Development of Executive Function among Different stages of Adolescents

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Abstract

Adolescence is a critical period of development with dynamic brain maturation characterized. by psychological, behavioural, and social change indicative of the transition to autonomy and independence (Steinberg and Morris, 2001). Developing brain is more malleable depending on the experiences than the adult brain. Executive function is defined as a combination of cognitive processes that allow humans to successfully plan, organize, regulate behaviour, and solve issues (Diamond, 2013). The current study explores the developmental pattern in different domains of executive function among three stages of adolescents as given by WHO. Visual scanning and Executive Control using Trail Making test by Ralph Reitan and Cognitive Flexibility, Response Inhibition, Cognitive Adaptability, and Cognitive Processing Speed using Wisconsin Card Sorting Test- 64 by Heaton et.al. The quantitative data was analysed using Kruskal Wallis H test. The results indicated that there is high significant difference ($p<0.001$) for Visual Scanning ($H=169.789$), Executive control ($H=161.925$), Cognitive flexibility ($H=55.134$), Response inhibition ($H=70.045$), Cognitive adaptability ($H=69.203$), and Cognitive processing speed ($H=212.56$) among Early, Mid and Late Adolescents.

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Adolescence is a critical period of development with dynamic brain maturation. characterized by psychological, behavioural, and social change indicative of the transition to autonomy and independence (Steinberg and Morris, 2001). Executive function (EF), often known as executive control or cognitive control, is a catch-all term for a group of similar but separate cognitive abilities. Planning, shifting (i.e., the flexibility of thought and action), fluency (i.e., generation of new responses), problem- solving, decision making, self-regulation, attentional control, working memory (i.e., concurrent remembering and processing), inhibitory control, and cognitive flexibility are just a few of the cognitive abilities mediated by the prefrontal cortex (Miyake and Friedman, 2000)

Executive functions initiate, co-ordinate, maintain, and inhibit other cognitive functions and are recruited in novel or demanding situations to perform goal-directed behaviour when routine behaviour is inadequate (Miyake et al., 2000)

Assessing executive function at various periods of adolescence is critical for understanding cognitive development throughout this critical era of life. Executive function is defined as a combination of cognitive processes that allow humans to successfully plan, organize, regulate behaviour, and solve issues (Diamond, 2013). As teenagers manage the obstacles of school, relationships, and decision-making, executive function testing becomes critical in identifying strengths, deficits, and possible areas for intervention or assistance (Blair & Raver, 2015).

Executive function develops significantly during adolescence, with diverse modifications found across different phases of this time (Luna, Padmanabhan, & O'Hearn, 2010). Researchers and practitioners can acquire insights into the development and functioning of executive function in adolescents by using various assessment techniques and procedures, laying the groundwork for targeted treatments, and supporting optimum cognitive growth (Best, Miller, & Naglieri, 2011).

However, assessing executive function in teenagers involves obstacles. Because of the complexity of executive function and the dynamic changes that occur during adolescence, diverse testing methodologies are required (Anderson, 2002). Furthermore, to ensure that assessments are accurate and culturally responsive, cultural, and contextual aspects must be examined (Romine & Reynolds, 2005).

Fortunately, a variety of evaluation instruments and methodologies for capturing executive function in teenagers have been created. Performance-based activities, self-report surveys, and behavioural observations are examples of these (Toplak, West, & Stanovich, 2013). Each approach provides useful information about various elements of executive function, such as working memory, inhibitory control, and cognitive flexibility.

This study examined many areas of executive function such as Cognitive Flexibility, Adaptability, Visual scanning and Information Processing speed, Cognitive processing speed etc. in teenagers at various phases of development using suitable assessment tools in this study. Studying developmental trajectory of executive functions will help researchers and practitioners to aid in career decision making, improve the cognitive capacities and general well-being of teenagers at this key stage of life.

Method

Objective

- To find out the level of executive functions among different stages of adolescents.

Hypotheses:

H1- There is a significant difference in the level of Executive Functions among early, mid, and late adolescents.

Operational Definitions: -

Adolescents – In the present study adolescents refers to the school going/college going adolescents male and female with the age range of 10-19 years. (WHO, 2019)

Executive Functions –In this study executive functions refers to the measure of Visual Scanning, Executive control, Cognitive Flexibility, Response Inhibition, Cognitive Adaptability, and Cognitive Processing Speed.

