INVESTIGATING THE EFFECT OF SMARTPHONE ADDICTION ON EXECUTIVE FUNCTION AND FLUID INTELLIGENCE IN NEUROTYPICAL OLDER ADULTS

MS. NIRANJANA J

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A Dissertation Submitted in Part Fulfillment of the

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(Speech-Language Pathology)

University of Mysore

ALL INDIA INSTITUTE OF SPEECH AND HEARING

MANASAGANGOTRI, MYSURU- 570006

JULY 2024

CERTIFICATE

This is to certify that this dissertation entitled **"Investigating the effect of smartphone addiction on executive function and fluid intelligence in neuro-typical older adults"** is a Bonafide work submitted in part fulfillment for the degree of Master of Science (Speech-Language Pathology) of the student Registration number P01II22S123021. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru

July 2024

Dr. M. Pushpavathi

Director

All India Institute of Speech and Hearing

Manasagangothri

Mysuru- 570006

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Mysuru

July 2024

Guide

Dr. Hema. N

Assistant Professor in Speech Sciences
Department of Speech-Language Sciences
All India Institute of Speech and Hearing
Manasagangothri, Mysuru- 570006

DECLARATION

This is to certify that this dissertation entitled **"Investigating the effect of smartphone addiction on executive function and fluid intelligence in neuro-typical older adults"** is the result of my own study under theguidance of Dr. Hema N, Assistant Professor in Speech Sciences, Department of Speech-Language Sciences, All India Institute of Speech and Hearing, Mysuru, and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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ABSTRACT

Cognitive Reserve is considered to be influenced by a variety of factors such as level of educational attainment, number of languages known, engagement in mentally and physically stimulating leisure activities. With a growing older population moving towards digital era, especially after the COVID-19 pandemic, it becomes necessary to look into the impact of digital technology use especially, smartphone devices on cognitive functioning of older adults. Previous studies have only looked into the effect of technology training using computer applications and have not tried to quantify the smartphone technology use to understand the extent of its impact on cognitive abilities in older adults. Hence, the current study aims to explore, the effect of smartphone addiction on cognitive abilities of executive function and fluid intelligence.

The study recruited 30 neuro-typical older adults as participants who passed the technological activity survey, created by the researcher which includes yes/ no questions regarding the type, duration and purpose of smartphone or any other technology device usage. This was followed by an administration of Smartphone Addiction Scale-short version on the selected participants to quantify the level of addiction and divided them into three groups: low, mid and high smartphone addiction. A series of cognitive tests in the domain of executive function and fluid intelligence were carried and results compared across the three groups. The executive function test included Trail making test, Alternate verbal fluency test and Digit Span test –Forward, Backward whereas the Raven’s coloured progressive matrices (RCPM) was used to estimate fluid intelligence.

The results revealed that individuals in high smartphone addiction group performed significantly better than those in low and mid addiction group in all the

executive function test except Digit span –forward. RCPM accuracy scores showed clear superiority in performance for those with high smartphone addiction, however the RCPM total time taken to complete the task was comparable in all the three groups.

The superior performance demonstrated by high smartphone addiction group shows, better cognitive flexibility, and larger working memory span as well as fluid cognitive abilities in older adults with intense smartphone usage. This can be attributed to novel learning and cognitive engagement employed through smartphone usage which might be aiding in strengthening the existing brain connections and improving the efficiency of cognitive resource usage. The study concludes that extensive use of smartphone promotes better and efficient cognitive functions contributing to cognitive reserve in older adults. Future research should try to quantify the smartphone addiction domains and also include accuracy and error types when assessing Trail making test to determine if accuracy is as sensitive a parameter as reaction time in evaluating cognitive function in older adults. Moreover, replication of the study in larger population and more diverse population with and without smartphone addiction using assessment tools with established psychometric values would help in early detection of cognitive impairments.

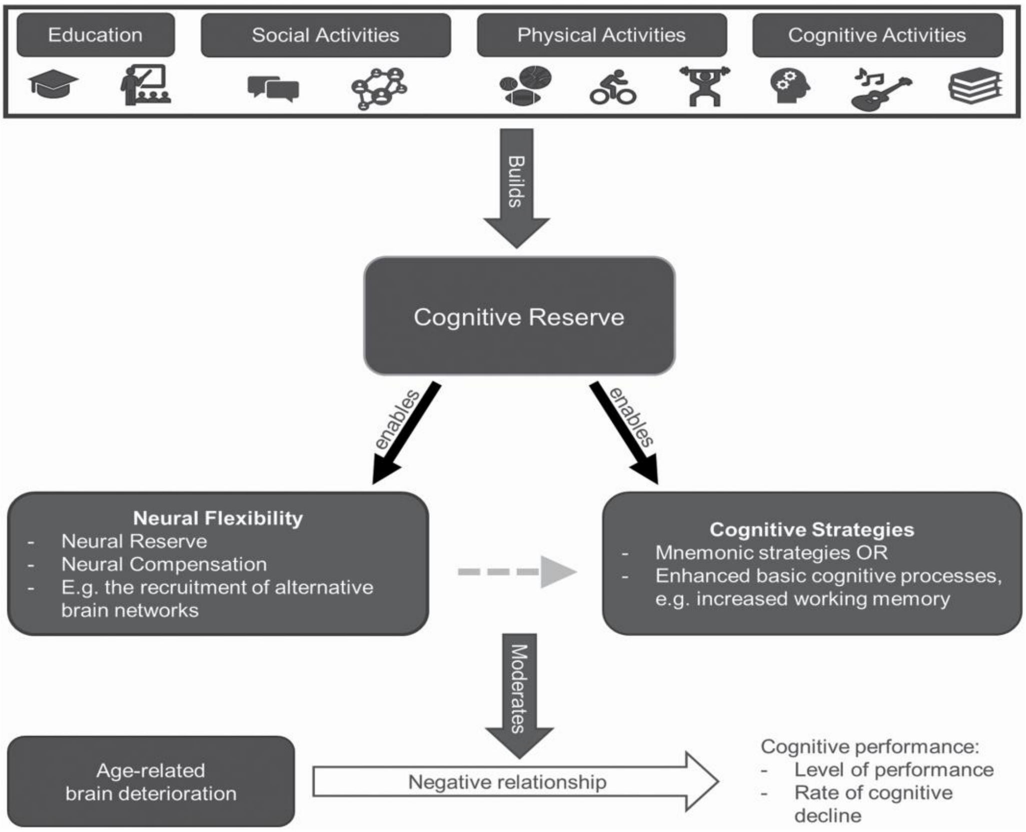
CHAPTER I

INTRODUCTION

Aging is an inevitable biological process that leads to progressive cognitive decline along with physiological changes that affects human functionality. The World population estimates as on 2020 expects an increase of 120% in number of older adults by 2050. The growing older adult population necessitates methods to improve cognitive training in them to prevent the onset of cognitive communication disorders. Increasing age brings in general reduction in executive functions and fluid abilities such as cognitive flexibility, problem solving, processing speed, working memory influenced by neuroanatomical changes (Fjell, & Walhovd, 2010). Livingston et. al., in 2020 suggested that the onset of approximately, 40% of cognitive communication disorder cases can be avoided by adopting a balanced life style involving physical, intellectual, and social activation. Such factors contribute to diverse aging trajectories which lowers the pace of aging in individuals than those who do not follow these practices.

There are several aging theories that explain the pattern of changes observed in cognitive functioning in older adults such as Compensation-related utilization of neural circuits hypothesis (Reuter-Loren, & Cappell, 2008), Posterior–anterior shift in aging (Davis et al., 2008), Hemispheric asymmetry reduction in older adults (Cabeza, 2002), Neural dedifferentiation hypothesis (Li et al., 2001) and theory of Cognitive Reserve (Stern et al., 2009). Among the available literature on theories, three of them are more relevant to the present study. The Frontal Lobe Hypothesis of Aging (West 1996), Posterior–anterior shift in aging (PASA) proposed by Davis et al., in 2008 and Theory of Cognitive Reserve (CR) by Stern et al, in 2009. The Frontal Lobe Hypothesis of Aging asserts that the cognitive functions that require frontal lobe engagement would show poor performance in older adults due to the vulnerability of frontal lobe for age related changes and those that rely on other brain areas would be relatively preserved. This would indicate a poor score of cognitive tasks involving frontal lobe, compared to those tasks that require temporal, parietal or occipital lobes. Contrary to this, the theory of Posterior–anterior shift in aging (PASA) states that, as aging progresses, older adults tend to show a shift in the cognitive areas engaged in accomplishing a task, specifically showing greater activity in the frontal areas and less activity in posterior brain regions. It also proposes that the increased frontal activation can be considered as a compensatory mechanism to maximise their task performance. Alternately, the theory of Cognitive Reserve (Fig 1.1) talks about an entirely different perspective of cognitive aging considering external factors as the pivotal determinants. Stern et.al, (2009) states that the human brain tries to compensate the age related changes by employing pre-existing cognitive factors acquired through life experiences. These can be educational, occupational and environmental (intellectual, physical or social activities) exposures attained early or later in life (Scarmeas et al., 2001). The theory explains that cognitive reserve can be divided into two parts, "neural reserve" and "neural compensation". Neural reserve pertains to the individual difference shown by older adults in cognitive processing, whereas neural compensation is the adaptive strategies adopted by the brain to compensate for the age related changes in the functional connectivity of brain , these can be increased activation in the secondary or new brain regions (McDonough et al., 2022). Both have been largely associated with the protective function of genetics, education, employment, socioeconomic status, and technology use (Oosterhuis et al., 2022). Stern et.al, (2020) suggests that the cognitive reserve aggregated over time, and improves cognitive flexibility by facilitating the use of higher order cognitive functions, thereby reinforcing the brain connections, and recruiting alternative brain networks when needed. More specifically, when two older adults with same age-related cognitive changes perform a cognitive task, the individual with higher cognitive reserve will be able to maintain the performance on the task, thereby combating the age-related reduction expected in the performance. Furthermore, Stern and colleagues, believed that, cognitive reserve can not only improve performance but also, pace down the rate of cognitive deterioration with a high level of cognitive reserve essentially reduces the pathological cognitive decline and chances of dementia onset.

Fig 1.1 Schematic Representation of Theory of Cognitive Reserve (Stern et.al., 2009)



From "Toward an Understanding of Healthy Cognitive Aging: The Importance of Lifestyle in Cognitive Reserve and the Scaffolding Theory of Aging and Cognition" by Elise J Oosterhuis, Kate Slade, Patrick J C May, Helen E Nuttall, *The Journals of Gerontology: Series B*, Volume 78, Issue 5, May 2023, Pages 777–788, https://doi.org/10.1093/geronb/gbac197, Recent research has focused on understanding the contributing factors to cognitive reserve. The common proxies of cognitive reserve listed out in literature are, years of education, participation in leisure activities that are intellectually engaging such as reading books, solving puzzles or social activities (Chan et al., 2018; Grotz et al., 2017; Scarmeas et al., 2001), physical activities such as aerobics or strength training (Reas et al., 2019; Sprague et al., 2019) and digital device use (Liang et al., 2023). Several studies have demonstrated the potential impact of these factors on cognitive functioning leading to improved executive function, fluid intelligence, memory and language processing in older adults (Thow et al., 2018;Berggren et al., 2018; Lavrencic et al., 2018; Caballero et al., 2021). Additionally, a longitudinal study conducted on healthy older adults showed that individuals who participated more frequently in these activities had 38% lesser chance on developing dementia (Scarmeas et al., 2001). There is well documented evidence on the effect of education level contributing to cognitive reserve, where increased literacy has shown to result in decreased cognitive functional decline (Chodosh, Reuben, Albert, & Seeman, 2002; ; Butler, Ashford, & Snowdon, 1996; Snowdon, Ostwald, & Kane, 1989; Christensen et al., 1997; Colsher & Wallace, 1991; Manly et al., 2003; Farmer, Kittner, Rae, Bartko, & Regier, 1995; Albert et al., 1995; Lyketsos, Chen, & Anthony, 1999) as well as studies explaining impact of physical training suggesting that the type of physical training can show different effect on cognitive abilities, such as aerobic exercises are shown to enhance cognitive flexibility, while strength training contributes to cognitive inhibition. The neurogenesis promoted during these activities is assumed to be the reason for enhanced performance in executive function and task by older adults (Beker et al., 2021; Reas et al., 2019; Sprague et al., 2019). However, one among the cognitive reserve proxies, technology use has been less looked into, with very few studies on the effect of integration of technology or digital devices into daily life activities of older adults. With more older adults moving into the digital era, it becomes necessary to understand the impact of technology or digital device usage on cognitive functions. Previous research has evidences on the effect of computer, or digital device usage resulting in betterment in overall cognitive function, processing speed and short-term memory in older adults compared to individuals who are not technologically active (Liang et al., 2023; Wu et al., 2019). However, these studies failed to quantify the level of device usage and understand its impact on the cognitive abilities of older adults. Hence, the present study is curious to understand the influence of technology on cognitive functions of neuro-typical older adults.

1.1 Technology use among neuro- typical older adults

The use of technology has become inevitable in today's world. Technology use can range from using a smartphone to a desktop computer. It can have a significant impact on the cognitive functioning of individuals from a child to an older adult. It holistically helps them to engage socially and cognitively in society (Dodge et al., 2015). Older adults are increasingly engaged in using technology to perform core functions in their day-to-day lives (Benge et al., 2020). Technological services play a major role in enhancing the quality of life in older adults (Westermeyer, 2020). Surveys conducted in older adults suggested post COVID-19 pandemic, more adults had positive attitudes towards technology use and had witnessed a sudden increase in smartphone users in older population. The period of isolation during the pandemic in fact facilitated the process of technology learning in older adults (Sixsmith et. al., 2022). Learning to use technology promotes cognitive engagement and utilizes more cognitive resources in older age leading to enhanced cognitive reserve in these individuals (Mansor et.al., 2020).

