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Correlation between Executive Function and Manual Dexterity in Community-Dwelling Older Adults

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Abstract

Background: The normal process of aging involves decline in cognitive and sensorimotor functions that affect performance of activities of daily living. Cognitive decline & motor system decline can coexist in elderly. Previous studies have indicated that cognitive factors in addition to peripheral changes are involved in dexterity decline. However, these studies have used either global measures of cognition or a selective domain of executive function. The purpose of the present study is to further explore this relationship and evaluate which specific domain/s of executive function is/are associated with manual dexterity in older adults.

Design: Cross-sectional, observational.

Setting: Physiotherapy department in a tertiary care center, Mumbai, India.

Participants: Community-dwelling older adults between 65-84 years of age (n= 35).

Main Outcome Measures: Executive functions were assessed for various domains using neuropsychological tests *viz*. TMT A & B (visuomotor tracking and mental flexibility, psychomotor speed), Stroop test (inhibitory process, selective control), Digit span forward & backward test (working memory), Clock drawing test (planning and visuoconstructive skills) and Verbal fluency test (semantic processing). Manual dexterity was assessed using Purdue pegboard test (assembly task).

Results: The mean (± SD) age of the participants (n=35) was 71.77 (± 5.88) years and they were predominantly male (63%). Analysis (using Spearman test, $p < 0.05$) showed a significant correlation of Purdue pegboard test with TMT A (r_s =-0.5496), TMT B (r_s = -0.6128), Stroop test (r_s =-0.4327), Clock drawing test (r_s =-0.5432) & Verbal fluency (r_s =0.5503). No significant correlation was found with the Digit span test.

Conclusion: Executive function (all the domains, except working memory) is significantly associated with manual dexterity in community-dwelling older adults aged 65- 84 years. These findings suggest that integration of complex cognitive and sensory mechanisms constitutes a crucial component of hand motor function in this population. This study provides a reasonable basis for implementing cognitive intervention strategies for manual dexterity impairment and new insights for hand rehabilitation in community-dwelling older adults.

Keywords: Executive Function; Manual Dexterity; Community-Dwelling Older Adults; Trail Making Test; Stroop Test; Clock Drawing Test; Verbal Fluency Test; Digit Span Test; Purdue Pegboard Test

Introduction

In Asia as a whole, the proportion of the elderly is expected to increase from 10.5% to 22.4 % during 2012-2050. According to the population census in India, 104 million people are elderly (aged 65 years above) in which 53 million are females and 51 million are males. The normal process of aging involves decline in cognitive and sensorimotor functions that affect performance of activities of daily living [1]. Affection of hand dexterity in elderly is interpreted in the context of sensori-motor and other peripheral changes only. Cognitive decline and motor system decline can coexist in elderly. Neurocognitive decline as a normal process of ageing brain is well documented in the scientific literature.

Cognition is an overarching term whereas executive function (EF) is a subset of it which is "broadly defined as control processes responsible for planning, assembling, coordinating, sequencing, and monitoring other cognitive operations" [2].

Executive functions (EF) refer to abilities involved in formulating goals, planning, executing plans effectively, and self-monitoring and correction. The primary difference between EFs and other cognitive functions is that the latter are related to "what" or "how much" a person knows [3]. With EF however, the focus is more on "how" an individual goes about performing tasks. These functions encompass the skills that enable individuals to successfully become engaged in independent, objective and self-monitored behavior, and thus involve the more complex aspects of human cognition [4].

More specifically, executive functions allow the ability to plan and develop strategies to achieve goals, a process calling for behavioral flexibility, an ability to integrate details coherently and manage multiple sources of information, in coordination with the use of previously acquired knowledge [5]. The executive system is also responsible for adapting behavior in order to solve problems of everyday living [6].

This multidimensional construct encompasses several other skills viz. planning, mental flexibility, working memory, inhibitory control, processing speed, etc. Planning refers to the identification of a sequence of actions required to achieve a goal. Efficient planning includes thinking about alternatives and choosing the most effective one. Mental flexibility refers to the ability of alternating between mental sets or tasks and changing the strategies within the same task [7]. Working memory (WM) is the ability concerned with active maintenance and manipulation of information that is used to guide ongoing and intended actions, and its capacity declines with aging, especially in tasks that also involve executive control [8]. Inhibitory control refers to the inhibition of a prepotent response, which facilitates the choice of an adequate response and avoids errors [9]. Processing speed refers to the time required to process a specific item of information.