Variables:

Independent Variable: Stages of adolescents (Early, Mid and Late)

Dependent Variable: Executive Functions (Visual Scanning, Executive control, Cognitive Flexibility, Response Inhibition, Cognitive Adaptability, and Cognitive Processing Speed)

Research design:

Cross sectional design was used to explore the executive functions among early, mid, and late adolescents. A cross-sectional approach enables us to capture a snapshot of these distinct age groups at a single point in time, shedding light on the diversity and prevalence of Visual Scanning, Executive control, Cognitive Flexibility, Response Inhibition, Cognitive Adaptability, and Cognitive Processing Speed within each age category.

Sample

Sample adolescents with the age range of 10-19 years were selected from the schools and colleges from diverse socioeconomic backgrounds. Using Purposive sampling technique, the sample was collected from various domiciles of Dakshina Kannada.

Table 1

Distribution of sample between various stages of adolescents

Gender	Stages of adolescents		
	Early	Mid	Late
Boys	50	50	50
Girls	49	49	49
Total	99	99	99

Inclusion criteria

1. Adolescents
    a. Age range between 10-19
    b. Average level of academic performance based on Annual report card/ marks sheet shared by academic coordinator.
    c. Physically and mentally healthy
    d. Proficiency in English

Exclusion Criteria

1. Adolescents with special need as mentioned by school authority, mentioned in socio demographic details.
2. Adolescents undergoing any medical treatment, interventions.
3. Students who are repeating the academic year for different reasons.

Tools:

The following tools were used for the study.

Executive functions:

1. **Wisconsin Card Sorting Test- 64 card version (Heaton, 2003)**

The WCST is a measure of "Executive functions" domains such as Cognitive Flexibility, Response Inhibition, Cognitive Adaptability and Cognitive Processing Speed. It can be administered to the age range between 6 and half till 89 years.

2. **Trail Making Test (Reitan, 1958)**

   The Trail Making Test is another classic test of executive function. This test is divided into two tasks of escalating complexity. Part A, which assesses rapid visual scanning and motor speed, requires participants to connect dots in numerical order. Part B requires participants to shift between number and letter sequences, thus requiring Executive Control.

Procedure:

After identifying the availability of samples in different hostels and schools situated in Ujire, Dakshina Kannada, Karnataka, India. Permission was sought from the institution heads and the wardens of respective hostels. Participants were met individually, and the purpose and objectives of the study were explained to them. After ascertaining their willingness to participate in the study, rapport was established, and written consent was taken from each participant. Socio demographic details were collected from the participants**.**

Data Analysis

The data showed deviations from the normal assumptions, a vital prerequisite for a lot of parametric tests. Since the skewness using Shapiro-Wilk test of the Executive variables such as Visual scanning (0.94; p=0.00) Information Processing and motor speed (0.95 p=0.00), Cognitive Flexibility (0.90; p=0.00) Response Inhibition (0.90; p=0.00) Cognitive Adaptability (0.99; p=0.00), Cognitive Processing Speed (0.92; p=0.00) was not normally distribution data, Kruskal Wallis H test was computed to see the difference between Variables of Executive Functions among early, mid and late adolescents.

Non-parametric test was employed because of this deviation and to make sure statistical analysis was valid. Because they do not depend on the assumption of a normal distribution, non-parametric tests—like the Kruskal-Walli's test—are better suited for datasets containing variables that are not normally distributed. (S.K. Mangal, 2002). To test whether there are significant differences in the independent groups- age groups, the Kruskal-Wallis H test was computed.

Ethical Consideration:

Ethical criteria of the research were met by getting permission from the institution's heads and the participants for data collection. Participants were assured of confidentiality regarding the information provided by them and of maintaining confidentiality regarding their identity. Participants were informed that they could withdraw from the research at any point.

Results and Discussions

Descriptive Analysis

Data obtained were subjected to descriptive statistics such as mean, standard deviation. Since the skewness of the Executive variables such as Visual scanning (0.94; p=0.00) Executive Control (0.95; p=0.00), Cognitive Flexibility (0.90; p=0.00)Response Inhibition (0.90; p=0.00) Cognitive Adaptability (0.99; p=0.00), Cognitive Processing Speed (0.92; p=0.00) was non normal, Kruskal Wallis H test was computed to see the difference between Variables of Executive Functions among early, mid and late adolescents.