The effect of technology use on the cognitive processes of older adults is discussed under two hypotheses: 1) the *digital distraction hypothesis*, which states that increased technology use leads to reduced cognitive functioning marked by executive dysfunction in terms of increased distractibility, difficulty with task organization or completion, memory deficits marked by forgetfulness in recalling the phone numbers, names of people and to-do list (Small et al., 2020). Based on the studies of Charness and his colleagues (2022), more technology use among older adults' reports increased subjective cognitive concerns. 2) the *technological reserve hypothesis* (Wolff, Benge, Cassel, Monin & Reuben, 2021;Benge & Scullin, 2020) which states that technology use, in turn, enhances cognitive functioning in adults leading to better cognitive reserve and thereby reduces the risk of pathological aging or dementia. Benge and Scullin (2020) referred to *Technological Reserve* as "to the development of a culture and environment of technology use in older adults that can buffer against the impact of cognitive decline on day-to-day activities". In other terms "a technologically rich environment and culture may lessen the impact of neuropathological changes on day-to-day activities for those afflicted with neurodegenerative conditions, even without directly altering the disease itself."

Technology use is categorized into four domains of use in older adults: technology for social communication, for leisure activity, food acquisition, and health care purposes. (Drazich et al., 2023). Technology use for social communication involved engagement in social media, emails and text messages while its use for leisure activity involved attending religious services, participating in volunteering or group activities. Technology used for food acquisition related to buying groceries and reflected independent functioning and finally, its use in availing health care services provides quick and easy access to diagnostic and treatment benefits. Liang et.al., in

2023 showed that multipurpose use of technology or digital device was associated with better cognitive reserve and higher cognitive functioning when compared to those who use technology for only social communication.

Among the technological devices used by older adults, SMARTPHONE USAGE is the greatest with more than 50% of older adults preferring smartphones over computers or tablets as sources of internet usage. This can be attributed to the convenience in handling and portability of the device (Gitlow, 2014) as well as its ease of use in activities related to finance, banking, healthcare, education, and entertainment purposes (Subramanyam, 2018). The YouGov survey reports that 67% of India’s urban population depends on their smartphone to use the internet with the majority of users in the age range of 60-65. It has also been reported that 11% of India’s internet users are in the age range of 55+ years with an estimated increase in this contribution to 25-30% in the coming years.

Similarly, smartphone usage has substantially increased in older adults with 59% of people in the age range of 65–69-year-old owning a smartphone and 49% among 70–75-year-old individuals (Anderson & Perin, 2020). This can have a remarkable influence on their physical, mental, and cognitive health. Conversely, the rate of social interaction among older adults has substantially increased which helped them to communicate with others with whom they may be able to communicate otherwise leading to reduced social isolation and depression rates (Gitlow, 2014). However, Navabi (2016) suggested that older people tend to have a negative outlook towards smartphone usage due to anxiety and fear of working with new devices. It was also reported that 67.37% of the older adults required help while using the smartphone against 32% who did not require the assistance. 20.65% needed assistance to save a contact number on their phone, 18.78% to download an application, 18.8% to browse the internet, 15.9% to edit their number, and 15.49% to check their SMS. Other studies talk about the barriers faced by older adults in using smartphones. There have been some assumptions among older adults that smartphones are complex and it would be difficult to recall the technical directions of their use. Some older adults also consider smaller font sizes and displays as factors that dissuade them from using the smartphone. Despite these barriers, older adults are moving toward a more digitally connected life (Bhate et.al, 2023). Older adults are increasingly relying on smartphones to socially engage with other members of the community to avoid possible social isolation and alienation. A study done on the internet life of older adults in 2020 has revealed that more than 1,00,000 older adults spend their time using their smartphones for more than 10 hours a day. Hence looking into the effect of smartphone addiction among older adults becomes important in the present study.

The pervasive usage of the smartphone is analyzed using a Smartphone Addiction Scale (SAS). Questions on daily life difficulties, pleasant anticipation, and withdrawal, relationships focused on online communities, excessive usage, and endurance were included in the design to determine which group was considered high-risk. It consisted of 33 questions with a 6-point scale to rate the problems observed (Kwon et al., 2013). However, the scale could not give the desired results in adults and university students due to the participants in the study and their age. Hence a short version of the scale was developed by Kwon et al., in 2013, which consisted of 10 items selected from SAS on a six-point Likert scale with responses recorded as 6= strongly agree, 5= agree, 4=weakly agree, 3= weakly disagree, 2= disagree and 1= strongly disagree. It has also demonstrated diagnostic ability by providing a validated cut-off for problematic smartphone usage. Additionally, Hamamura et al, (2023) showed that the Smartphone Addiction Scale – Short Version (SAS-SV) was able to establish a direct relationship between pervasive smartphone usage and psychopathological traits such as impulsiveness and neuroticism and disorders such as ADHD, Internet gaming disorder, Depression, Anxiety, and obsessive-compulsive disorder.

1.2 Cognitive functions and technology usage in neuro-typical older adults:

Executive Functions are a set of complex cognitive functions employed by humans to carry out daily life activities. Miyake et.al., in 2000 suggests that Executive Function encompasses three main components, cognitive flexibility which estimates task switching ability, interference and inhibition control and finally, working memory. Whereas Fluid Intelligence is considered to be the ability to carry out problem solving and abstract reasoning especially, when the task is novel (Kievit et.al, 2018). Digital device use employs these higher order cognitive abilities to carry out smooth operations which involves switching between apps to use, learning to use new applications and understanding the general methods of using devices. Jin et.al, in 2019 suggested that the use of technology or smart devices in geriatric population has shown delay in cognitive decline, enhanced social communication and better independent functioning thus promoting cognitive reserve in them.

A longitudinal study in 2003 concluded that cognitive engagement works as a protective mechanism for age related cognitive deterioration**.** The study involved 700 older adults who had undergone clinical evaluations over 5 years suggesting that those individuals with longer engagement in cognitively stimulating activities had lesser age-related cognitive decline and had lower chance of developing Alzheimer's disease (Wilson et al., 2003).

Mentally stimulating activities over period of time encourage the development of "neural scaffolds" which is a supportive neural circuitry that offers supplementary neural resource that helps compensate for brain atrophy and degradation due to aging (Park & Reuter-Lorenz, 2009). There is evidence showing such compensatory neural activity in older adults in comparison to younger counterparts (Gutchess et al., 2005). Slegers, Van Boxtel, and Jolles (2009) state that the domains of executive function demonstrate cognitive flexibility and the ability to switch between tasks as well the processing speed as the indicators of better cognitive functioning because of technology use. It has been demonstrated that executive function and memory are reliable indicators of technological skill and use (Czaja et al., 2013).

The best example, the Cognitive Enrichment Theory (CET) (Hertzog et al., 2008) suggests that older adults are capable of improving their cognitive reserve by engaging in useful intellectual, physical, and social activities. In that view, learning to use the technology and using them on a regular basis can be considered intellectually challenging in old age. It significantly impacts their everyday cognitive functioning ranging from long-term memory with respect to remembering the usage of the icons and navigating through the applications to attention, executive functioning, and eye-hand coordination (Choi et al., 2021). Additionally, The Senior Technology Acceptance Model (STAM), proposed by Chen and Chan (2014), posits that individual traits including age, cognitive status, gender, health ,socioeconomic status, and self-efficacy and as well as environmental factors like accessibility, assistance, and guidance, predict older adults' use of technology more so than attitudinal factors like usefulness and ease of use. The author also found that age and self-efficacy were the most important determiners of technology use among older adults. The present study proposes to investigate these personal characteristics in relation to technology usage and cognitive performance in neurotypical older adults.

Literature also suggests that general smartphone usage can cause distractibility resulting in difficulty carrying out multi-tasking. This holds true for tasks with greater cognitive demand and attention for a certain period of time. The notifications from different applications in the smartphone can have a negative impact on attention (*digital distraction hypothesis*) (Small et al., 2020). However, Benge and his colleagues (2023) showed that people who had better technology use had reduced overall subjective cognitive concerns (SCC), as well as lower memory and executive function concerns (*technological reserve hypothesis*). Prior studies have shown improvement in working memory, processing speed and episodic memory in adults trained to use technology (Myhre et al.,2017; Chan et al., 2016, Czaja et al.,2013;). Additionally, epidemiological studies on older population suggested that, individuals with a decreased chance of acquiring Alzheimer's disease or cognitive communication disorders have shown higher levels of education, fluid intelligence abilities such as problem solving, reasoning skills, vocational level, and leisure activity engagement (Salas, Escobar, & Huepe, 2021).

In the present study, the cognitive performance is assessed at the executive function level and fluid intelligence. The technology use is estimated through the administration of a simple questionnaire related to the type, and purpose of technology usage on a survey basis and the administration of a smartphone addiction scale for neurotypical older adults.

Need for the present study

The cognitive processes such as executive function, attention, and memory which play major roles in everyday activities will start to show decrement in their functioning with aging (Salthouse, Atkinson & Berish, 2003). The capacity to acquire, store, and deliberately recall information regarding previously learned events that take place in a daily life of an individual is the episodic memory, or encoding new information. Age-related cognitive decline impacts fluid intelligence, leading to difficulty in reasoning and problem-solving abilities (Berkowsky & Czaja, 2018; Czaja et al., 2006; Czaja & Lee, 2006).

The Executive Functions (EF) is a broad category of skills associated with behavior that is goal-driven, including organizing, keeping track of information, and making choices. While these EF skills are essential for using information and communication technology (ICT) effectively in general, the specific types of activities that involve using ICT devices (smartphones) are likely to vary activate each cognitive domain. For instance, while looking for information is directly related to executive function, memory function is needed while learning a new task (like using social networking sites). It is unclear, therefore, if there are differences between each domain and digital device use. Alternately, age related decline in Fluid intelligence are well documented (Ghisletta et al., 2012; Salthouse, 2010). Surprisingly, Sharit et.al., in 2019 showed that engagement in cognitively stimulating leisure activities tend to increase fluid intelligence abilities in older adults. In 2014, there was a surge in study on smart technology for older persons; yet, studies that look into the effect of smart technologies on geriatric cognitive health are still few (Kim & Lee, 2017).This represents a missed opportunity, as a vast number of older individuals are increasing showing positive attitude in using smart technology devices (Pew Research Center, 2014; Menéndez Álvarez Dardet et al., 2020).

Prior studies have investigated the effect of training use of technology on the cognition of older adults where older adults were trained for a short period of time and pre- and post-assessments were carried out. Results showed better cognitive performance during the post-assessment period. Therefore, there is an association between cognitive function and technology use, but, the impact of smartphone addiction on older persons' cognitive functioning could not be conclusively linked by these investigations. However, there is scant literature that looks into the specific effect of smartphone usage on the executive functioning abilities and fluid intelligence of neurotypical older adults who are increasingly moving towards a digitally connected lifestyle. Hence it becomes critically important to investigate the effect of smartphone addiction on executive functioning and fluid intelligence in neuro-typical older adults.

Using a nationally representative sample of neurotypical older adults, the current study intended to evaluate the relationship between technology use (smartphone use) and cognitive function. This research would offer new perspectives on the relationship between the two and recommendations for strategies to support cognitive health as people age. The goal of this study was to better understand how neuro-typical older adults use technology and to understand the direction of relationship between technology use and various cognitive functions.

Aim of the present study

To evaluate and study the relationship and the extent of association between technology use (smartphone addiction) at executive function (cognitive shifting and working memory) and fluid intelligence in neurotypical older adults.

Objectives

1. To determine the level of smartphone usage using the smartphone addiction scale (SAS) in neurotypical older adults.
2. To measure and compare the performance on cognitive assessments at Executive Functions (shifting and working memory tasks measuring reaction time and accuracy score respectively) and Fluid Intelligence (visuospatial processing tasks measuring accuracy score and reaction time) in neurotypical older adults with high scores, moderate scores and low scores of smartphone addiction scale.
3. To investigate the correlation between Executive Functions (shifting and working memory skill) and the scores of smartphone addiction scales in neurotypical older adults.
4. To investigate the correlation between Fluid Intelligence (visuospatial processing ability) and the scores of smartphone addiction scales in neurotypical older adults.

Hypothesis

1) The administration of the smartphone addiction scale does not categorize neurotypical older adults into low, moderate, and high addiction levels.
2) There is no significant difference in the performance on cognitive assessments of Executive Functions and Fluid Intelligence in neurotypical older adults with high scores, moderate scores, and low scores on the smartphone addiction scale.
3) Smartphone usage does not have a significant effect on executive function - cognitive shifting in neurotypical older adults.
4) Smartphone usage does not have a significant effect on executive function- working memory in neurotypical older adults.
5) Smartphone usage does not have a significant effect on fluid intelligence in neurotypical older adults.

CHAPTER II

REVIEW OF LITERATURE

Learning new technology has been demanding for older adults. However, elderly individuals are trying to adapt to the smart technology based world due to their need for optimal functioning in society. Alternatively, based on the Ecological Model of Aging by Lawton (1989) and Tun and Lachman, (2010) studies, cognitive function has proven to be a major predictive factor of technology usage in typical older adults concluding that reduced participation in technology use was related to poor cognitive abilities.

2.1 Technology training and effect on cognition in older adults

Chan and his colleagues (2016) trained 54 older adults to use iPads for various internet activities for 3 months and assessed the participants on four cognitive constructs namely 'processing speed' using digit comparison, 'mental control' using Cogstate Identification, Flanker Centre letter task, Flanker Centre symbol task, Flanker Centre Arrow task and 'visuospatial processing' using Raven's Progressive Matrices and found that the 'processing speed' and 'episodic memory' had significant improvement in them compared to the socially active control group. The authors pointed out a need to understand the association between the level of cognitive engagement and the enhancement of cognitive functions.