Executive dysfunction is characterized by the inability to carry out adaptive tasks and dissociation between volition and action [10]. In everyday activities, this is reflected by problems commencing tasks, loss of sense of time, difficulties switching between tasks, controlling impulses, planning and time sequencing, as well as impatience and emotional liability [10]. Executive dysfunctions lead to significant limitations in the performance of activities of daily living and also instrumental activities of daily living, which reduces autonomy and quality of life [10,11]. Thus, stimulation and preserving this cognitive domain is crucial for this population group [12].

Structural basis of executive functioning became associated with the frontal lobes [13-16,3]. Within the frontal lobes, the motor strips control motor functions, the premotor areas are associated with planning and execution of complex motor sequences, and prefrontal areas are associated with intent, planning, and control of behaviour [17,18]. Each frontal area has numerous connections with the other cortical structures, thalamic nuclei and basal ganglia forming frontal lobe systems. In addition the cortical portions of these systems have connections with different posterior cortical regions [14]. Changes in EFs are suggestive of impairment to the frontal lobes or disconnection of the lobes from other brain areas which can lead to deficits in further cognitive functions. Changes in the front striatal circuit (neural circuit integrated to the lateral prefrontal cortex which accesses information related to working memory) are possibly the most significant cause of impaired executive function in elderly with no dementia.

Executive dysfunction in aging can be measured objectively with neuropsychological tests [13]. There are several executive function tests which vary according to the domains assessed.

Hand dexterity is defined as "the skillful manipulation of the hands" [18,19]. It is the ability to make coordinated hand and finger movements to grasp and manipulate objects. It includes muscular, skeletal, and neurological functions to produce small, precise movements. Thus, from the definition of hand dexterity it is evident that there are cognitive, sensorimotor, neurophysiological elements involved in the preparation, control and execution of a functional movement. In normal aging, changes in hand dexterity have been demonstrated in gripping, pinching, grasping, lifting, and manipulation of objects, which limit older adults' ability to perform activities of daily living. Some examples of the difficulties with manual ability experienced by elderly adults are handling small objects such as coins or buttons, telephoning, and preparing meals [20]. Previous studies have found that loss of hand or finger strength, precision, and manual speed are the principal declines observed in subjects over 65 years of age [21,22]. A recent study has demonstrated that declines in grip strength have a deleterious effect on hand steadiness, aiming, tapping and tracking in healthy elderly [23]. Other causes for dexterity decline in aging have been attributed to, morphological changes in finger and wrist joints, deteriorating vision [23], lack of tactile sensation, and cognitive deterioration [24,25]. Although the role of peripheral changes in dexterity has been established, these changes cannot consistently account for dexterity decline in elderly [26-28]. Study done by Cole R, et al. [25] showed that there is no decline in older adults' performance on an object-lifting task when they were deprived of tactile information. Similarly, some researchers [27,28], found no association between the ability to control fingertip force and performance in a peg-inserting task. These findings imply that other factors in addition to peripheral changes are involved in dexterity decline.

Among the above causes for dexterity decline, the role of cognitive decline is the least understood. Cognitive factors are increasingly being recognized as important for motor control. However, currently little is known about the cognitive constraints underlying manual dexterity decline in ageing. Previous studies targeted elderly with mild cognitive impairment or dementia while reduced EF is prevalent even among healthy older adults without overt cognitive impairment. Another methodological limitation of these studies is that they either used either global cognition or a selective domain of EF as performance measures. There is limited empirical evidence evaluating the connection between specific domains of the executive function and dexterity in normal aging. Taking into account that declines in attention and dexterity happen in the normal course of aging, it is important to evaluate which specific domain of executive function is associated with dexterity. Unraveling the role of executive function, we thus aimed to determine the correlation of manual dexterity with core EF functions viz. cognitive flexibility, inhibitory control, working memory, planning and verbal fluency.