In the present study Visual scanning was measured by the Time taken to complete TMT A task from trail Making test, where individuals are required to connect a series of encircled numbers in ascending order. Participants must quickly scan the visual field, locate each number, and connect them sequentially. Information processing and motor speed was measured by time taken to finish TMT B task where individuals are required to connect both numbers and letters alternately in ascending order (1-A-2-B-3-C, and so on). TMT-B assesses not only visual scanning but also information processing, and motor speed.

Cognitive Flexibility is measured by using scores on Perseverative response of WCST test which requires assessing their ability to adapt to changing rules and modify their cognitive strategies. It reflects an individual's ability to disengage from a previous strategy and flexibly adapt to the evolving task demands.

Response Inhibition is measured using scores of Perseverative errors of WCST test where previous principle inhibits the response, despite of the change in principle.

Wisconsin Card Sorting Test (WCST) total scores provide a measure of cognitive adaptability by assessing an individual's ability to flexibly adjust their cognitive strategies in response to changing task demands.

The Wisconsin Card Sorting Test (WCST) total time taken serves as an indicator of cognitive processing speed by assessing the efficiency with which individuals complete the task. The measure reflects the speed at which individuals can process information.

Table 1.2

Descriptive statistics of three groups of adolescents for TMT A Time taken, TMT B Time taken, Perseverative Response, Perseverative Errors, WCST total score, WCST total time taken of Early, Mid and Late adolescents.

Variables	Test variant	Group	Mean	SD	Minimum	Maximum

Visual scanning	TMT A (time taken in sec.)	Early	86.44	19.25	37	135
		Mid	42.62	12.157	20	73
		Late	53.11	15.225	26	101
Information processing and Motor Speed	TMT B (time taken in sec.)	Early	119.79	19.042	65	162
		Mid	81.87	13.783	42	127
		Late	80.44	12.521	45	107
Cognitive Flexibility	Perseverative response	Early	1.93	0.961	0	5
		Mid	2.78	0.828	1	4
		Late	1.86	.796	0	4
Response inhibition	Perseverative error	Early	7.63	2.888	0	14
		Mid	5.94	1.942	2	11
		Late	8.71	2.242	0	13
Cognitive Adaptability	WCST Total score	Early	33.84	7.12	17	47
		Mid	38.64	5.97	25	50
		Late	30.01	6.00	12	42
Cognitive processing speed	WCST Total time taken (sec.)	Early	386.02	56.33	219	489
		Mid	296.9	28.4	216	346
		Late	249.53	18.50	190	285

The mean time taken by adolescents under visual scanning -TMT A time taken reveals that early adolescents (X=86.44 seconds) have taken longer time to finish the task compared to Mid (X=42.62) and Late adolescents (X=53.11). And that Mid adolescent has finished the visual scanning task faster than the early and late adolescents.

The mean time taken by adolescents under Information processing and Motor Speed-TMT B time taken shows that early adolescents (X=119.79) have taken longer time than the Mid (X=81.87) and late (X=80.44) adolescents.

Under the dimensions of Cognitive Flexibility measured by Perseverative Response of WCST scale, Mid adolescents(X=2.78) did much better than the early (X=1.93) and late adolescents (X=1.86).

Under the dimensions of Response Inhibition measured by Perseverative Error scores of WCST, Late adolescents (X=8.71) did better than early(X=7.63) and Mid-Adolescents (X=5.94).

For the dimension of Cognitive Adaptability measured by WCST Total scores, mid adolescents (X=38.64) showed better cognitive adaptability compared to early (X=38.64) and late adolescents (X=38.64).

The mean time taken for Cognitive Processing speed measured by time taken to complete WCST test shows that Late adolescents (X=249.53) have better processing speed since they have taken less time compared to Early (X=386.02). and Mid adolescents (X=296.9) to complete the task.

Kruskal Wallis Test Analysis

Table 1.3

Kruskal Wallis H Test for Group Differences in Executive Functions of Early, Mid and Late Adolescents

Variables	Group	N	Mean Rank	H	df	Sig.
TMT (A) Time	Early	99	236.81	169.78***	2	0.00

taken. (Visual scanning)						
	Mid	99	81.85			
	Late	99	128.34			
TMT(B) Time taken. (Information processing and Motor speed)	Early	99	238.61	161.92***	2	0.00
	Mid	99	107.01			
	Late	99	101.38			
Perseverative Response (Cognitive Flexibility)	Early	99	127.03	55.13***	2	0.00
	Mid	99	198.53			
	Late	99	121.45			
Perseverative errors (Response Inhibition)	Early	99	158.37	70.04***	2	0.00
	Mid	99	94.26			
	Late	99	194.37			
WCST total score (Cognitive adaptability)	Early	99	146.72	69.20***	2	0.00
	Mid	99	200.82			
	Late	99	99.46			
WCST total time (Cognitive processing speed)	Early	99	237.57	212.56***	2	0.00
	Mid	99	149.81			
	Late	99	59.62			