For eight weeks, Myhre and colleagues (2017) taught 41 elderly adults how to use Facebook or an online diary website. They also used the Rey Complex Figure Test to measure verbal memory. Digit Symbol Substitution Test was utilized to assess the processing speed and the Deary-Liewald reaction time test was used to measure reaction time. A Controlled Oral Word Association test was employed by the authors to assess verbal fluency in addition to the category fluency test. The Trail-making test was used to assess visual scanning, speed of processing, and executive function. To examine various executive function domains, the authors had included six further assessments. Two tests were included for each of the three executive functions—inhibition, shifting and updating,—using the Stroop and Simon tasks, Global-Local and Letter Number task, Letter Memory and Keep Track test, respectively. While there were notable variations in other measures, the results indicated enhanced executive function in relation to complicated working memory tasks.

Zhang and his colleagues (2017) conducted a study on 97 older adults in the age range of 60-95 and administered a Computer proficiency questionnaire to divide them based on the level of proficiency in using computers. These participants were further administered a set of cognitive tests such as Number Comparison test, where the participants had to decide if two numbers displayed on the computer are the same or not very quickly. The maximum of correct responses in 90s were considered as the response. This task measured the perceptual speed component of cognition. Psychomotor speed was quantified using simple and choice reaction time tests which required the participants to press a button on the keyboard when stimuli is seen. The study utilized Letter Series Test were participants had to complete the next letter in the series, to assess inductive reasoning. Alternately, episodic memory was measured using Paired-associates paradigm test which included recalling the presented list of word pairs. Spatial ability was determined by paper folding test. Furthermore, Task switching test was employed in assessing Executive function. This was a two part letter number pair test in the first part, participants were expected to decide whether the given letter is consonant or vowel while ignoring the number and vice versa. Part two was presented with a switching test between two tasks, with instructions given on the screen. The results demonstrated improved inductive reasoning, psychomotor speed, and perceptual speed with little or no improvement in executive function and spatial ability in participants who had higher proficiency than others. The authors concluded that, the mental stimulation involved in the computer usage might have contributed to the better cognitive functions observed.

Similarly, Quinn (2018) conducted a study on 34 older individuals dividing them into an experimental of 17 participants and 17 in control group to understand the impact of social media training and cognitive function. Participants were assessed on 4 domains of executive function, which were inhibitory control, working memory, attention, and processing speed, using, California Stroop test, Wechsler Digit span, Trail making test – Part A along with symbol digit modalities test, at 3 different time intervals: at baseline, at 4 weeks, and after 4 months respectively. The findings suggested an increased processing ability and inhibitory control and a slight improvement in attention and working memory in the experimental group in comparison to their matching control group. This led the authors to recommend future studies to include additional factors such as socioeconomic status, level of digital literacy and education levels to study its impact on cognition.

Subsequently in 2019, Sharit et al., conducted a study on 131 neuro-typical older adults who were living alone with minimal to no computer or internet usage. All the participants were given a computer with a software application tailored for older users named, PRISM (Personal Reminder Information and Social Management system). They were given 3 day personal training to use the computer application. The level of usage was measured using an inbuilt code in the software that quantifies the range of use from 0 to 8. This divided the participants into two groups of, less frequent users and more frequent users. The level of PRISM usage, computer proficiency attained and its effect on cognitive functioning was measured at three time periods starting at baseline, followed by one at 6 months and then at 12 months. The cognitive functions were determined through a battery of tests comprising Trail Making test A, B, Digit symbol, and letter sets. The hypothesis involved assessing whether computer training will contribute to better fluid intelligence in older adults. The data obtained for the cognitive test at baseline showed similar responses for both the groups. Surprisingly, at the end of 12 months, older adults who were more frequent users of computer demonstrated better performance in cognitive tests carried out, showing reduced reaction times and better accuracy than those with lower frequency of computer usage. Thus, the authors concluded that, individuals with lower usage had reduced fluid intelligence. Conversely, older individuals who had more cognitive stimulation because of new learning and problem solving strategies employed had better fluid cognitive abilities.

In similar lines, Choi et al. (2021) examined the impact of technology use on cognitive abilities in 3904 older individuals, with an age of 65 or above, who resided in a community. The first phase involved, administration of questionnaires regarding the use of technology in everyday life and digital health that included a series of yes/no questions to determine the type and purpose of the technology used by the participants following which the clock drawing test was used to assess executive function and the immediate and delayed recall tests with 10 items to assess episodic memory. The results indicated that episodic memory was related to learning to use technology and executive function was important for the qualitative domain of technology use showing how well the individuals are able to use technology on a daily basis. The assumption made were that, the executive tasks used in the study may not have reflected real life challenges enquired when using technology. Hence the authors suggested to carry out studies that assess different domains of executive function such as cognitive flexibility, psychomotor speed and response inhibition in technology use to determine domain specific association.

A longitudinal study done by Scarmeas et.al., in 2001, pointed out that individuals who participated in leisure activities that were intellectual such as taking classes, reading books or playing mentally stimulating games or socially active with frequent visits to friends or family had shown a 38% less chance of developing dementia. They recruited a 1,770 typical older adults in the age range of 65 or above and followed them up for 7 years. The outcome measurement was done at four timelines: baseline and three evaluations during the 7 year period. Domains of different neuropsychological battery was used to asses short, long term verbal and non-verbal memory, verbal and non-verbal abstract reasoning, orientation, language assessment included tests of naming, comprehension, repletion and verbal fluency. Copying and matching tasks were used to estimate construction ability. Finally, these individuals were administered Blessed Dementia Rating Scale and England Activities of Daily Living Scale to diagnose dementia in the population. Additionally, a modified version of Clinical Dementia Rating scale was those identified with dementia on other scale. The level of leisure activity participation was quantified using an interview and scores were considered as low if they were engaged in less than or equal to 6 leisure activity to do and high, if they were involved in more than 6. The results showed better cognitive function in older adults who had high leisure activities that had intellectual activation demonstrating slower rate of cognitive decline and were less prone to acquire dementia. These findings urge us to conduct research on the impact of modern device usage and its effect on cognition on older adults.

A yet more older study done in 1999 sampled 250 middle aged and older adults and followed them up for three times in 6 years hypothesizing that cognitive engagement in the daily activities can reduce the pace of cognitive decline in older adults. The cognitive variables involved were, fact recall using two sets of 40 questions of world knowledge, word recall assessed through immediate recall of two lists with 30 words in different semantic categories, story recall with participant expected to narrate the summary of the two stories given to them. Vocabulary was measured through performance on a multiple choice word recognition test with 54 items while verbal fluency was assessed through their ability to produce synonyms, antonyms and figures of speech within 5 minutes of time. Reading comprehension assessment made the participants to read short passages and answer the questions asked. Working memory was analyzed using three different components, sentence construction tasks by recalling key words from the presented sentences, comprehension speed was calculated from the reading speed on six passages and finally, semantic speed was measured through lexical decision task and semantic decision tasks. The level of engagement in daily activities were estimated through a self- reported rating scale. The results revealed a correlation between participants who were involved in intellectually stimulating activities and better performance on cognitive tests carried out.

2.2 Smartphone or touch screen usage and cognition in older adults

Among the available literature, very few studies have tried to determine the impact of touchscreen devices or smartphones, on cognitive functioning in older adults. One such study conducted in an Indian context looked into the impact of smartphone addiction on the reaction time measure of typical older adults. The study involved administration of a Mobile Phone Addiction Scale (MPAS) that categorized them based on the level of smartphone addiction scores. The participants were expected to perform the Ruler Drop Method test to assess the reaction time. The results revealed that the group with higher scores on the MPAS performed better in ruler drop tests, indicating lesser reaction time. Additionally, it was found that these individuals had stronger activation of the somatosensory cortex with increased fingertip representation in the homunculus as a result of intense smartphone usage (Grewal & Sahni, 2019).

Another study in 2019 investigated the cognitive function of typical older adults who had exposure to a computer and smart screen device. The study recruited a total of 323 older adults for the research. They were categorized into four categories based on the frequency of the usage of the devices through an interview. The four categories were those who did not have daily use of digital devices, those who had exposure to touch screen devices, those who used computers daily, and those who used both touch screens and computers daily. Cognitive assessment included a Mini Mental State Examination to assess overall cognitive function, followed by a forward and backward digit span test to measure the impact on working memory. Trial Making test A and B were the estimations used for processing speed and executive function abilities. Other tests include semantic category fluency, letter word list generation tests, K-T cancellation tests, and Free and Cued Selective Reminding Test (FCSRT- French version) to measure episodic memory. The results pointed out that, a notable percentage of individuals in the non-daily use of digital devices had acquired Alzheimer's dementia in long-term follow-up. In addition, there was a larger gap in performance between those who did not use digital devices daily and those who used both computers and touch screens in cognitive variables of executive function, processing speed, and short term-memory. They showed significant differences in overall cognitive function as well. Thus, the authors concluded that the use of digital technology promotes mental stimulation by acquiring new and problem-solving skills in older adults which can have a remarkable impact on their memory, executive functions, and reasoning skills.

Alternately, Gindrat et.al., in 2015 tried to study the cortical sensory processing in 37 older adults who used smartphone technology and those who used old keypad-based phones. Electroencephalographic measurements carried out in both groups revealed a larger cortical potential in those who used smartphones which demanded the use of three fingers: thumb, index, and middle finger, compared to those who were using old technology phones. Surprisingly, it was noted that individuals with higher levels of smartphone usage had larger cortical potential. The results suggested that constant and repetitive movement on the smartphone could have reorganized cortical sensory processing showing potential effects of brain plasticity in older adults.

More recently, in 2023, a group of researchers from Malaysia (Liang et.al., 2023) conducted a study to determine the neuroprotective role of digital devices such as smartphones in reducing the risk of cognitive impairment. More specifically, the study aimed to establish a relationship between digital device use, cognitive reserve and cognitive health in older adults. A total of 210 participants were recruited for the study and a series of tests were administered to them. This included Malay Mini-Mental State Examination (M-MMSE), Geriatric Depression Scale – Malay version (M-GDS-14), Malay Cognitive Reserve Scale (M-CRS), and Addenbrooke's Cognitive Examination-III (ACE-III). Digital device usage was noted using a set of questions on number of hours used and the purpose of usage. The results indicated that, individuals who use digital device for multiple purposes had showed better cognitive reserve that those who had used the digital device only for communication. Additionally, statistical analysis revealed a significant difference at the cognition levels of two groups with higher cognitive functioning for those who used digital device multi-purposely compared to those who used it only for communication. The authors recommend future studies that establish relationship level of digital device addiction and its impact on brain health because of the rapid growth of digital device use in older adults.

CHAPTER III

METHOD

The present study aimed to assess the effect of Smartphone Addiction on Executive Function and Fluid Intelligence in neuro-typical older adults.

3.1 Research design

The present study followed a community-based survey and a cross-sectional comparative study design.

3.2 Participants

Thirty neurotypical older adults in the age range of 60-70 years who had smartphone usage were selected. The participants consisted of 17 males and 13 females.

3.3 Participant Selection

3.3.1 Ethical Considerations

When choosing study participants, ethical considerations were considered. All the participants were clearly explained the study's goals and methods. An informed consent was signed by the participants (APPENDIX- A). The data collection followed the All India Institute of Speech and Hearing, Mysore, ethical committee guidelines for Bio-behavioral Sciences for human subjects (2009).

3.3.2 Source of Participants

The participants were sourced from work/residential places in Mysore and Kerala. Participants were selected only if they fulfilled the selection criteria of the study. Neurotypical older adults who satisfied the 80% criteria in the Technological activity survey questionnaire and the inclusionary criteria were recruited for the study.

3.3.3 Inclusionary criteria for the participants

1. All participants were in the age range of 60-70 years and were neurotypical older adults with no history or complaints of speech, language, hearing or other communication disorders.
2. All participants had at least ten years of formal education in English as the medium of instruction.
3. All the selected participants knew English and information regarding their native language was noted.
4. All the individuals belonged to a middle socio-economic background, which was established through the administration of the Modified Kuppuswamy Socio-economic status scale (Dalvi et al., 2023).
5. The participants had a basic knowledge and experience in technology usage.
6. The participants had facilitatory conditions supporting the use of technology (a specific person or group of people is available for assistance with technological difficulties and financial status to afford a technological device).

3.3.4 Exclusionary criteria of the study

1. Participants with other neurological illnesses and psychiatric disorders were not considered for the study.
2. Participants with visual field or other sensory-perceptual deficits were excluded from the study.
3. Individuals who were into substance abuse were not considered for the study.
4. Neuro-typical older adults with any history of metabolic disorders or under any medication were noted down and were sub grouped.

5. Cognitive deficits were ruled out using the Montreal Cognitive Assessment (Nasreddine et al., 2005). Individuals with scores below the cutoff (<26) were excluded from the study.

Table 3.1

Demographic details of the participants.

Participant number	Age/Gender	Education	Participant number	Age/Gender	Education
P1	65/M	PG	P16	64/M	PG
P2	65/M	PhD	P17	64/F	PG
P3	70/M	UG	P18	70/M	UG
P4	70/M	PUC	P19	62/F	UG
P5	68/F	PG	P 20	67/M	UG
P6	70/M	UG	P 21	60/F	PG
P7	62/F	UG	P 22	70/M	PUC
P8	69/M	UG	P 23	64/M	UG
P9	61/F	UG	P 24	66/F	PG
P10	60/F	UG	P25	70/M	PG
P11	63/M	PUC	P26	61/M	PUC
P12	66/F	UG	P27	67/F	UG
P13	66/M	PG	P28	70/F	UG
P14	60/F	UG	P29	70/M	UG
P15	60/F	PG	P30	66/M	UG

*Note**: ABBREVIATIONS: UG-** undergraduate*, ***PG-** Post graduate* ***Dip-** Diploma,* ***PUC-** Pre-university course*

3.4 Procedure

3.4.1 Materials used in the study

1. **Technological Activity Survey questionnaire (**Chen & Chan,2014; Choi, Wisniewski & Zelinski, 2021)
2. **Smartphone Addiction Scale -short version** (Hamamura et al, 2023)
3. **Montreal Cognitive Assessment** (Nasreddine et al., 2005)
4. **The Trail Making Test (TMT)** (Reitan, 1958)
5. **The Alternate Verbal Fluency** (Demand, 2013)
6. **Digit Span Test** (Weschler, 2009)
7. **Raven's Coloured Progressive Matrices (RCPM)** (Raven, 1998)

3.4.2 Mode of Assessment and Seating

The participants were comfortably made to sit in a quiet, well-lit room. The instructions were explained again to avoid confusion. It was made sure that the room had minimal distraction as possible.