Methods

It was a cross sectional study conducted in the Physiotherapy department of a tertiary care center. Institutional review board approved design and conduct of the study. The procedures followed protocol and accord with the ethical standards of the institutional review board. Informed written consent was obtained from all the participants before their participation in the study.

Baseline evaluation for eligibility entailed sociodemographic and clinical data which included age, income, years of schooling, marital status, general health status, presence of other clinical disease and use of medications. Inclusion criteria of the study was

- Age: 65 years to 84 years,
- Male or female,
- Community-dwelling (not in assisted living/nursing homes),
- Able to follow three-step commands,
- Able to read basic English,
- Age appropriate pinch strength: male ≥17.7 lb, female ≥10.5 lb [28].

Individuals were excluded from participation if they had

- Central or peripheral neurological disorders,
- Symptomatic musculoskeletal condition in upper limb or neck,
- Hand tremors,
- Global cognitive impairment (MMSE < 18/30),
- Uncorrected visual impairments,
- Hearing impairments,
- Speech related impairment,
- Unstable medical condition,
- Presence of depression (>5 on Geriatric Depression Scale), or
- Receiving medication which can affect cognition or hand dexterity.

Thus, as per these criteria, broadly speaking participants were physically and mentally healthy older adults. Eighty individuals were screened, out of which forty-four individuals met the eligibility criteria. As per the estimated sample size thirty-five subjects were recruited in the study by simple randomization using a computer generated table.

For the outcome measures of the study, subjects were assessed for Executive Function and Manual Dexterity. Executive function was assessed using six neuropsychological tests viz. TMT A & B, Stroop test, Digit span forward and backward test, Clock drawing test & Verbal fluency test. All of these five tests measure different cognitive constructs employing different brain processes (table 1). These are standardized, reliable and validated tests; and are simple paper and pencil tests in clinical context [29,34]. Whereas Purdue pegboard test is a hand and finger dexterity test assessed using an equipment. The subjects were assessed by two different assessors for cognitive and manual dexterity tests and in an identical manner for all the subjects. To negate the effect of fatigue and practice, rest period of 1 minute was given after every neuropsychological test and the order of testing was randomized for every subject.

Statistical Analysis

Data thus collected was analyzed using statistical software. Descriptive statistics for demographic characteristics are as given in Table 2. In this association model, The EF test values served as the independent variables whereas the manual dexterity served as the dependent variable. Variable distribution was tested using Kolmogorov-Smirnov test which exhibited significant departures from normality, and therefore non-parametric tests were used for all the analyses. Statistical significance was set at $p < 0.05$ (2-tailed). Spearman correlation coefficient test was applied for correlation analysis between Purdue pegboard test and Trail making test A & B, Verbal fluency, Clock drawing test, Digit Span test (forward and backward), Stroop test (table 3) The result showed that the PPT (Purdue pegboard test) performance was significantly moderately correlated in descending order with TMT B (r_s -0.6128, p <0.0001), Verbal fluency (r_s 0.5503 p = 0.0006), TMT A (r_s -0.5496, p= 0.0006), Clock drawing test (r_s-0.5432, p= 0.0007) and Stroop test (r_s -0.4327, p=0.0094). No significant association was found with the Digit span forward and backward test (FDS, r_s= 0.2904 at p 0.0906 & BDS, r_s= 0.2988 at p 0.0813) [30-33].

Variable	Domain	Test	Unit
Executive function	Visuomotor tracking, Cognitive flexibility	Trail making test A & B	Time (sec)
	Selective attention, Inhibitory control	Stroop test	Interference score
	Working memory (verbal)	Digit span forward & backward	Number of responses
	Planning	Clock drawing test	Number of errors
	Semantic processing	Verbal fluency	Number of responses
Manual Dexterity	Execution of controlled movements	Purdue pegboard test (Bimanual Assembly task)	Number of pins inserted

Table 1: Outcome measures.

Age (in years) (Mean ± SD)	71.77 ± 5.88
Gender: Male/Female (%)	63 / 37
Dominance: Right/Left (%)	97 / 3
GDS score	1.22 ± 0.97
MMSE score (Mean ± SD)	28.88 ± 1.40
Lateral Pinch Strength (lb)	18.98 ± 2.76
	13.32 ± 2.74

Table 2: Demographic characteristics of the participants.