*(p<0.05) statistical test: Kruskal Wallis, ****p<0.001 Very Highly Significant

Normal distribution Analysis by Shapiro-Wilk test for the present research data yielded a non-parametric distribution, which means that the data does not adhere to the assumptions of a normal distribution. This is an important consideration as it allows us to employ robust statistical methods that do not rely on assumptions of normality. By utilizing non-parametric tests, we ensure the validity of our analyses while avoiding potential biases that could arise from deviations from normality. These tests provide reliable insights even when our data does not meet the stringent assumptions of traditional parametric methods, enhancing the credibility of our findings and conclusions.

In this study, normality was tested using the Kolmogorov-Smirnov and Shapiro-Wilk tests to determine whether the data adheres to a normal distribution.

The Kolmogorov-Smirnov test yielded a maximum D value of 0.104 (p=0.000) for TMT A -Visual Attention, (D=0.101; p=0.00) for TMT B - Information Processing and motor speed, (D=0.231; p=0.0) for Perseverative Response - Cognitive Flexibility, (D=0.86; p=0.00) for Perseverative Error - Response Inhibition, (D=0.49; p=0.08) for WCST total score - Cognitive adaptability and (D=0.12; p=0.00) for WCST Total time taken- Cognitive Processing Speed.

Similarly, the Shapiro-Wilk test produced W values (0.94; p=0.000) for TMT A-Visual Attention, (0.95; p=0.00) for TMT B - Information Processing and motor speed, (D=0.90; p=0.00) for Perseverative Response- Cognitive Flexibility, (W=0.97; p=0.00) for Perseverative Error- Response Inhibition, (W=0.99; p=0.09) for WCST total score- Cognitive adaptability and (W=0.92; p=0.00) for WCST Total time taken- Cognitive Processing Speed. Both the tests revealed significant departures from normality (p=0.00) in variable distribution.

The Kruskal-Wallis H test was used to compare the mean ranks of Early, Mid, and Late Adolescents. The test was chosen as an appropriate non-parametric alternative to the one-way analysis of variance (ANOVA).

The results of the Kruskal-Wallis H test revealed a significant difference in the scores of the teenagers in the three groups (Early, Mid, and Late). An appropriate pairwise comparison is a post-hoc analysis of difference in each age group.

Early adolescents (X= 236.81**, $p<0.01$) exhibited significantly higher mean ranks in Visual Scanning (TMT A) than Mid Adolescents (X= 81.85**, $p<0.01$) and Late Adolescents (X= 128.34**, $p<0.01$). As Early adolescents took more time to complete visual scanning task compared to Mid and late adolescents, which suggests the Visual Scanning ability increases with advancement of age among adolescents. There are significant differences between the three groups' average ranks (H=169.789***, $p<0.01$). Similar results were found by Luna, Velanova, & Geier, (2008) and Crone et al., (2009) they attribute the improvements in visual search efficiency during adolescence to neural maturation processes, contributing to the understanding of how cognitive abilities, including visual scanning mature during adolescence. The visual scanning is an important ability required for reading speed an indicator of academic performance of adolescents as it is the time to decide their career. The present study sample shows highest speed in mid adolescents i.e in grade 8 to 10. We can note that the visual scanning is highest during this period which will aid in their academic performance. With the increase in the amount of time taken to complete the task of visual scanning, decreases the ability to visual scan.

Early adolescents (X=238.61, $p<0.01$) took significantly longer time on the Information Processing and motor speed (TMT B time taken) than Mid Adolescents (X= 107.01, $p<0.01$) and Late Adolescents (X=101.38, $p<0.01$). This demonstrates that there is an advancement with age. Information Processing and motor speed increases among different stages of adolescents. Similar results were found by Best, Miller, & Jones, (2009); Rubia, Smith, Taylor, & Brammer, (2007) where dynamic nature of Information Processing and motor speed and their improvement over time among adolescents was noted. Since early adolescents of age range 10-12 years show low level of information processing. Slower information processing indicates poor mental and motor ability. This can result in challenges following the pace of instruction and syllabi, completing assignments or meeting deadlines.