The present study was carried out in three phases as explained in the following section: **Phase I,** administration of Technological Activity Survey Questionnaire and **Phase II**, administration of Smartphone Addiction Scale- Short Version and **Phase III,** Cognitive Assessment.

1. **Phase I-** A total of 60 neurotypical older adults in the age range of 60-70 years were considered for this Phase I. In Phase I, the participants were requested to answer the General Questionnaire on Technology Usage along with their demographic details. After an extensive review of the literature, the researcher prepared the questionnaire. A simplified version of the questionnaire is provided below in Table

3.2 as part of the pilot study. Content validation of the developed questionnaire was done by 3 Speech Language Pathologists (Goswami et al., 2012).

Table 3.2

Technological Activity Survey Questionnaire

1. Technology use and Ownership a) Do you own a cellphone and do you use it in regularly? b) If yes. Is it a Smartphone? c) Do you use your smartphone as a primary source to access the internet? d) Do you own a Tablet or iPad and use it? e) Do you own and use a desktop or laptop?
2. Do you use technology for more than 3 hours a day?
3. Do you use technology for less than 3 hours a day?
4. Do you use your technological device to SMS/ e-mail primarily?
5. Do you use your technological device to make calls primarily?
6. Do you use your technological device to browse social media primarily?
7. Do you use your technological device to do finance, health care related facilities primarily.
8. Do you use your technological device to consume knowledge primarily?
9. Do you use technology not to feel social isolation and alienation?
10. Do you use technology for better communication with your family members or acquaintances?

The questions were a binary choice of yes/no response on technology usage concerning specific technological activities. The technological activity questions were related to general device usage, the type of the device used, and the purpose of usage in their social interaction, mental and physical well-being, health care, general financial assistance, entertainment, etc. The participants obtaining ‘yes’ responses for 80% of the questions in the questionnaire were further subjected to Phase II of the present study.

2. Phase II- Thirty participants who passed the criteria (‘Yes’ response for 80% of the questions in the questionnaire) for experience in technology use based on the technological activity survey questionnaire were considered for this phase of data collection. These thirty participants were subjected to the administration of a short version of the ‘Smartphone Addiction Scale’ (SAS). Based on the scores obtained for the SAS scale, the participants were then divided into 3 groups of ‘high addiction’, ‘moderate addiction’, and ‘low addiction’ to smartphones. These individuals were subjected to cognitive assessments of executive functions and fluid intelligence.

The **short version of the Smartphone Addiction Scale (SAS-SV):** The brief version of the Smartphone Addiction Scale, created by Kwon, Jin, Cho, and Yang (2013) as shown in Table 3.3, was used to determine whether a person is addicted to a smartphone. The 10-item SAS-SV is built around a 6-point Likert scale. When a person's score reaches or surpasses the cut-off point of 31, it is considered to be a sign of smartphone addiction for men, while it reaches or surpasses the cut-off point of 33 for women.

Interpretation: Score of: 31-40 = Low Addiction.

41-50= Moderate Addiction

51-60 = High Addiction

Table 3.3

Smartphone Addiction Scale- Short Version (SAS-SV)

Missing planned work due to smartphone use.
Having a hard time concentrating in class, while doing assignments, or while working due to smartphone use.
Feeling pain in the wrists or at the back of the neck while using a smartphone.
Won't be able to stand not having a smartphone.
Feeling impatient and fretful when I am not holding my smartphone.
Having my smartphone in my mind even when I am not using it.
I will never give up using my smartphone even when my daily life is already greatly affected by it.
Constantly checking my smartphone so as not to miss conversations between other people on Twitter or Facebook.
Using my smartphone longer than I had intended.
. The people around me tell me that I use my smartphone too much.

3**. Phase III-** The thirty participants categorized into low, moderate, and high smartphone addiction groups (Group 1, Group 2, and Group 3 respectively) were further subjected to cognitive assessment under the domain of executive functions and fluid intelligence. The domains of the executive functions considered for the present study were cognitive set-shifting, working memory span, and fluid intelligence as shown in Table 3.3.

The tasks for each domain of executive functions and fluid intelligence, along with the instructions and scoring are explained in the following section.

Table 3.4

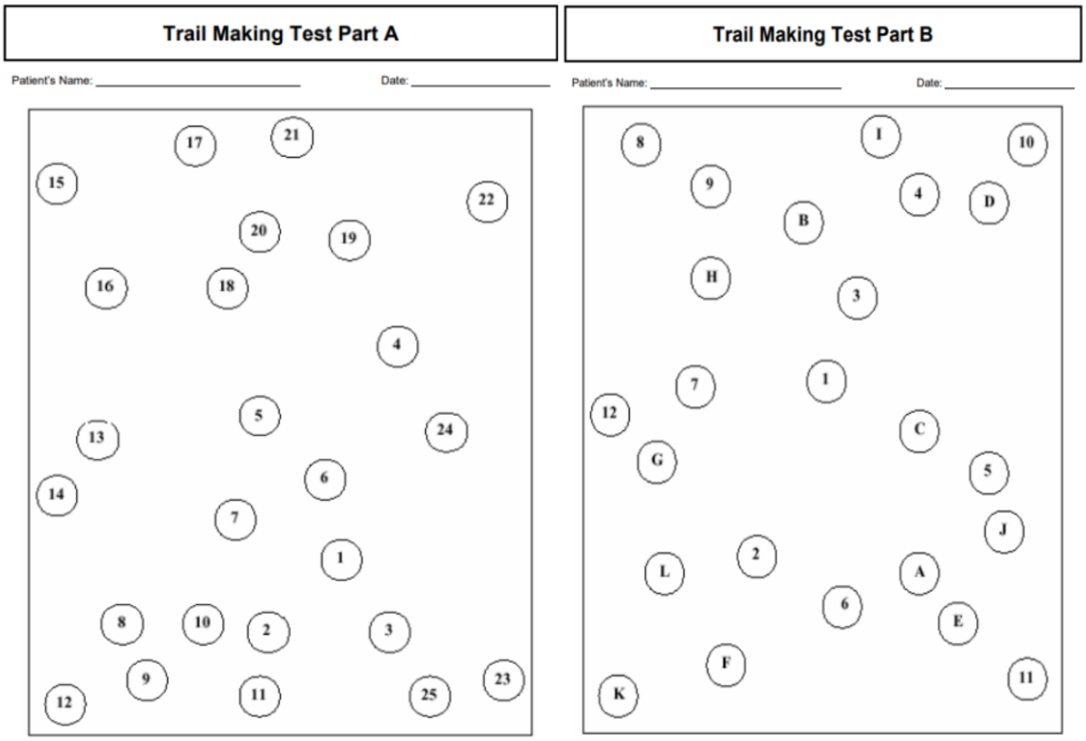
Tasks of Executive functions and Fluid Intelligence Test

Sl no.	Tasks of executive functions	Task to assess
1.	**Set-Shifting- Non-verbal Verbal**	Trail Making Test Alternate Verbal Fluency
2.	**Auditory Working Memory Span**	Digit Span Test-Forward and Backwards
3.	**Fluid intelligence test**	Raven's Coloured Progressive Matrices (RCPM)

1. The Trail Making Test:

Task Description: The Trail Making Test (Reitan, 1958) was used to measure shifting. It is a two-part paper-pencil work that consists of Part A and Part B, as seen in Figure 3.1. In Part A, participants were given a sheet of paper with 25 circled numbers (connecting 1, 2, 3,...) on it. Present study refer to the overall amount of time needed for Part A as TMT-A (Trail Making Time-A). In Part B of the test, participants had to link the circles in an alternate manner using a mix of circled letters and numbers (e.g., 1 to A to 2, B to 3 to C, and so on). Trail Making Time- B, or TMT-B, is the entire time needed for Part B.

Figure 3.1: *The stimulus for Trail Making Test Part A (left) and Part B (right)*



Instruction: The participants had to connect letters and numbers starting with 1-A, going up to A-2, and so forth, in alternating sequences and ascending order.

Scoring: The milliseconds needed to finish each task component was recorded. The duration computed starting from the start of the task and ending at the finish was noted. The Trail Making Test was given to the participants in Part A and Part B. There was just one attempt allowed for the participants to finish the job. Using a stopwatch, the total time it took the participants to finish Part A and Part B of the TMT was noted from the start (1) to the stop point (25 or L). The general analysis indicated that the time period is expressed in milliseconds (ms).

2. Alternate Verbal Fluency Task

Task description: Diamond (2013) suggests modifications to verbal fluency tests might make them more specialized for the test of cognitive flexibility, such as a switching condition between various information items (For example, fruit and animals). These types of measurement require constant altering between two or more separate pieces of information, which necessitates a stronger use of the cognitive flexibility function. Concerning Diamond (2013), the participants were instructed to mix the two categories; they were asked to say any fruit name followed by any animal name within 60 seconds.

Instruction: The participants were instructed to say any fruit name followed by any animal name within 60 seconds.

Scoring: Participants' responses were calculated by scoring the overall correct word-pairs generated within 60 seconds. Each pair consisted of a fruit followed by an animal, but the use of an animal followed by a fruit was also scored as correct. The higher the score, performance was better. For each category name, a score of 1 was given, and for a wrong category name, a score of 0 was given.

3. Auditory Working Memory Span (forward and backward digit span)

Task Description: A person's memory span is the largest list of items they can correctly recite in an order immediately following a presentation on 50% of trials. A person's working memory span was estimated with the Forward and Backward Digit Span tests. Participants in this verbal task would hear the stimulus provided to them. They were expected to repeat back the stimulus in the same sequence for the forward digit span task and in the opposite order for the backward digit span test. It is the greatest number of digits that a person can quickly repeat when the stimulus is presented. Repetition of the stimulus was prohibited, and the inter stimulus interval was set to two seconds. The backward digit span concentrated on working memory skills, whereas the forward digit span is primarily concerned with attention skills. Table 3.5 lists the stimuli taken into consideration for this investigation. The memory of digit sequences in both forward and backward order was assessed using Wechsler's Memory Scale—4 (Wechsler, 2009). Two two-digit span stimuli were used at the beginning of the test, and as it progresses, the number of digits were gradually increased. The Digit Span series was increased in steps from 2 to 8, each span consisted of 2 trials, except the 2 Digit Span, which had 4 trials. Testing ended when participants were unable to accurately recall two trials in a row at any given span size or when the maximum list length of eight digits had been reached

Table 3.5

The stimuli for Forward and Backward Digit Span (Wechsler's Memory Scale—4 (Wechsler, 2009)

STIMULUS OF FORWARD AND BACKWARD DIGIT SPAN TEST			
S. No.	**Item Span**	**Trial**	**Stimulus**
1	2	Trial 1	2-1
		Trail 2	1-3
2	2	Trial 1	3-5
		Trail 2	6-4
3	3	Trial 1	5-7-4
		Trail 2	2-5-9
4	4	Trial 1	7-2-9-6
		Trail 2	8-4-9-3
5	5	Trial 1	4-1-3-5-7
		Trail 2	9-7-8-5-2
6	6	Trial 1	1-6-5-2-9-8
		Trail 2	3-6-7-1-9-4
7	7	Trial 1	8-5-9-2-3-4-6
		Trail 2	4-5-7-9-2-8-1
8	8	Trail 1	6-9-1-7-3-2-5-8
		Trail 2	3-1-7-9-5-4-8-2

Instructions: The participants were asked to repeat the above series of numbers in either forward or backward order (Holdnack & Drozdick, 2010). The participants received the stimulus orally, with a gap of roughly two seconds between each number.

Scoring: Every right response on a trial resulted in a score of 1, and every wrong response resulted in a score of 0. In an item trial, the test continued if a participant scores zero on one of the trials; it ended if the individual gets zero on both trials. The total of the two trials' ratings for a given item is the item score. The sum of the scores for each item made up the overall score. In addition to that, the participant's longest digit span was also recorded.

4.Raven's Coloured Progressive Matrices (CPM):

Task Description: A test used to analyze fluid intelligence non verbally (Raven 1998). It assesses cognitive aptitude up to the point at which an individual can reason sufficiently by analogy and uses this line of reasoning as a consistent means of drawing conclusions. As per Raven's protocol, the RCPM was given to each person individually, in book format, and without any time restriction. The test contains 3 sets: A, AB, and B each containing 12 items. The questions in the test were visual geometric designs with a missing piece.

Instructions: The participants were expected to complete the missing pattern from the given 6 options. This test does not rely on language ability or cultural knowledge of the participants. The patterns are relatively simple and become complex as the test progressed.

Scoring: The maximum possible score is 36, with 1 point awarded for each subset's correct response and 0 points for each erroneous response.

The data obtained from the participants were noted down and, all the information related to the aforementioned parameters for the Executive Functions tests as well as the Fluid Intelligence were subsequently imported into an SPSS spreadsheet and Microsoft Excel. Each value was manually verified to guarantee accuracy of data entry.

CHAPTER IV

RESULTS

The present study aimed to investigate the effect of smartphone addiction on executive function and fluid intelligence in neurotypical older adults. A smart phone addiction scale was administered to thirty neurotypical older adults in the age range of 60-70 years. The scale categorized the participants into three groups based on their level of smart phone addiction, namely, low, mid and high smartphone addiction. All the three groups were subjected to cognitive tests that assessed Executive Function and Fluid Intelligence. Three distinct tests of executive function and one test of fluid intelligence were carried out to understand the impact of smartphone addiction on the cognitive status of neurotypical older adults.