Test	Mean	SD	p value	r value	Interpretation
TMT A	54.32	0.97	0.006	-0.5496	Significant negative moderate correlation
TMT B	98.37	37.9	< 0.0001	-0.6128	
Stroop Interference	401.17	52.19	0.0094	-0.4327	
Digit span forward	4.94	0.96	0.0813	0.2988	Not significant
Digit span backward	3.4	0.77	0.0906	0.2904	Not significant
Clock drawing test	3.14	2.61	0.0007	-0.5432	Significant negative moderate correlation
Verbal fluency	12.28	4	0.0006	0.5503	Significant positive moderate correlation

Table 3: Correlation analysis of Executive function tests with Purdue pegboard test (mean = 6.17, SD = 1.94).

Discussion

This cross-sectional study aimed to determine the correlation between specific domains of executive functions and manual dexterity in community-dwelling older adults between the age group of 65-84 years. 35 subjects with a mean (±SD) age 71.77 ± 5.88 years participated in the study. Executive function assessment consisted of neuropsychological tests whereas manual dexterity was assessed by assembly task of grooved Purdue pegboard test.

Results of the study showed that all domains of executive function are significantly associated with manual dexterity except working memory. This provides direct evidence for functional connectivity between EF and MD and suggests an underlying common cause which drives this association. The rationale for this association resides in that hand dexterity requires cognitive engagement and processes such as visual search, speed of processing, attention, judgment, task flexibility, inhibition and motor planning. These findings are in line with the previous studies and thus the null hypothesis is rejected.

TMT and Manual Dexterity

Trail making test A and B showed a significant negative correlation with the assembly task. (for TMT-A r_s= -0.5496 at p= 0.0006; for TMT-B r_s=-0.6128 at $p < 0.0001$). TMT A is a measure of psychomotor speed, selective attention, visual scanning and visual-motor tracking [12]. Whereas Part B is a measure of mental flexibility in managing more than one stimulus at a time, set-shifting and inhibition. In addition, Part B assesses visual scanning, number recognition, numeric sequencing and motor speed, working memory. TMT A & B both provide visuomotor tracking, however, cognitive flexibility necessary for the set shifting requirement in part B increases the executive demands of this subtask. In the present study, older adults showed longer completion time for part B relative to part A. Prolonged time in TMT-B is associated with deficient planning and action monitoring performance in assembly tasks. PPT involves visually guided action monitoring. Thus, the findings suggest that visuomotor tracking and especially cognitive flexibility is coupled with manual dexterity. These findings are in line with the previous studies in which a significant association between performance of pegboard test with executive functioning on TMT was found [35].

Hiroyuki H, et al. [12] suggested that low finger dexterity scores on Purdue pegboard tests may be due to cognitive delay rather than finger dexterity. Two studies examined the relationship between manual dexterity and executive function in elderly using kinematic analysis. Along with increased movement variability in dexterity and lower executive functioning on Trail making test B. In another study by Mari LE, et al. [36], strong association for variability in the assembly task and cognitive performance as measured by TMT was found in healthy elderly. Also significant correlations in the older group were found on the measurement of angular displacement and not on the angular velocities. Authors suggested that processing speed and executive function (as measured by TMT) as well as general appropriate mental status may explain the limited performance in the elderly.

Stroop Interference Effect and Manual Dexterity

Stroop test creates cognitive interference and predominantly assesses active inhibitory control over more automated responses and selective attention. Stroop color and word test assess the ability to inhibit cognitive interference, which occurs when the processing of stimulus features affects the simultaneous processing of another attribute of the same stimulus. i.e. (in the third test C-W) the participants are required to perform a less automated task (i.e. naming the ink color) while inhibiting the interference arising from a more automated task (i. e. reading the word). This difficulty in inhibiting the more automated process is called the Stroop effect, while Stroop test widely measures the ability to inhibit cognitive interference; previous literature also reports its application to measure other cognitive functions such as attention, processing speed, cognitive flexibility. All these cognitive attributes are also important for manual dexterity tasks.

