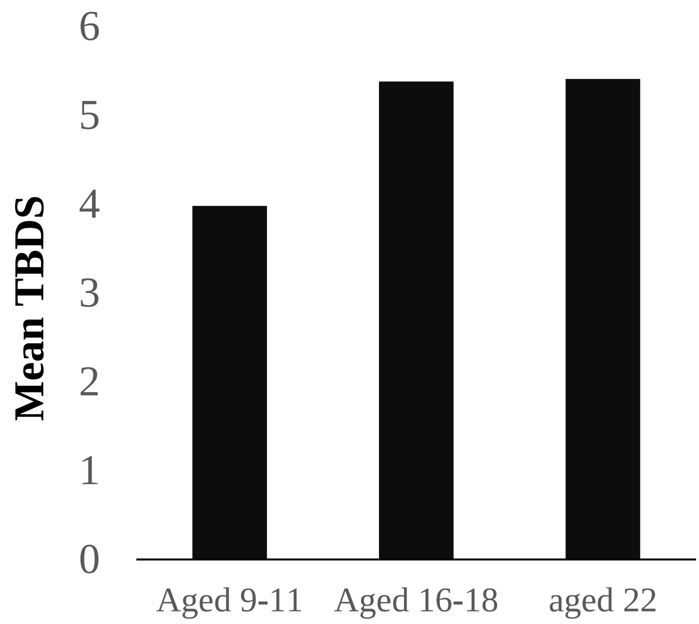

Figure 1. TBDS in Terms of Ages

In group 2 aged between 16-18, 15 male and 15 female students demonstrated a mean TBDS of 5.08 and 5.68 respectively. Similar phenomena were found in group 3 aged 22. Here, sex differences in TBDS were 5.67 and 5.00 for male (05) and female (03) students respectively.

4. Discussion

The present study demonstrated different TDBS for each group of subjects. These TBDS gradually increased across different age groups between 9 and 22 years. The results are, therefore, consistent with previous findings that memory increased in line with gradually increasing ages, particularly from 7 to 22 years old (e.g., Olson *et al.,* 1984). Significant differences were found among groups that participated in the present study. More particularly, these differences were remarkable between the groups of 9-11 and 16-18 (MD= 1.40, $p<.05$). A number of studies (e.g., Hayslip & kennelly, 1982; Babcock & Salthouse, 1990) have reported age differences in BDS tasks that conformed to that of the present study. For example, Hayslip and Kennelly (1982) employed 162 subjects with ages ranging from 17-76 categorizing them into three groups (group 1 aged 17-26; group 2 aged 39-51; group 3 aged 59-76) and administered experiments with BDS tasks. Their studies found age differences in BDS tasks among these three groups. Effects of age on memory tasks were also supported by a recent study (e.g., Pitts and Sarter, 2018) that examined age-related differences in detecting concurrent visual, auditory and tactile cues. In this regard, 36 participants were instructed to detect and respond to a series of signals, pairs and triplets of visual, auditory and tactile cues that were absent in Experiment 1 and present in Experiment 2. Their studies reported higher error and longer response time to cues/cue combinations in older adults as compared to those of younger adults, suggesting that age played a role in the case of memory tasks. However, significant differences between the age groups of 9-11 and 16-18 might be explained by the relative contributions of storage and attentional resources or the differential employment of memory strategies. The physiological view explains that executive functions (e.g., cognitive flexibility) are limited in preadolescence. Along with increasing ages, children gradually acquire skills to employ the ability of cognitive flexibility (the mental ability to switch between thinking about two different concepts and thinking about multiple concepts simultaneously) across multiple contexts as a result of the ongoing development of inhibitory control, one kind of executive functioning. It (gradually increased age) also contributes to mature synaptic connections, increased myelination and regional grey matter volume in the brain (Morton, Bosma, & Ansari, 2009). Sufficient changes in the constant myelination of neurons in the prefrontal cortex of the human brain during early adulthood (20-29) make the executive functions fully operational allowing adult people to perform the most challenging mental tasks.