The participants underwent a series of tests under the Executive Function tests including the 'Trail Making test' and 'Alternate Verbal Fluency test' to evaluate the cognitive flexibility or ability to shift between tasks and the 'Digit Span test' (Forward and Backward) to analyse the auditory working memory span. The test battery also included a non-verbal test, 'Raven's Coloured Progressive matrices' (RCPM) to assess Fluid Intelligence, thereby analysing the reasoning and problem-solving skills in neurotypical older adults who had different levels of smartphone usage. The Friedman and Miyake (2000) framework was followed in categorizing executive functions investigated in this study.

The Trail Making test in the domain of Executive function was evaluated based on the performance of two components, namely, Trail Making Test-A (TMT-A) and Trail Making Test-B (TMT-B). The total amount of time required to finish two parts of the test, the reaction time for TMT-A and reaction time for TMT-B was noted. Additionally, TMT-Difference (TMT-D) calculations were also performed. The Alternate Verbal Fluency test analysed the task-switching ability based on the accuracy of the word pairs produced by the participant in 60 seconds. The Digit Span test – Forward and Backward, gauged the Auditory Working memory span by assessing the entire range or span of repeated numbers in the forward and backward order of sequence. Finally, the Fluid Intelligence estimated through administration of Raven's colored progressive matrices (RCPM) gave two parameters of assessment, accuracy scores for the total number of correct responses by the participant and total time taken to complete the test. All these parameters shown in Table 4.1 were subjected to statistical analysis using the statistical package for Social Science (SPSS) software (version 26.0).

Table 4.1

Enumeration of parameters evaluated within each test category of executive function and Fluid Intelligence.

Tests Administered	Quantitative Analysis	Unit of measurement
Trail Making Test	• TMT-A • TMT-B • TMT-Difference	• In seconds
Digit Span Test Forward-(DSF)	• Forward total score	
Digit Span Test Backward– (DSB)	• Backwards total score	
Alternate Verbal Fluency	• Accuracy score	
Raven's Coloured Progressive Matrices	• Accuracy Score • Total Time taken	 • In minutes

The raw scores of the thirty participants obtained from Smartphone Addiction Scale along with the performance on these executive function test and fluid intelligence are given in APPENDIX-B

Test of Normality

The data was first subjected to the test of normality. The Shapiro-Willis test of normality was used to determine whether the data was normal for the entire set of variables. The results showed that the data is not normally distributed for all variables. Hence, nonparametric tests were used to address every objective as the data did not meet the requirements of a normal distribution ($p < 0.05$).

The results of the present study are described in four distinct sections: **Section I:** Determining the level of smartphone usage on the administration of the smartphone addiction scale (SAS) in neurotypical older adults**. Section II**: Comparing the performance on cognitive assessments at Executive Functions (shifting and working memory tasks measuring reaction time and accuracy score respectively) and Fluid Intelligence (visuospatial processing tasks measuring accuracy score and reaction time) in neurotypical older adults with high scores, moderate scores, and low scores of smartphone addiction scale. **Section III**: Correlation Analysis- Step I- Correlation between Executive Functions (shifting and working memory skill) and the scores of smartphone addiction scales in neurotypical older adults. Step II- Correlation between Fluid Intelligence and the scores of smartphone addiction scales in neuro-typical older adults.

4.1 Section I- Determining the level of smartphone usage on the administration of the smartphone addiction scale (SAS) in neurotypical older adults

Thirty participants in the age range of 60-70 years, who satisfied the inclusionary criteria of the study were selected for the administration of the Smartphone Addiction Scale (SAS) - short version. Based on the responses provided by the participants on smartphone usage, individual scores were computed and the participants were divided into three groups (Low, Mid, and High Smartphone addiction) that demonstrated their level of smartphone addiction. Participants who scored from 30-40 were categorized in **the Low Smartphone addiction** group **(Group 1)**, those who scored in the range of 41-50 were grouped in **Mid Smartphone addiction** group **(Group 2)**, and participants with smartphone addiction scores in the range of 51-60 were in the **High Smartphone addiction** group **(Group 3)**. The low and high smartphone addiction groups had twelve participants each and the mid smartphone addiction group had six participants in them.

The descriptive statistics in Group 1 showed a mean age range of 65.75±3.6. While Group 2 had an average age of 67.33±3.5, Group 3 consisted of participants with an average age of 64.42±3.5. The statistical analysis of the SAS score revealed a mean score of 33.38± 2.2 in Group 1, 42.83±1.1 in Group 2, and 53.00±4.3 in Group 3. The findings of the descriptive statistics representing the mean and standard deviation (SD) for age and SAS score are given below.

Table: 4.2

Descriptive Statistics of Age and Smartphone Addiction Scale Score of Neurotypical Older Adults

Smartphone Addiction Group	Low (Group 1)		Mid (Group 2)		High (Group 3)	
	Mean	SD	Mean	SD	Mean	SD
Age	65.75	3.67	67.33	3.59	64.42	3.55
SAS Score	33.83	2.20	42.83	1.16	53.00	4.36

4.2 Section II- Comparing the performance on cognitive assessments at Executive Functions and Fluid Intelligence in Group 1, Group 2, and Group 3.

The scores of the participants in Groups 1, Group 2, and Group 3 for the set of Executive Function tests and Fluid Intelligence tests were subjected to statistical analysis and the same is explained in the following section.

4.2.1 Level I- Comparison of Performance of Group 1, Group 2, and Group 3 on Executive Function Tests

The results of descriptive statistical analysis with respect to mean, standard deviation, minimum, and maximum values on a series of executive tests, namely, Trail Making Test for Group 1, Group 2 and Group 3 are shown in Table 4.3.

Table 4.3

Descriptive Statistics on Comparison of performance of Group 1, Group 2, and Group 3 on Executive Function tests

Parameter	Smartphone Addiction Group								
	Group 1			Group 2			Group 3		
Executive Function	**Mean**	**Median**	**SD**	**Mean**	**Median**	**SD**	**Mean**	**Median**	**SD**
Trail Making A Reaction time (TMT-A)	60.35	60.30	10.79	54.51	52.75	10.59	42.10	41.1	10.48
Trail Making B Reaction time (TMT -B)	131.75	136.20	33.33	118.30	131.10	25.34	69.08	67.50	11.35
Trail Making test Difference (TMT-D)	71.39	67.5	33.28	63.78	74.15	28.03	26.97	26.77	8.00
Digit Span-Forward Accuracy (DSF)	11.50	11.50	1.977	11.83	12.00	1.602	12.67	13.00	1.96
Digit Span-Backward Accuracy (DSB)	7.33	8.00	1.72	8.00	8.00	1.09	10.08	9.00	2.84
Alternate Verbal Fluency Accuracy (AVF)	9.83	10.00	2.32	11.33	12.00	3.26	14.17	14.00	2.88

In the domain of Executive Function, descriptive statistics were carried out for the scores on the Trail Making Test- A (TMT-A), Trail Making Test- B (TMT-B), and the time difference between the reaction time of TMT A and TMT B, the TMT-

Difference (TMT-D) of neurotypical older adults grouped with reference to SAS (Group 1, 2 and 3). The results revealed a substantial difference in the mean, median, and standard deviation values between Group 1, Group 2, and Group 3. Group 1 demonstrated slower performance (increased reaction time) compared to Group 2 and 3 on both TMT A and B, resulting in higher mean and median reaction time values. Participants in Group 2 exhibited better performance on reaction time measures (reduced reaction time) for both TMT A and B than Group 1, but slower when compared to Group 3. Group 2 has lower mean and median values compared to Group 1 indicating better cognitive functioning in terms of cognitive flexibility and task switching than Group 1, but not as strong as Group 3. Analysis of the performance of Group 3 revealed that Group 3 had the lowest mean and median values (reduced reaction time) on both the tasks, TMT A and B suggesting superior cognitive functioning. TMT D results were in congruence with that of TMT A and B, with Group 3 outperforming both Group 1 and 2. Group 2 demonstrated a significant difference in performance compared to Group 3 and Group 1, which indicated that their executive function abilities were better than individuals with low addiction yet, lower than high smartphone addiction group. Group 1 consistently, exhibited the poorest performance in Trail making tests.

Working memory span, as assessed through the Digit Span Test- Forward series, a comparison of mean, median, and standard deviation, values demonstrated that the three groups had similar performance in terms of accuracy scores indicating comparable working memory span between the groups. In contrast, the Digit Span test-Backward has revealed notably higher mean, and median scores for Group 3 compared to Group 1 and 2 demonstrating that individuals with high use of smartphones were able to retain more digits in their working memory.

Scores obtained on the Alternate Verbal Fluency task, assessing the set-shifting ability demonstrated that Group 3 had the highest mean and median scores, followed by Group 2 and then Group 1. The remarkable difference in accuracy values for Group 3 suggests that they have robust cognitive abilities in terms of flexibility and verbal fluency.

Overall, participants in Group 3 displayed superior performance consistently, except in the Digit Span test- Forward series, suggesting better cognitive abilities in those with high smartphone usage.

The performance of Group 1, Group 2, and Group 3 on Executive Function tests were analysed quantitatively. Kruskal Wallis Test was used to study the comparison of the performance on Executive Function tests by the participants of Group 1, Group 2, and Group 3 and as there were more than two independent groups to be compared, the results are shown in Table 4.4.

Table 4.4

Results of Kruskal-Wallis test for comparison of performance on Executive Function

Parameter	**Smart Phone Addiction Scores**	
Executive Function	**/H/**	***p* value**
Trail Making A Reaction time (TMT-A)	12.055	**0.002
Trail Making B Reaction time (TMT -B)	19.553	**0.000
Trail Making Test Difference (TMT-D)	13.313	*0.001
Digit Span-Forward Accuracy (DSF)	2.025	0.363
Digit Span- Backward Accuracy (DSB)	6.916	*0.031
Alternate Verbal Fluency Accuracy (AVF)	11.384	**0.003

Note: * $p < 0.05$, ** $p < 0.01$

There was a significant difference in the Kruskal Wallis Test performance on the Executive Function test in all the Executive Function tests except in the Digit Span Forward series. A pair-wise comparison was done to compare the performance of three groups (Group 1, Group 2, and Group 3) on the Executive Function tests. The results of the pair-wise comparison are given in Table 4.5.

Table 4.5

Results of Pair-wise comparison of the performance of Group 1, Group 2 and Group 3 on Executive Function tests

Pairwise Comparisons of Executive Function	Group 1 -2		Group 2-3		Group 3-1	
Parameter	**/H/**	***p-value***	**/H/**	***p-value***	**/H/**	***p-value***
Trail Making A Reaction time (TMT-A)	3.750	0.394	8.542	0.520	12.292	**0.001
Trail Making B Reaction time (TMT -B)	3.208	0.466	12.167	**0.006	15.375	**0.000
Trail Making Test Difference (TMT-D)	1.042	0.813	11.250	*0.011	12.292	**0.001
Digit Span- Backward Accuracy (DSB)	2.333	0.579	6.500	0.122	8.833	*0.010
Alternate Verbal Fluency Accuracy (AVF)	4.458	0.293	7.167	0.091	11.625	**0.001

Note: * p <0.05, ** p <0.01

The pairwise comparisons of performance across the three smartphone addiction groups reveal distinct patterns in performance on the Trail Making Test (TMT) tasks. For Trail Making A (TMT-A), measuring the reaction time, there were no statistically significant differences in Group 1 vs Group 2 and Group 2 vs Group 3. However, Group 3 displayed significantly better scores, thereby faster reaction times compared to Group 1. More specifically, Group 2 had exhibited a marginal significant difference in performance when compared to Group 3.

In contrast, notable variations have been observed for Trail Making B (TMT-B), which incorporates more sophisticated executive processes such as cognitive flexibility. Group 3 had shorter reaction times than Group 1, which may indicate that those with low smartphone addiction may not be as cognitively flexible as they should be. However, there was no significant difference in the performance of individuals with low (Group 1) vs mid (Group 2) smartphone addiction. In addition, Group 2 and 3 has shown significant difference in their reaction time scores.

When comparing the differences between the reaction time in Part A and B of Trail Making test, (TMT-D), there was no significant difference between Group 1 and Group 2, suggesting that both groups performed consistently in terms of task-switching efficiency at both low and moderate addiction levels. Alternately, both Group 3 verses Group 1 and Group 2 verses Group 3 displayed significant differences in TMT-D scores, demonstrating higher levels of cognitive flexibility and task-switching efficiency in people with high smartphone addiction.

The findings on Digit Span Backward (DSB) accuracy and Alternate Verbal Fluency (AVF) accuracy showed prominent differences among the performances of the three groups. For the Digit Span Backward accuracy measure, there is a significant difference in the performance between the performance of Group 3 and Group 1, demonstrating superior working memory span in those with high smartphone addiction. Conversely, there was no significant difference noticed in the performance of Group 2 verses Group 3 and Group 1 verses Group 2.

In Alternate Verbal Fluency tasks, Group 3 demonstrated outstanding performance with high accuracy scores compared to Group 1 and 2. In contrast, the performance of Group 1 verses Group 2 and Group 2 verses Group 3 did not show significant difference in the accuracy scores obtained with a p value of 0.2 and 0.09 respectively. This suggests that Group 3 displayed significantly higher scores in generating and alternating between words across given semantic categories under time constraints, indicating superior verbal fluency skills and switching ability when compared to both Group 1 and Group 2.