Stroop Interference effect showed significantly moderate negative correlations with assembly task (r_s= -0.4327 at P=0.0094). Similarly Mari Lise Eriksen, 2012 found a strong association between dexterity task and cognitive tests measured by Stroop and TMT test and suggested that the executive functions and attention play a role in elderly to execute the dexterity task. When compared to young adults, old adults (those over age 60) tend to show large strop interference effects which may indicate an age related selective attention impairment.

Digit Span Test and Manual Dexterity

Digit span measures working memory. Working memory promotes active short term maintenance of information for later access and manipulation. Forward digit span primarily measures attention and storage while backward digit span may affect both storage and processing because it requires that a person must maintain a number in memory and manipulation of those numbers. According to Joel Mayerson, aging could have an effect on working memory. Digits span only shows small decline in normal aging as mentioned by Rodriguez- Arnanda C, et al. [1]. In a study by Mari LE, et al. [36] Digits Span Forward and Digits span backwards did not show significant differences between younger versus older adults who indicate that the elderly group had good performance in the short term and working memory by Choi HJ, et al. [31].

Glisky EL, et al. [37] suggested that older adults show minimal/ no deficits in short term memory and can typically hold about 7±2 digits in mind [38]. Repeating the numbers backward, however, requires an active reorganization and manipulation of the information held in short term memory which requires working memory and shows impairment with age. Similar findings have been reported by Rodriguez-Arnanda., et al 2016 the elderly group was particularly able to execute immediate recall of serial numbers forward while they were less proficient to perform the backwards part that relied on the higher levels of active manipulation of information. However, some studies by Jacques G, et al. [38], Myerson J, et al. [39] found no significant effect of age on the difference between digit span forward and backward. As because aging is characterized by a decline in the central executive while automatic processes (phonological loop) remain intact. In the working model, a phonological loop is arranged to maintain a string of verbal items in a given temporal order while, Backward digit span is a more extensive involvement of the central executive [39]. Thus, previous studies evaluating working memory in elderly as well as those comparing forward versus backward digit span have shown controversial findings. In the present study, no significant association could be found between forward digit span and backward digit span with assembly task (FDS, r_s= 0.2904 at p 0.0906 & BDS, r_s= 0.2988 at p 0.0813). It was observed in this sample that older adults showed a trend of reduced ability in backward digit span progressively from the age of 65 years to 84 years however, were able to remember the sequence of assembling pins, collars and washers in the dexterity task. It is important to mention that previous studies have reported that DS performance is significantly influenced by education and also by gender. In the present study, both these factors were not considered for analysis. Previous studies evaluating working memory in elderly as well as those comparing forward versus backward digit span have shown controversial findings [39]. Thus, these findings need to be explored further considering all the confounding factors in future studies.

Clock Drawing Test and Manual Dexterity

Clock drawing test measures visuo-constructive & visuo-spatial skills, along with executive functions which include planning, organization & parallel processing. Gunten AV, et al. [40] suggested that normal elderly subjects often have problems placing Figures 1-7 on the clock face and differentiating the clock hands correctly. The studies have shown that the older age and fewer years of education are typically associated with poorer clock drawing test performance by Hubbard EJ, et al. [41] In the present study, clock drawing and manual dexterity showed significant negative correlation (r_s= -0.5432 at p= -0.0007). Previous studies have also demonstrated spatial and planning errors in elderly using clock drawing tests indicating deficits in visuo-constructional abilities. PPT has certain spatial and temporal task rules. In the assembly task, different movements and pegs are required to be handled at faster rates. Thus, proper manipulation of various pegs is required which relies on good planning of finger and hand movements as well as coordination of type of movements in the right order. Therefore, low manual dexterity score of assembly tasks may be due to cognitive delay rather than or in addition to affection of finger dexterity. Chiang-soon Song using some other tests concluded that visual perceptual impairment and cognitive dysfunction may influence manual dexterity in older adults [42].