A major line of thinking about human cognitive development is that it is driven by learning and maturation (an automatic process by which individual and behavioural characteristics emerge through the growth process over time) that are obtained through ages, daily life experiences, education and so forth (Meumann, 1907). For instance, a complex task that a child cannot do at the age of five may be solved at the age of eight. Intellectual ability, patience, emotional balance, discretion, integrity, problem-solving, decision-making, and attention develop along with increasing age. The more a child becomes old, the more experiences, education, and learning he obtains that will contribute to his intellectual ability, or to forming strategies to remember more materials such as chunking by reorganizing information into smaller groups or clusters. This assumption is supported by a famous developmental psychologist named Jean Piaget (1936) who stated that the cognitive development of children occurs through a succession of stages, the first stage of which, is a sensory-motor stage (0-2 years) where a child learn the relationship between their bodies and the environment through the sense. In the pre-operational stage (2-7 years), children learn to form concepts and use symbols but have difficulty in classifying information. The third stage called the concrete operational stage (7-12 years) produces logical thinking in children. The most notable feature of this stage is that children acquire the concept of conservation, a notion that quantity does not change despite changes in spatial arrangement or form. Abstract thinking, hypothesis, and analogy begin to develop at the formal operational stage (12-adult). Summarily, Piaget's cognitive development theory indicates that human cognition gradually develops from tasks of simple to complex nature in terms of the increase of age. This assumption may be applicable to explain the differences of TBDS between the groups of 9-12 and 16-18. It was worth mentioning that three groups (group 1, group 2 and group 3) had three different level of education along with three different levels of age. For example, group 1 aged 9-12 belonged to the level of primary education studying at 4^{th} and 5th grade, whereas group 2 aged 16-18 studied at eleventh and twelfth grade. The third group aged 22 studied in the fourth year (honours). Interestingly, these three groups (group1, group 2 and group 3) secured mean TBDS of 3.98, 5.38 and 5.41 suggesting that TBDS differed and gradually increased in terms of the level of education along with the different level of ages. A significant correlation (r=.97) was found between the level of age and education. These findings were strengthened by a previous studies carried on by Osterweil, Mulford, Syndulko and Martin (1994) who reported that subjects with 0 to 4 years of education scored more poorly on cognitive tests than other subjects who were older in terms of age and education (MMS [n = 127, F = 11.20, P = 0.0011] and Cube Copying [n = 125, F = 11.24, P = 0.0011].

The present study has some limitations. One of them is that the performances of 8 subjects belonging to group 3 in the BDS tasks might not represent BDS of the people with ages ranging from 22. Thus, to enhance the reliability and to generalize the findings of the subjects aged 22, further researches should be administered with large number of subjects for the said group. Earlier, it was mentioned that we verbally presented the lists of digits to all the subjects (one by one) in the present study. In this case, despite our having sincere efforts to maintain the same level of sound we made to verbally present the digits to the subjects, we could not do it for all the subjects at a similar rate. Therefore, we cannot rule out the possibility, despite our best effort, of the effect of the degree of sound we made for the subjects. Of course, this limitation is true for the vast majority of the immediate memory span experiments with an auditory condition involving human subjects. A better design for future studies might use the techniques of employing recorded presentation of the lists of digits in which experimenters or a professional presenter will record his verbal presentation of the lists of digits maintaining the same level of sound (as much as possible) for all the lists of digits and play the same record for all the subjects. This procedure might lessen the effect of sound experimenters make on the subjects during a verbal presentation to some extent.

5. Conclusion

The present study demonstrated the numerical cognitive development across different age groups. In particular, It sheds light on how TBDS developed and differed from childhood to early adulthood via adolescence by explaining the physiological and some socio-educational factors. These findings have real implications for the domains of research, assessing short-term and working memory. More importantly, it may provide an insight into distinguishing between normal age-related changes and the warning signs of serious cognitive impairment.

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Ethics and Participant consent

The experiment was conducted under the supervision of Associate Professor Md. Abu Bokor Siddik according to the Declaration of Helsinki. The experimental room was enriched with convenient apparatus and equipment. The subjects' behaviours were measured in a safe environment where no potential risks were available and where they felt comfortable working. Only those subjects (and their parents, in the case of minors) who gave their consent participated in the experiment. They had the right to withdraw themselves from the projects at any moment. Research performances demonstrated by the participants were kept with anonymity and confidentiality securing the privacy of the participants. During experimentation, sound mental and physical states were ensured by providing them congenial research environment. No other potential ethical or environmental issues were expected to arise concerning this study.

Does this article screen for similarity? Yes

Conflict of Interest

The present study bears no conflict of interest.

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