4.2.2 *Level II-* ***Comparison of performance of Group 1, Group 2, and Group 3 on the Fluid Intelligence Test***

Descriptive Statistics for the performance of Group 1, Group 2, and Group 3 on Raven's Coloured Progressive Matrices (RCPM) consisting of reaction time and total duration measures are provided in terms of mean, standard deviation, minimum, and maximum in Table 4.6

Table 4.6

Descriptive Statistics on Comparison of Performance of Group 1, Group 2, and Group 3 on the Fluid Intelligence Test

Parameters of Fluid Intelligence	**Smart Phone Addiction Group**								
	Group 1			**Group 2**			**Group 3**		
	Mean	**Median**	**SD**	**Mean**	**Median**	**SD**	**Mean**	**Median**	**SD**
Raven's Coloured Progressive Matrices Accuracy (RPMA)	19.58	19.50	3.91	26.50	26.00	4.13	30.67	30.50	3.22
Raven's Coloured Progressive matrices Total Time (RPMTT)	7.08	6.50	2.15	7.00	6.50	1.78	5.66	5.00	0.88

Participants in Group 3 demonstrated a remarkably higher accuracy score resulting in higher mean and median values in comparison to both Group 1 and 2. The quantitative analysis for total time measure presented comparable mean and median values in Groups 1 and 2, and Group 3 had slightly lower mean and median values suggesting a faster completion time showing a quicker processing speed in solving abstract reasoning tasks compared to Groups 1 and 2. Overall, Group 3 outperformed when compared to Groups 1 and 2, exhibiting superior Fluid Intelligence abilities with the highest accuracy and fastest processing speeds among the three groups.

The performance on Raven's coloured progressive matrices, assessing Fluid Intelligence was compared between Group 1, Group 2 and Group 3 using the Kruskal Wallis Test since the data did not follow the normal distribution. The results are displayed in Table 4.7.

Table 4.7

Results of Kruskal-Wallis test for comparison of performance on Fluid Intelligence Test between Group 1, Group 2 and Group 3

Parameter	Smart Phone Addiction Scores	
Fluid Intelligence	**/H/**	***p* value**
Raven's Coloured Progressive Matrices Accuracy (RPMA)	20.040	**0.000
Raven's Coloured Progressive matrices Total time (RPMTT)	4.745	0.093

Note: * p <0.05, ** p <0.01

The analysis of accuracy scores produced by the three groups on the Fluid Intelligence task, Raven's Coloured Progressive Matrices (RCPMA), revealed a notable significant difference in the performance of the three groups in task. Whereas, the total time parameter (RCPMTT) did not show significant difference in the performance of the three groups. Hence, a pair-wise comparison was only carried out for the RCPMA variable. The results of pairwise comparison are given in the Table 4.8.

Table 4.8

Results of Pair-wise comparison of performance of Group 1, Group 2 and Group 3 on Fluid Intelligence Test

Parameter	Group 1 -2		Group 2-3		Group 3-1	
Pairwise comparisons of Fluid Intelligence	**/H/**	***p* value**	**H/**	***p* value**	**/H/**	***p* value**
Raven's Coloured Progressive Matrices Accuracy (RPMA)	9.458	*0.031	6.542	0.136	16.000	**0.000

Note: * p <0.05, ** p <0.01

The results demonstrated a prominent difference in the performance of Group 3 compared to Group 1, signifying higher non-verbal intelligence in terms of abstract reasoning and problem-solving abilities. A notable significant difference was also observed between Group 1 and Group 2, suggesting better cognitive functioning in older adults with moderate smartphone usage compared to low smartphone usage. However, no significant difference was observed between Group 2 and Group 3.

The extended observation of the study included identifying the participants with metabolic disorders. Of the participant population, 3 had the history of metabolic disorders and were under medication. Two participants belonged to low addiction group and one participant belonged to mid addiction group. The individual raw scores on the cognitive tests were compared because of the lesser number of participants hindering the possibility of a statistical analysis. It was found that in low addiction group, the two individuals with metabolic disorders had poorer score compared to others without history of metabolic disorders. Similarly, the one participant with metabolic disorder in mid addiction group demonstrated poorer performance than his peers in the group which can be assumed as the effect of medication or metabolic disorder on their cognitive health.

4.3 Section III- Correlation Analysis

4.3.1 Step I- Correlation between Executive Functions *(shifting and working memory skill)* ***and the scores of smartphone addiction scales in neurotypical older adults***

To understand the trajectory of performance on the Executive Function tests across the Smartphone Addiction Scale scores, a correlation analysis was carried out using Spearman's rank correlation test. The results of the same is given in the Table 4.9.

Table 4.9

Results of Spearman's rank-order correlation between Smartphone Addiction scores and Executive Function tests

Parameter	Smart Phone Addiction Scores (N=30)	
Executive Function	***r value***	***p value***
Trail Making A Reaction time (TMT-A)	-0.559	*0.010
Trail Making B Reaction time (TMT -B)	-0.770	**0.000
Trail Making Difference (TMT-D)	-0.650	**0.000
Digit Span-Forward Accuracy (DSF)	0.079	0.679
Digit Span- Backward Accuracy (DSB)	0.343	0.063
Alternate Verbal Fluency Accuracy (AVF)	-0.335	**0.000

Note: * p <0.05, ** p <0.01

The result showed a negative correlation between Trail Making Test A, B and TMT-D and SAS scores, indicating that as the SAS scores increases, the reaction time reduces, demonstrating better cognitive flexibility. The correlation was statistically significant as well. A similar pattern was noted in the performance on Alternate Verbal Fluency task, a negative correlation with the SAS scores with significant *p* value. Alternately, a positive correlation was observed between Digit Span Forward and Backward performance and SAS scores. However, there was no statistical significance for the correlation.

4.3.2 Step II- Correlation between Fluid Intelligence test (visuospatial processing ability) and the scores of smartphone addiction scales in neurotypical older adults

Spearman's rank correlation test was performed to find out the correlation between Raven's Coloured Progressive Matrices (the accuracy and total time taken) and the performance of participants SAS scores. The results are shown in Table 4.10.

Table 4.10

Results of Spearman's rank-order correlation between Smartphone Addiction scores and Fluid Intelligence

Parameter	**Smart Phone Addiction Scores (N=30)**	
Fluid Intelligence	***r value***	***p value***
Raven's Coloured Progressive Matrices **Accuracy (RPMA)**	0.791	**0.000
Raven's Coloured Progressive matrices **Total Time (RPMTT)**	-0.335	0.071

Note: * $p < 0.05$, ** $p < 0.01$

The correlation findings reveal strong links between smartphone addiction scores and measures of fluid intelligence, particularly accuracy on Raven's Coloured Progressive Matrices (RPMA). A strong positive correlation was found between RCPM accuracy and smartphone addiction scores, suggesting this relationship is highly statistically significant.

In contrast, RCPM Total Time taken has shown negative correlation, indicating weak relation with SAS scores. This implies that although there is a trend showing that higher smartphone addiction scores leading to higher accuracy scores, this may not aid in result in quicker completion times on RCPM task.

CHAPTER V

DISCUSSION

The study aimed to investigate the effect of Smartphone addiction on Executive Function and Fluid Intelligence in neurotypical older adults. The recent introduction of Smartphones into the daily lives of older adults has sparked discussions about its impact on cognitive abilities. While previous research has established the potential benefits of technology usage on cognitive functioning in older adults, the implication of pervasive use of technology has not been documented. The current literature suggests that neurotypical older adults show a slight decline in Executive Function and Fluid Intelligence as age progresses (Ferguson et al., 2021). A series of Executive Function tests assessing set-shifting, and cognitive flexibility and a single Fluid Intelligence test evaluating problem-solving, and abstract reasoning abilities are carried out. These age-related changes can be attributed to structural changes in the pre-frontal cortex, as suggested by the 'prefrontal-executive theory' affecting attentional control, inhibition, speed of processing and other executive functions. (Idowu & Szameitat, 2023).

The findings of the current study signify a paradoxical and intriguing narrative. In opposition to the traditional views, regarding the pervasive use of smartphones, having a negative impact on the cognitive abilities of human beings, the results of the study reveal that the neuro-typical older adults who had High smartphone addiction (Group 3) performed better in both Executive Function tests and Fluid Intelligence compared to Low (Group1) and Mid (Group 2) addiction groups. These results of the present study are discussed in the following sections in detail.

5.1 Level of Smartphone Usage using the Smartphone Addiction Scale (SAS) in Neurotypical Older Adults

The first objective of the study was to categorize the selected participants into groups based on the level of smartphone addiction after the administration of the Smartphone Addiction Scale – Short version (SAS-SV). The quantification of the addiction levels helped in the classification of the individuals (neurotypical older adults) into three groups of Smartphone Addiction- Low, Mid, and High (Group 1, Group 2, and Group 3 respectively). To support these findings of the present study, SAS-SV is found to be a simple and efficient scale, easy to administer, and has shown good reliability and validity in different cultural contexts. It was originally developed in Korean language, but has been translated and validated into English. SAS-SV has shown results in different age groups ranging from young adolescents to older adults (Hamamura et al., 2023; Luk et al., 2018). Additionally, Hamamura et al, (2023) showed that the Smartphone Addiction Scale – Short Version (SAS-SV) was able to establish a positive correlation between pervasive smartphone usage and psychopathological traits such as impulsiveness and neuroticism and disorders such as ADHD, Internet gaming disorder, Depression, Anxiety, and obsessive-compulsive disorder.

To explore the impact of the pervasive usage of smartphones on the cognitive functioning, cognitive tests under the domain of Executive Function and Fluid Intelligence was further administered for the neurotypical older adults with reference to the classification as Group 1, Group 2, and Group 3.

5.2 Performance on cognitive assessments at Executive Functions and Fluid Intelligence in Group 1, Group 2 and Group 3

5.2.1 Performance comparisons among Group 1, Group 2 and Group 3 on Executive Function Tests

The second objective of the study was to understand how the three Smartphone Addiction groups, Group 1, Group 2, and Group 3, performed on the executive Function tests, such as Trail Making test, Digit Span –Forward and Backward and Alternate Verbal Fluency and to compare the performance between the groups. While the study investigated Executive Function domains such as ‘working memory’, ‘cognitive flexibility’ and ‘verbal fluency’, and in the context of Fluid Intelligence, ‘abstract reasoning’ and ‘problem solving’ which facilitate in new learning were the domains interested in the present study. The outcome was measured in terms of accuracy and reaction time scores.

Contrary to conventional expectations, that individuals with intensive smartphone usage tend to have poorer cognitive abilities leading to poor attention, and executive functions because of the extensive cognitive engagement involved in smartphone usage (digital distraction hypothesis given by Small et.al., 2020), the results of the present study revealed that Group 3, consisting of individuals with High smartphone addiction outperformed the Group 1 and Group 2 in all the tests of Executive Functions except Digit Span –Forward series. There was a significant difference in the accuracy and reaction time scores between High (Group 3) and low addiction groups (Group 1) in all the executive function tests except the Digit Span –Forward series, where the outcome measures had comparable scores. However, Group 3 versus Group 2, had demonstrated a significant difference only in Trail Making test parameters, leaving the performance of Group 2 similar to that of Group 3 in the Digit

Span and Alternate Verbal Fluency tests. A possible reason for this finding in the domain of working memory can be that, Digit Span forward series engages storage and maintenance of working memory, which might not be cognitively taxing, owing to the similar performance of the three groups (Hester et al., 2004)

Unlike Digit Span forward, Digit Span- Backward is a more cognitively demanding task which requires storage as well as simultaneous processing to rearrange the stimulus in the reverse order. Baddley and Hitch in 1974, suggested a model of working memory that utilises a phonological loop and visuospatial sketch pad which has limited capacity for storage of new information, while manipulating or processing the incoming information employing a central executive and episodic buffer. While the forward digit span is assumed to represent a measure of the phonological loop (auditory) capacity, the performance on the backward digit span evaluates the scale of utilisation of the central executive function due to the additional manipulation of information required in the backward span making it more complex. The MRI findings identified neural correlates for working memory tasks, which are frontal and parietal lobes of the cerebral cortex. More specifically, the dorsolateral prefrontal cortex is utilised in the active retaining of the information as simultaneous processing is happening for the incoming stimuli (Barch et al., 1997; Newman et al., 2002; Smith & Jonides, 1997; Smith et al., 1998). These authors also suggested that Broca's area is activated during verbal rehearsal. Additionally, the parietal areas gets activated when the incoming stimuli has linguistic information and is cognitively demanding (Newman et al., 2002; Smith & Jonides, 1997; Smith et al., 1998). According to the frontal aging hypothesis, the prefrontal cortex is the most vulnerable to the process of aging, with an average rate of 5% decrease in functioning every 10 years in older adults (Raz & Rodrigue, 2006). Furthermore, the study conducted by Wu et.al, in 2019 had similar findings to that the present study. They divided the older adults into three groups, those with no daily use of smart technology, those who had either of the one – smartphone or computer and those who had exposure to both computer and smartphone daily. The findings were that the group with daily exposure to both computer and smart device had smaller reactions time measures in Trail Making test compared to other two groups, whereas the Digit span test – forward and backward demonstrated marginal difference in performance. All these evidences suggest that, as task complexity increases, older adults tend to perform poorer, as they would need to allocate more cognitive resources to compensate for the decreased cognitive efficiency. Hence, the better performance by Group 3 in Digit Span Backward gives hint about improved cognitive efficiency in older adults with high smartphone usage. An added assumption is that since Digit span Backward is cognitively intensive task, older adults may be engaging more parietal areas, reducing the contribution of the fast-aging frontal lobes.

In the past, research had demonstrated that the performance on the digit span test both forward and backward decreases with age (Babcock & Salthouse, 1990; Gregoire & Van der Linden, 1997). Another meta-analysis of 14 studies suggested that, the level of decline in scores for backward digit span were far greater than those for forward span with a magnitude of 14% and 8% respectively (Babcock & Salthouse, 1990). This evidence strengthened the clinical perspective that, as age progresses, the forward digit span is persevered when compared to backward digit span (Lezak, 1995). However, a large scale study conducted by Gregoire and Van der Linden in 1997, involving 1000 participants revealed that the rate of decline observed in both forward and backward are same. Supporting studies conducted by Robert.et.al., in 2003 also indicated that, it can be considered that normal aging may not directly affect the central executive functioning, but may influence the efficiency of the functioning.