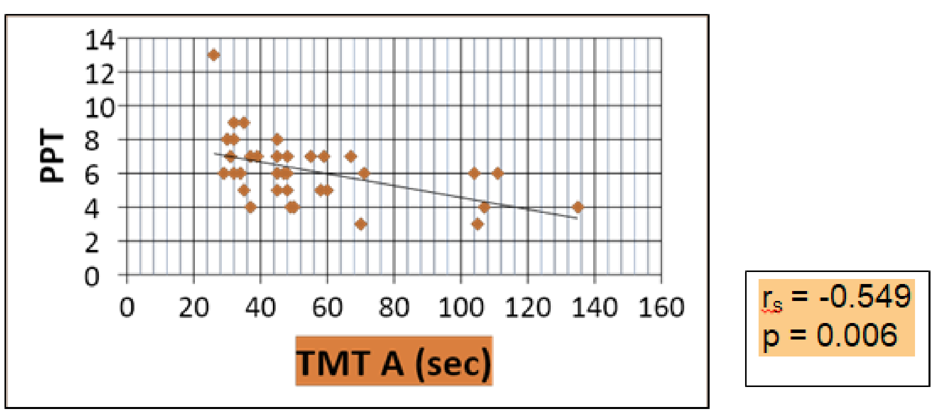

Figure 1: Correlation analysis of TMT A test with Purdue pegboard test.

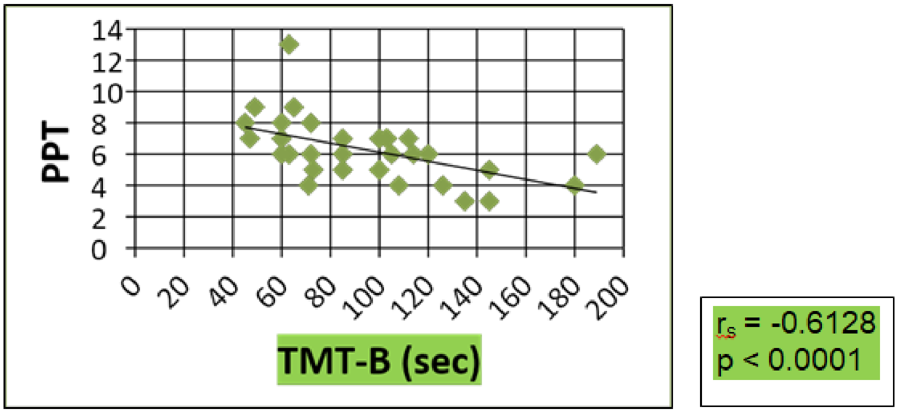

Figure 2: Correlation analysis of TMT B test with Purdue pegboard test.

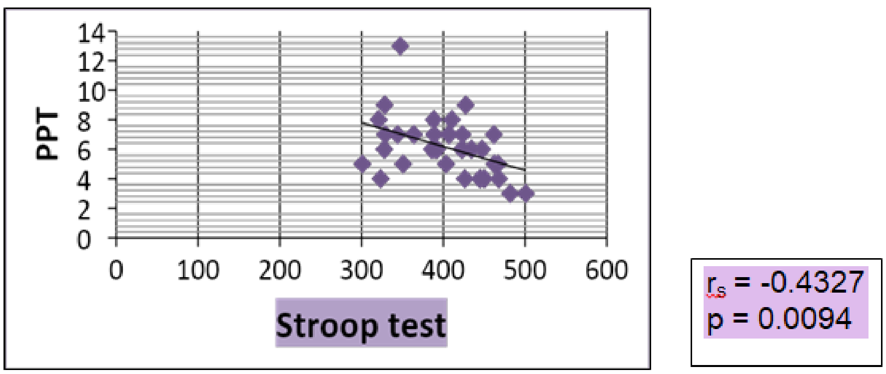

Figure 3: Correlation analysis of Stroop test with Purdue pegboard test.