Under the dimension of Cognitive Flexibility Mid adolescents ($X=198.53$, $p<0.01$) scored significantly higher than early ($X=127.03$, $p<0.01$) and late adolescents ($X=121.45$, $p<0.01$). Crone & Dahl, (2012) also found that cognitive flexibility and its neural basis changes throughout childhood and adolescents. The present data shows that mid adolescents of age range 13-15 years adapt to changes in academic tasks and instructional methods and contribute effectively to the group projects. They can transit smoothly between different subjects.

Compared to Early adolescents ($X=158.37$, $p<0.01$) and Mid-Adolescents ($X=94.26$, $p<0.01$), Late adolescents ($X=194.37$, $p<0.01$) exhibited significantly higher mean ranks for Response inhibition (Perseverative errors) examined using WCST. There are significant differences between the three groups' average ranks ($H=70.045^{***}$, $p<0.01$). Research on response inhibition by Luna, Padmanabhan, & O'Hearn, (2010); Hare, Tottenham, Davidson, Glover, & Casey, (2005) found that inhibition abilities in adolescents improved with age, reflecting the maturation of the prefrontal cortex and other relevant brain regions.

In the present data, Late adolescents of grade 11-12 performed better in response inhibition, than Early or Mid-adolescents, whose capacity to do so decreases from Early to Mid and appears to grow in Late Adolescents. They can resist the temptation to engage in impulsive or disruptive actions, leading to a more conducive learning environment, allowing them to concentrate on their studies without being easily swayed by irrelevant stimuli.

Under Cognitive Adaptability Mid adolescents (X=200.82, p<0.01) scored higher mean rank compared to early (X=146.72, p<0.01) and Late Adolescents (X=99.46, p<0.01). In addition to the findings of Luna, Padmanabhan, & O'Hearn, (2010) the present study found the specific age at which the adolescents develop cognitive adaptability i.e. mid adolescents.

Early adolescents (X=238, p<0.01) scored significantly higher than Mid Adolescents (X=238, p<0.01) and Late Adolescents (X=60, p<0.01) in terms of cognitive processing speed as measured by the WCST Total time taken. This suggests that cognitive processing speed increases dramatically with age and is low in Early Adolescents compared to Mid and Late Adolescents. Additionally, there are significant differences between the three groups' average ranks (H=212.56***, p<0.01). Increase in the time taken indicates slower Cognitive Processing. The study has added to the findings of Gathercole & Stegmann, (2003) where the specific executive function is developed at what point of period in adolescents is not mentioned.

Implications

Findings reveal that cognitive processes such as Visual scanning, Information Processing and motor speed, Cognitive Flexibility, Response inhibition, Cognitive adaptability and Cognitive processing speed exhibit distinct trajectories during early, mid, and late adolescence. These variations highlight the dynamic nature of executive function development, the ability of adolescents to plan, organize, and carry out tasks efficiently is greatly influenced by their executive functions as they navigate the difficulties of their academic journey.

We can help the next generation succeed academically and develop holistically by including executive function training such as- Activity switching games, use of planners or digital tools to help students organize their schedules, assignments, and deadlines- into school curricula and offering resources such as in person Workshops, booklets that outline the importance of executive functions in academic success and include practical tips, activities, to help parents support their children in developing these skills at home.

In the present study an effort is made to find the trajectory of development of Executive functions that mediates emotional and interpersonal skill development. A pattern of development is seen in the results where Cognitive Flexibility, Adaptability and Cognitive processing speed tends to develop more in mid adolescents and slightly decreases in late adolescents. Reason for the decline in Late adolescents of grade 11-12 could be due to study pressure and stress emerging from various factors.

Another study is required to explore the factors that could be resulting in the decline of these executive function in Late adolescents. However, factors like emotional regulation and personality traits can throw more light on the overall personality development at adolescents. Moreover, fostering a holistic approach that integrates both cognitive and socio-emotional development can have long-lasting implications. Encouraging activities that promote the overall well-being of adolescents, can positively influence executive functions and, consequently, academic outcomes.

Conclusions

The objective of the present study was to study the level of executive function development in adolescents and to check whether there exists any significant difference between three stages of adolescents. The study finally found that:

1. Visal Scanning, Cognitive Flexibility and Cognitive Adaptability is significantly higher in Mid adolescents of age group 13-15 years than Early and late adolescents.
2. Information Processing and motor speed, Response Inhibition and Cognitive Processing Speed is significantly high among late adolescents of age group 16-19 years compared to early and mid-adolescents.

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