These evidences may justify the notable significant difference obtained in the performance of Group 3 compared to Group 1 and 2 that can be attributed to enhanced ability of Group 3 in complex engagement of central executive, visuospatial sketchpad and phonological loop based on the complexity of the task. This is clearly established with the accuracy scores of Group 3 with an average score of 10, while Group 1 and 2 had only 7 and 8 respectively. Therefore, the better performance of the Group 3 individuals could indicate that, those who have high smartphone addiction are cognitively more active and their working memory that is larger and more efficient compared to older adults with moderate and low smartphone addiction because of the extent of cognitive engagement in high addiction individuals owing, more mental stimulation and efficient utilisation of cognitive resources.

The results obtained for the performance in Trail Making test parameters were quite different from the pattern of other tests. In addition to the superior performance exhibited by Group 3 compared to Group 1 in all the outcome measures of the test, there was significant difference noted only between Group 3 and 2 in the Trail Making test with all other executive function tests showing no significant variation. The results of all the three parameters in the Trail Making test, that is, the reaction time taken to complete TMT-A, TMT-B and the difference in the reaction time TMT-D has shown clear significant difference in the performance of Group 3 compared to Group 2. The effect of age and education on the performance of Trail making test has been widely studied (Goul & Brown, 1970; Hamdan et al, 2009; Kennedy, 1981). The collective conclusion suggests that as age progresses, the time taken to complete the Trail making test increases. In contrast, there are inconsistent results regarding the influence of education level on the performance in Trail making test (Hashimoto et al., 2006). Since efforts were taken to control this variable in participant selection, the influence of education across the participants can be negligible. However, the effect of motoric speed reduction due to aging can be an influencing factor. TMT-A is thought to estimate visuospatial search, psychomotor speed, goal driven motor tracking whereas TMT B is measures these parameters with an additional requirement of set-shifting making it more cognitively demanding than TMT A (Gaudino et al., 1995). However, TMT B cannot be thoughtlessly considered to measure central executive engagement which can lead to over or under estimation of executive function. Therefore, another parameter that calculates the difference in reaction time of Trail making test A and B , TMT difference (B-A) was incorporated in the study to evaluate TMT-B more accurately (Varjacic et al., 2018). Because the TMT engages a multitude of processes, a specific neural correlate that is recruited during the task cannot be defined, rather a network of functionally connected nodes is likely to be engaged. A number of brain regions such as left and right inferior, middle and superior frontal areas, left insular cortex generally activated with an additional activation of bilateral superior parietal and temporal areas seen for TMT-B task were found in brain imaging studies (Varjacic et al., 2018; Jacobson et al., 2011; Zakzanis et al., 2005; Moll et al., 2002). Tisserand et al., in 2004 revealed that, the frontal lobe showed greatest age related significant changes in the grey matter of healthy older individuals. Another study by Stuss et al, in 2001, demanded that there is a correlation between TMT-B reduced performance and frontal lobe damage when compared to older adults with normal aging. These studies imply that TMT can be considered to reflect the status of frontal lobe functioning, with more emphasis on TMT-B scores. These findings are in congruence, with the results of the present study. With the age and education variables controlled, individuals with high smartphone addiction demonstrated better performance with a smaller reaction time to complete TMT-A and B, suggesting greater activation of frontal, parietal and temporal areas and better efficiency in those compared to low smartphone addiction group. Surprisingly, the marked difference noted in the performance of moderate smartphone addiction group (Group 2) can be because of enhanced activation of the above-mentioned brain areas, with smartphone usage, that necessitates the users to switch between two applications, browse multiple tabs while maintaining attention on each of them, thereby engaging them tasks similar to set shifting in TMT.

The outcome measurement of the performance of the three groups in Alternate Verbal Fluency were in synchrony with that of Digit span and Fluid Intelligence test. A plausible reason can be obtained by looking to the mechanism of brain activation during the task. The Alternate Verbal fluency can be assessed at phonemic fluency level and semantic fluency level, with the former tasking requiring the individual to recall words starting with two given phonemes alternatively and latter required to switch between two different semantic categories to retrieve and say the lexical items. The research evidence given by Paula et al., in 2015, suggests that the demand posed by the alternate verbal fluency task on cognitive system to switch between the semantic categories gives a robust idea about extent of engagement of executive function rather than the verbal fluency or language processing of the individual. Kaplan and Kramer in 2011 suggested that older adults exhibited poor performance in alternate verbal fluency tasks compared to younger counterparts attributing it the frontal lobe aging hypothesis. Another study by Downes et al., in 1993 suggested that the alternate verbal fluency task is carried out by devising algorithms determined by the search parameters. These rules guide the search for the lexical items pertaining to the correct semantic categories. Even so, studies have demonstrated that older adults are able to perform better in non-alternating vernal fluency task including phoneme or semantic verbal fluency than alternate verbal fluency, indicating switching between the tasks are cognitively challenging for older adults (Henry et al., 2006, Paula et al., 2015). Several authors have suggested potential correlation of alternate verbal fluency with processing speed and cognitive flexibility (Henry et al., 2006; Nutterupham et al., 2008, Parkin et al., 1995). Conversely, meta-analytic studies by Vehaeghen and Cerella in 2002 found that the poor performance of older adults in switching tasks cannot be solely attributed to normal aging process. Therefore, it can assumed that the ability to produce correct word pairs would be more cognitively demanding for flexibility, implying that the effort required will be more to employing the two different algorithms to probe for the right lexical item based on the rule.

Another possible reason for the findings can be the correlation of alternate verbal fluency task with fluid intelligence. Age related decline in fluid intelligence has been well established (Raven et al., 1987; Salthouse, 1991). The smartphone usage in older adults paves way for new learning there by encountering problems to be solved regarding navigating through the applications, to understand the technicalities of smartphone usage, urging to employ more cognitive resources to solve them. Hence, the continuous usage of smartphone may indirectly be engaging the cognitive areas, thus slowing the pace of age-related changes.

5.2.2 Performance comparisons of Group 1, Group 2 and Group 3 on Fluid Intelligence Test

The analysis of the outcome measures in the Fluid Intelligence test, Raven's coloured progressive matrices (accuracy and time), followed the trend of results of executive function test. Individuals of Group 3 exhibited exceptionally high scores compared to low and mid addiction group (Group 1 and 2 respectively) in accuracy scores. Contrary to these findings, the total time to complete the task did not show a significant difference among the three groups. These results can be attributed to the fact that Fluid Intelligence in solving novel problems when the task specific knowledge is absent, is shown to decline steeply as aging progresses through cross- sectional (Hartshorne & Germine, 2015; Kievit et al., 2016) as well as in the longitudinal studies (Ghisletta et al., 2012; Salthouse, 2009; Schaie, 1994). Salthouse et al. in 2004 suggests that, the estimated onset period of Fluid intelligence decline can be between third to sixth decades of life. The results can be justified by the thought that the now older adults might have started using smartphones during this period, leaving them with a novel problem to solve, decoding the method of using smartphone. The continuous cognitive engagement involved in the new learning during the process might have enhanced their fluid intelligence. Tucker-Drob in 2011, found that the level of decline in fluid intelligence was highly correlated to the decline in quality of life of the older adults. An assumption can be made that, as the older adults spend time in using the smartphone, they tend to master the operational aspects of the smartphone, which can help them be cognitively more active, as well , socially more involved in their relationships, thereby holistically improving their ability to function independently.

Most of the previous studies have attributed frontal lobe network as the strongest determinants of fluid intelligence (Duncan, 2010; Jung & Haier, 2007; Kievit et al., 2014; Kievit et al., 2016; Santarnecchi et al., 2017a). However, another study in 2018 by Kievit et al, found out that the frontal lobe tracts are not the strongest predictors rather the posterior thalamic radiations are the major contributors. An assumption put forth by the authors is that, the parietal areas of the brain are generally recruited when the demanding tasks need to be carried out. The study had also revealed that, frontal lobe system had relatively strong role with fluid intelligence, thereby emphasising the frontal lobe aging hypothesis once again.

5.3 Correlation Analysis:

5.3.1 Correlation between Executive Functions and the scores of smartphone addiction scales in neuro-typical older adults.

The correlation analysis between executive function and scores on the smartphone addiction scale has shown heterogeneous correlation patterns across tests in the domain of executive function. The time taken to complete the Trail making test considerably reduced as the scores of the smartphone addiction scale increased with a significant difference value of 0.00, suggesting a strong negative correlation, thus implying that, smartphone addiction can be a blessing in disguise, which essentially improves cognitive flexibility. In contrast, the Digit span test both forward and backward exhibited a positive correlation with the scores on smartphone addiction with a *p* value of 0.679 and 0.063 respectively, which is not statistically significant. Assumptions can be made on the grounds that, with the strict control of the variables, such a finding can indicate the need to consider larger sample size to determine the correlation. Nevertheless, the non-parametric tests have demonstrated better performance in Group 3 individuals in Digit span backward, suggesting some evidence to improved working memory span in those with high smartphone usage. The correlation patterns noticed in Alternate verbal fluency tasks was in accordance with that of Trail making tests. A high confidence in results with a *p* value of 0.00 suggesting a strong negative correlation with the scores of the smartphone addiction scale, indicate that, as the smartphone addiction level increases, individuals were able to provide more number of correct word pairs switching between the two given categories. These findings may be indicating an increase in cognitive stimulation utilized to operate the smartphone device and use of higher-order cognitive strategies employed by older adults in dealing with the requirements of smartphone usage, suggesting an efficient use of cognitive resources by older adults who are addicted to smartphone usage.

5.3.2 Correlation between Fluid Intelligence test and the scores of smartphone addiction scales in neuro-typical older adults

The present study aimed to explore the association between smartphone addiction scores and fluid intelligence in terms of two outcome measures- accuracy and total time taken. The results demonstrated an extremely strong evidence against the null hypothesis, a positive correlation of fluid intelligence with smartphone addiction scores in terms of accuracy in the RCPM test, with a statistically significant *p* value of 0.000. Alternately, there was negative correlation with the total time taken to complete the task by the individuals, with a *p* value of 0.071. This indicates that, as the smartphone addiction scores increases, the total time taken has reduced marginally, though not significantly. The high confidence in the result noted for the accuracy in the RCPM test, suggesting, those with high smartphone addiction tend to show slower decline in fluid intelligence, can indicate more cognitive areas in the older brain, being engaged due to smartphone usage, forming newer neuronal connections, when novel problems are encountered and solved by them. The constant cognitive training employed by those with pervasive use at old age, tend to increase activation of cortical connections thereby enhancing the overall function of the brain. The lack of significant difference in the total time taken, in fact gives a new perspective on the efficiency of the high smartphone addiction group (Group 3) to respond accurately to the abstract reasoning task within the same amount of time taken by those with low and moderate smartphone addiction (Group 1 and 2 respectively).

CHAPTER VI

SUMMARY AND CONCLUSION

The current investigation aimed to assess the effect of Smartphone addiction on Executive function and Fluid Intelligence levels in neuro-typical older adults.

The objectives of the study were,

1. To determine the level of smartphone usage using the Smartphone Addiction Scale (SAS) in neuro-typical older adults.
2. To measure and compare the performance on cognitive assessments at Executive Functions (shifting and working memory tasks) measuring reaction time and accuracy score respectively and Fluid Intelligence (visuospatial processing tasks) measuring accuracy score and reaction time in neurotypical older adults with high scores, moderate scores and low scores of Smartphone Addiction Scale.
3. To investigate the correlation between Executive Functions (shifting and working memory skills) and the scores of Smartphone Addiction Scales in neurotypical older adults.
4. To investigate the correlation between Fluid Intelligence and the scores of Smartphone Addiction Scales in neuro-typical older adults.

The study involved the recruitment of thirty neuro-typical older adults in the age range of 60-70 years. These participants were selected on the administration of a technological activity survey to assess their background in technology use. These participants scoring a minimum of 80% ‘YES’ response were considered for the study. All the participants had knowledge of the English language and had a minimum of 10 years of formal education. The socioeconomic status of the participants was ensured to be in the middle-class category on the administration of Kuppuswamy socioeconomic status scale. The selected individuals were subjected to a cognitive screening using the Montreal Cognitive Assessment (MOCA), individuals who scored less than 26, were excluded from the study. Participants with hearing or visual acuity problems were not considered for the study. Along with that, individuals, who had a history or diagnosis of psychological disorders, as well as substance abuse were strictly not considered for the study. Those participants with metabolic disorders or who were under medication were noted.

All the participants were explained about the goal and methods of the study and an informed consent was obtained from each of them. The tests were carried out in a well-lit and quiet room with less distraction as much as possible. Care was taken to make sure, that the participant had a comfortable seating and had grasped the instructions of the tests thoroughly.

6.1 Smart Phone Addiction and Cognitive Functions in Neurotypical Older Adults:

The selected participants were administered a short version of Smartphone Addiction scale (SAS) (Hamamura et al, 2023), to estimate the level of smartphone addiction they had. Based on the scores obtained by the participants, these neuro-typical older adults were divided into three groups according to the level of smartphone addiction. Group 1 consisted older adults with low smartphone addiction, spanning scores from 30-40. Group 2 individuals scored 41-50 and were categorized as mid smartphone addiction group. Finally, Group 3 comprised of high smartphone addiction group with scores ranging from 51- 60 in the SAS.

These participants were further subjected to a series of cognitive tests to understand the effect of the smartphone usage on their cognitive functioning.

Particularly, Executive Function and Fluid intelligence were the two domains of cognition aspects considered in the present study. The executive function tests included Trail Making test (TMT), Alternate Verbal Fluency test and Digit Span Test- Forward and Backward. The evaluation of fluid intelligence was carried using Raven's Coloured Progressive Matrices (RCPM). The outcome measures considered were, reaction time of TMT-A, TMT-B and TMT-D, accuracy scores of Digit Span Forward, Backward, Alternate Verbal Fluency, RCPM and total time taken to complete the RCPM task.

The data obtained from the participants were noted manually, and then entered into an excel sheet, which later was used to perform the statistical analysis using SPSS (version 26.0). The data analysis using statistical methods included a descriptive statistic involving the mean, median, and standard deviation of the performance score of the three groups, followed by a test of normality, and finally, the data was subjected to inferential statistical analysis. The Shapiro-Wilks test of normality revealed that the data did not follow a normal distribution pattern, hence a non- parametric test was used to evaluate the data.