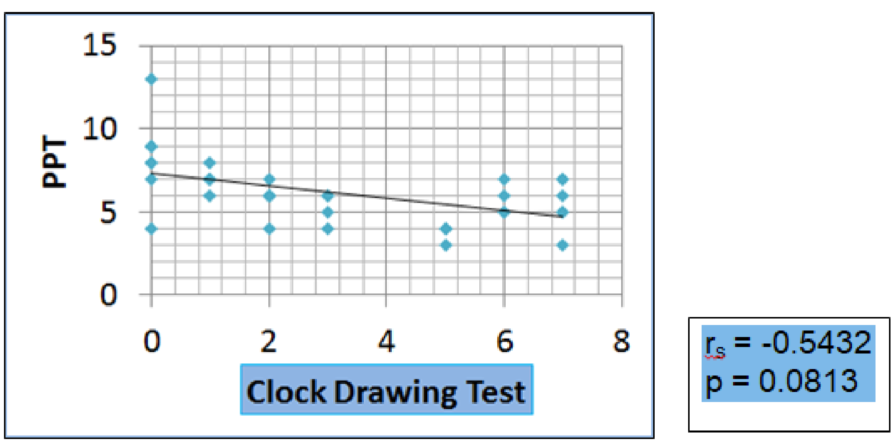

Figure 4: Correlation analysis of Clock drawing test with Purdue pegboard test.

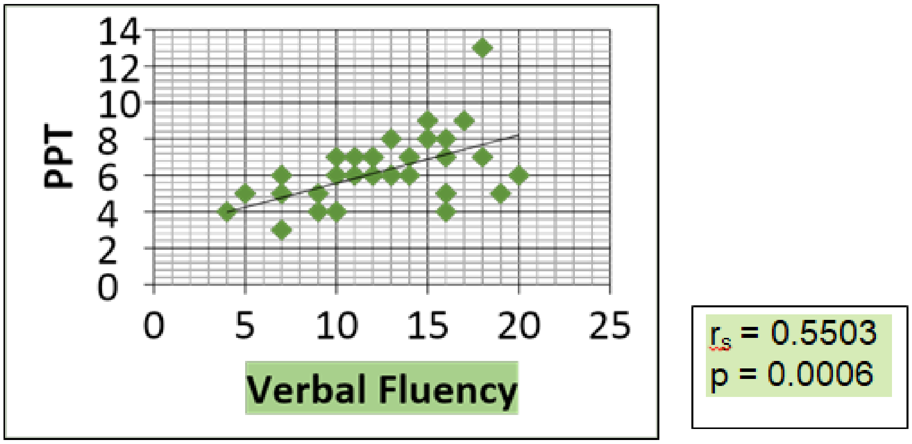

Figure 5: Correlation analysis of Verbal fluency test with Purdue pegboard test.

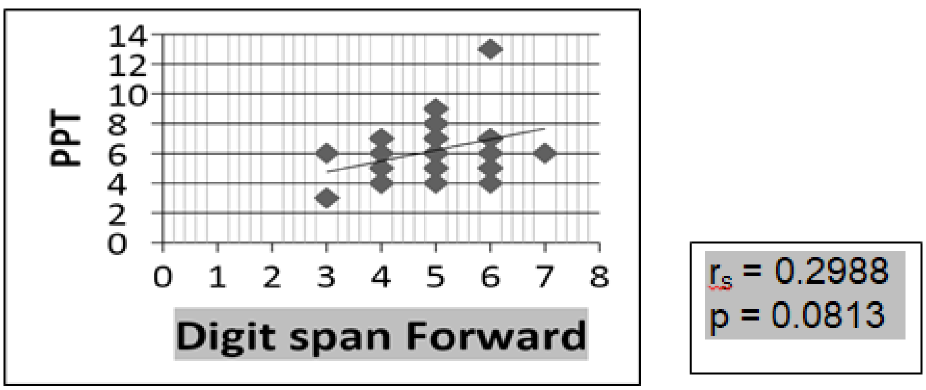

Figure 6: Correlation analysis of Digit span forward test with Purdue pegboard test.

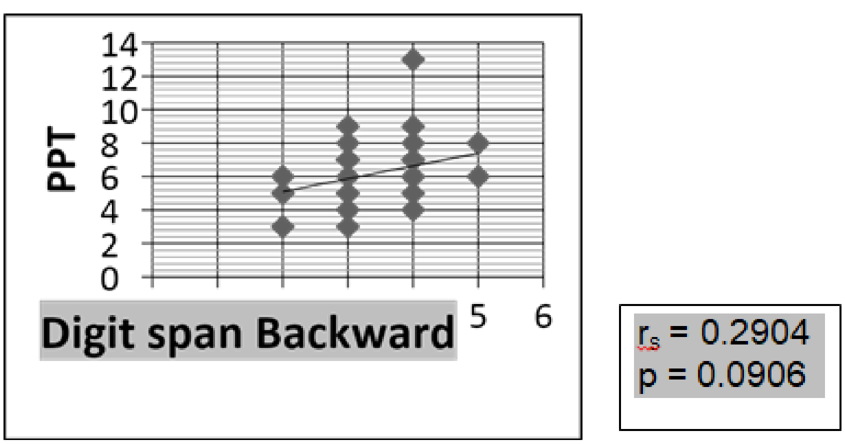

Figure 7: Correlation analysis of Digit span backward test with Purdue pegboard test.

Figures 1-7 are scatter diagrams of the relationship between executive function variables and hand dexterity.

Verbal Fluency and Manual Dexterity

Verbal fluency measures an active search for specific information in memory. Phenomic and semantic verbal fluency is measured by an individual's ability to generate words beginning with a specific letter (FAS) and semantic category (animal category). In the present study semantic verbal fluency was measured by animal category test. The result showed significant positive correlation between semantic verbal fluency test (animal category) and manual dexterity (r_s= 0.5503 at P 0.0006). Literature search conducted for the present study could not identify any study on elderly. A study done in preschool children by Smirni P, et al. [43] found that manual dexterity correlated with verbal and visuo-spatial performances.

Apart from this functional connectivity the neural basis can be derived from neuroimaging and functional MRI studies which suggest similarity of the prefrontal brain activities postulated between executive function and manual dexterity which are particularly altered in elderly. Specifically, recent studies have also demonstrated the potential involvement of a network of several brain areas related to EF, including the parietal cortex, cerebellum, and two prefrontal cortices: the anterior cingulate cortex and the dorsolateral prefrontal cortex [44]. In elderly, prefrontal brain activities are altered [45].

An important highlight of this study is more comprehensive evaluation of and the specific tests used for executive function which provide additional information about this relationship in addition to existing evidence. Also, in contrast to the previous studies, the age appropriate handgrip strength set as a cut off in inclusion try to disentangle sensorimotor affection from manual dexterity decline.

However, we acknowledge some limitations in the present study. Though it is speculated that cognitive decline has affected the manual dexterity performance; due to the cross-sectional nature of the study, this cause and effect relationship could not be established. Also, considering the dynamic relationship of both of these attributes in the mediating effect of age, a longitudinal design would have been more appropriate. Potential confounding factors such as education, gender, social engagement, etc (as identified in the literature), were not adjusted or eliminated in the present study. Data obtained from this sample was not compared with normative age and/or gender matched data to determine the extent of affection in cognition and manual dexterity function. Differences in age sub-groups were also not analyzed. With regards to generalizability, results are applicable to community-dwelling elderly only and may not be extrapolated to or include institutionalized elderly.

Conclusion

Executive function (all the domains, except working memory) is significantly associated with manual dexterity in community-dwelling older adults aged 65- 84 years. These findings suggest that integration of complex cognitive mechanisms constitute a crucial component of hand motor function and thus provide a reasonable basis for implementing cognitive intervention strategies and new insights for hand rehabilitation. Thus, there are cognitive, sensorimotor, neurophysiological elements involved in the preparation, control and execution of a functional movement in older adults.

Implications for Rehabilitation

Findings of the study provide clinical evidence of functional connectivity between EF and manual dexterity in elderly. The specific domains of executive function identified through this study need to be targeted for training dexterity function. Recognizing that they both can interact reciprocally with each other, therapeutic strategies for elderly with hand dexterity affection should be differently mediated for those with cognitive decline than those with intact cognition. New technological devices designed to improve hand functions should consider the cognitive demands for their application by the elderly. Correlation of cognitive skills with dexterity tasks assessed using Purdue Pegboard test further strengthen the evidence of neuro psychomotor property of Purdue Pegboard test.

Implications for Research

This study provides empirical evidence about the role of EF in execution of hand dexterity in elderly. Future research is required to establish causal relationships and considering the dynamic relationship, a longitudinal design is recommended. It will be worth exploring if performance of manual dexterity can predict cognitive deterioration in elderly. Also, this will serve to formulate therapeutic strategies to direct cognitive-based approach to motor rehabilitation.

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Conflict of Interest

The authors declare that they have no conflict of interests.

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