The results for the first objective, determining the level of smartphone addiction and categorizing the participants into three groups, were defined by the descriptive statistics carried out using the data. The mean age in all the three groups were as follows: Group 1 had a mean age of 65.75, Group 2 had a mean age of 67.33 and Group 3 consisted of participants of mean age 64.42. The SAS score showed an average score of 33.83 in Low addiction (Group 1), 42.83 and 53.00 in Mid (Group 2) and High addiction (Group 3) respectively.

The second objective, was the between group comparisons on the performance on Executive Function and Fluid Intelligence test carried out using the Kruskal-Wallis, a non-parametric test, since there were more than two independent groups to be compared. The descriptive statistics pertaining to performance on Executive Function tests and Fluid Intelligence indicated that Group 3 generally outperformed Group 1 and Group 2.

For executive function tests, the participants of Group 1 obtained the highest mean total score of 60.35 on TMT-A, while Group 2 and 3 had a mean total score of 52.75 and 42.10 (indicating reduced reaction time) respectively. The performance of TMT-B demonstrated a mean total score of 131.75 for Group 1, 118.30 for Group 2 and 69.08 for Group 3 (indicating reduced reaction time). TMT-D derived from TMT A and B, displayed a score of 71.3 for Group 1, 33.28 for Group 2, and 26.97 for Group 3 (indicating reduced reaction time). However, The Digit span test- Forward showed only a slight difference in the mean value, with Group 1 score 11.50, and 11.83 for Group 2 and Group 3 with a mean total score of 12.67 (indicating higher accuracy score). Digit Span-Backward had shown a greater difference in mean total score compared to performance on forward series. The mean value obtained in Group 1 was 7.33, Group 2 had a mean value of 8.00 and Group 3 had 10.08 (indicating higher accuracy score). Alternate verbal fluency task showed noticeable difference in the mean values, with Group 1 mean value, 9.83, Group 2 mean value to be 11.33 and Group 3 having a mean total score of 14.00 (indicating higher accuracy score).

In the domain of Fluid Intelligence, test scores on RCPM accuracy measures demonstrated a mean value of 19.58 for Group 1, 26.50 for Group 2 and 30.7 for Group 3 to be the highest among the three group. Alternatively, the RCPM total time parameter demonstrated comparable means across the groups. Group 1 took an average of 7.08 minutes to finish the task, Group 2 took 7.00 minutes to finish the task, whereas, Group 3 only took 5 minutes to complete the task (indicating reduced reaction time).

The inferential statistics analysis using Kruskal Wallis test demonstrated statistically significant difference only in TMT A (*p* value=0.002), TMT B (*p* value=0.000), TMT D (*p* value=0.001), Digit Span Backward (*p* value=0.031), Alternate Verbal Fluency test (*p* value=0.003) and RCPM accuracy measure (*p* value=0.000). There was no significant difference for the Digit Span Forward (*p* value=0.363) and RCPM total time taken (*p* value=0.093) to showcase comparable performance among the three groups.

Consequently, a pairwise comparison was carried out between groups to assess the difference among groups. It was found that in the domain of Executive Function, Group 3 exhibited superior performance compared to Group 1 in TMT- A, TMT- B, TMT- D, Digit Span Backward and Alternate Verbal Fluency test. The Group 3 verses Group 1 results demonstrated a *p* value of 0.001 for TMT- A, *p* value of 0.000 for TMT- B, *p* value of 0.001 for TMT- D, *p* value of 0.010 for Digit Span Backward, and *p* value of 0.001 for Alternate Verbal Fluency test. In contrast, Group 3 had performed better than Group 2 only on Trail Making Test parameters, TMT-A (*p* value=0.052), TMT-B (*p* value=0.006), and TMT-D (*p* value=0.011). Alternately, Group 1 and 2 failed to show significant difference in their performance across Executive function tests. This shows that, individuals with high smartphone addiction had generally better cognitive functioning than low smartphone addicted older adults and better cognitive efficiency than moderate smartphone addicted individuals in some of the cognitive function.

In the domain of Fluid Intelligence, the pairwise comparison of different groups on accuracy and total time taken scores on RCPM demonstrated a dominance in performance by Group 3 over Group 1 and Group 2. In contrast, Group 2 performed better than Group 1 in accuracy scores for RCPM, a finding, only noted for this parameter with a significant difference of *p* value 0.031. RCPM total time taken measure did not show significant difference between the three groups.

The third and fourth objective comprised of finding correlation between SAS scores and Executive Function and Fluid Intelligence respectively. The results indicated that there was a statistically significant correlation between SAS scores and Executive function tests. All the parameters of Trail Making test, showed significant negative correlation with SAS scores, implying that as the smartphone addiction scores increased, there was a remarkable reduction in the reaction time of the individuals. However, the correlation patterns of the Digit span test- Forward and Backward demonstrated a positive correlation, but without significant differences with *p* values for Forward test, 0.679 and *p* value for Backward test to be 0.063. Alternately, there was strong negative correlation, observed between the SAS scores and the Alternate Verbal Fluency, suggesting that the number of correct word pairs increased as the addiction level increased, suggesting better cognitive switching ability.

The correlation analysis carried out between SAS score and Fluid Intelligence test, Raven's Coloured Progressive Matrices (RCPM) showed a significant positive correlation (*p* value=0.000) of RCPM accuracy scores with SAS scores, thereby indicating that those with higher addiction levels had better problem solving, abstract reasoning and visuospatial abilities. Contrary to that, RCPM total time taken measure displayed weak negative correlation with SAS scores, suggesting that, even though the accuracy got better, total time taken by the individuals was similar irrespective of the severity of SAS scores.

To summarize, the key findings of the present study were that the individuals with High smartphone addiction levels were able to perform better than those with low smartphone addiction level in all the cognitive tests carried out in the study. There was significant difference in the performance of the individuals with moderate smartphone addiction compared to those with low and high smartphone addiction in some of the executive function and fluid intelligence tests. The Trail making test showed notable difference in performance of moderately addicted and those highly addicted to smartphone. Conversely, individuals with mid smartphone addiction levels, displayed better performance than those with Low smartphone addiction level in RCPM accuracy measure. Some of the tests, demonstrated similarities between the performance of older adults with high and moderate addiction to smartphone, such as RCPM accuracy, Alternate Verbal Fluency and Digit span Backward test. Additionally, strong correlations were observed for SAS scores and Trail Making test, Alternate Verbal Fluency test in Executive Function tests, as well as, between SAS and RCPM accuracy scores in the domain of Fluid intelligence. These results suggest that the extended periods of cognitive engagement involved in smartphone usage, in turn, activates more cognitive areas, rather than having a detrimental effect on them in old age. It can be inferred that, high smartphone addiction can in fact improve cognitive flexibility, problem solving and abstract reasoning skills in older adults, thereby enhancing the cognitive efficiency that helps to build cognitive reserve.

6.2 Clinical Implications

This study offers valuable insights into the cognitive abilities of older adults who use smartphone technology. The superior performance demonstrated by older adults with high smartphone usage indicates that, age related changes in cognitive functions can be paced down by actively being involved in technology use. The present study emphasis that, level of smartphone usage can be considered as marker of cognitive health due to the higher order cognitive function involved in the operation of smartphone which boosts the executive functions and fluid intelligence level in older adults. By encouraging active participation in complex and problem solving tasks involved in smartphone usage, older adults can strengthen their executive functions such as planning, decision making and switching abilities along with improvement in abstract reasoning and visuospatial processing. The increased cognitive engagement associated with smartphone usage can potentially enhance cognitive reserve, thus delaying the onset of cognitive communication disorders. The motor coordination and precision required in the smartphone usage, can help improve fine motor skills in older adults. The continuous learning and adaptability required in using the smartphone can enhance the cognitive flexibility and resilience against cognitive decline. Furthermore, the results of the study can be utilised to design cognitive training programs appropriate for smart phone technology and ideal for older adults as rehabilitation strategies. Older individuals can live a more independent life with the help of smartphone based communication, health services and food acquisition methods, thus increasing overall cognitive function and quality of life.

6.3 Limitations and Future Directions

The current study has some limitations to be noted. The assessment of smartphone usage was through self-reported scale, which could have introduced bias. Although the level of addiction was quantified, the domains of usage was not really looked into. Hence, future research should look into establishing the results with large sample size to confirm the generalisation of the result to a larger population with proved construct validity of the assessment material. Longitudinal studies are required to understand the long-standing effect of smartphone usage on cognitive function of older adults with retrospective profile of individuals' smartphone usage. Additionally, Trail making test can also be evaluated for performance accuracy and types of errors exhibited by the individuals when joining the letters in TMT-A or switching between letters and alphabets in TMT-B. This can help increase the specificity with which early cognitive impairment can be identified. Furthermore, a sub cluster analysis for Alternate verbal fluency test and an assessment tool with more psychometric value can be used to quantify the smartphone usage, to deepen our understanding of the extent to which cognitive abilities are enhanced due to smartphone usage in older adults.

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APPENDIX A

All India Institute of Speech and Hearing,

Naimisham Campus, Manasagangothri, Mysore-

INFORMATION AND CONSENT FORM

Information to participants:

I, Ms. Niranjana J, studying MSc in Speech-Language Pathology at All India Institute of Speech and Hearing, Mysuru, am conducting a study titled " Investigating the Effect of Smartphone Addiction on Executive Function and Fluid Intelligence on Neurotypical Older Adults " under the guidance of Dr. Hema N, Assistant Professor, Department of Speech-Language Sciences, AIISH, Mysuru. You are invited to participate in the study which aims to understand the effect of smartphone addiction on the cognition of older adults. The study will take around 15-20 minutes.

Participants will be interviewed to obtain personal details, including their educational background and other necessary information, before confirming eligibility for the study. The participant's identity will not be revealed at any time and will be confidential. The data obtained from the participants will not be disclosed, and access will be limited to individuals working on the study. Participation in this study is voluntary. You can refuse to participate or withdraw at any point in the study without penalty or loss of benefits to which you are otherwise entitled. The procedures of the study are non-invasive, and no risks are associated.

INFORMED CONSENT

I have been informed about the aims, objectives, and procedure of the study. I have read the foregoing information, or it has been read to me in the language I understand. I have had the opportunity to ask questions about it, and any questions that I have asked have been answered to my satisfaction. I consent voluntarily to participate in this study.

I, ____, the undersigned, give my consent to be a participant in this investigation/study.

Signature of the participant **Signature of the investigator**

Name & Contact No: **Name of the investigator:**

APPENDIX B

P. No	Age/G	SAS score	SAS group	DSF (acc)	DSB (acc)	TMT A (s)	TMT B (s)	TMT D (s)	AVF (acc)	RCPM A (acc)	RCPM TT (in min)
P1	65/M	34	low	8	8	38.90	148.80	109.90	8	25	10.00
P2	65/M	32	low	14	8	80.40	135.00	54.60	12	13	6.00
P3	70/M	36	low	10	6	66.00	180.00	114.00	10	14	5.00
P4	70/M	35	low	10	10	67.20	137.40	70.20	12	19	7.00
P5	68/F	33	low	12	8	60.60	181.80	121.20	8	18	8.00
P6	70/M	31	low	14	8	52.96	145.20	92.24	6	19	5.00
P7	62/F	34	low	14	5	60.00	143.40	83.40	10	21	12.00
P8	69/M	39	low	11	5	58.76	87.60	28.84	12	20	6.00
P9	61/F	32	low	13	8	69.00	133.80	64.80	12	21	7.00
P10	60/F	33	low	10	6	59.77	82.80	23.03	12	27	6.00
P11	63/M	32	low	12	10	46.45	84.00	37.55	10	18	5.00
P12	66/F	35	low	10	6	64.20	121.20	57.00	6	20	8.00
P13	66/M	58	high	10	8	21.36	47.02	25.66	18	35	5.00
P14	60/F	53	high	12	7	38.72	66.60	27.88	12	31	5.00
P15	60/F	55	high	12	12	51.44	76.80	25.36	16	29	5.00
P16	64/M	51	high	14	10	55.92	69.00	13.08	12	23	5.00
P17	64/F	56	high	16	16	42.50	63.00	20.50	14	31	5.00
P18	70/M	51	high	10	8	59.00	90.00	31.00	10	30	7.00
P19	62/F	54	high	14	14	41.67	64.20	22.53	16	30	6.00
P20	67/M	51	high	14	10	48.59	78.00	29.41	12	35	7.00

P21	60/F	42	high	12	8	38.36	82.20	43.84	14	30	6.00
P22	70/M	56	high	14	8	33.72	64.20	30.48	14	31	5.00
P23	64/M	51	high	14	12	33.47	68.40	34.93	12	34	7.00
P24	66/M	58	high	10	8	40.53	59.56	19.03	20	29	5.00
P25	70/F	44	mid	12	8	70.20	135.00	64.80	16	27	10.00
P26	61/M	42	mid	12	8	46.70	130.20	83.50	6	24	6.00
P27	67/F	43	mid	10	7	41.67	132.00	90.33	12	27	8.00
P28	70/F	44	mid	10	8	63.00	90.60	27.60	12	25	7.00
P29	70/M	41	mid	14	10	50.42	81.60	31.18	10	22	5.00
P30	66/M	43	mid	13	7	55.09	140.40	85.31	12	34	6.00

Abbreviations: ***SAS*** *–Smartphone Addiction Scale –Short Version,* ***DSF*** *– Digit Span Forward ,* ***DSB*** *– Digit Span Backward, TMT – Trail Making Test,* ***AVF-*** *Alternate Verbal Fluency***, RCPM A** *– Raven's Colored Progressive Matrices*-Accuracy scores, ***RCPMTT-*** *Raven's Colored Progressive Matrices Total time taken,* **acc**- *Accuracy scores.*

M- Male, F-Female