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Theoretical Paper

Cognitive Aging: Opportunities and Challenges in Existing Theories

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ABSTRACT

Theoretical understandings of different components of cognitive functioning which are affected by aging have witnessed a significant development in the past few decades. Initial cognitive aging researches were descriptive and they were focused mainly on the identification of different components of intellectual functioning, which affects older adults compared to younger adults. However, mid 1960s' witnessed a widespread change in the approaches towards understanding the aging mind with an increasing interest to understand the dynamics of specific components of cognitive domains that are categorically affected in the aging process. Rather than focusing on only what changes are taking place, new studies and researches started focusing on the why and how behind the changes in cognitive capacities. The present article provides a brief over view of some of the theories are approaches adopted in cognitive aging research and discusses the opportunities and challenges faced in it.

Keywords: *Cognitive Aging, Cognition, Intelligence, Neurocognition, Processing Speed, Memory, Attention*

Although many facets of human abilities remain constant over lifespan, but in many cases they evolve and develop as people grow old and gain maturity e.g. the ability to make sound decisions and good judgement. However, there is a widespread acceptance and agreement that, a gradual decline of cognitive functioning in multiple domains occur as people age, more specifically in middle and older ages. Cognitive domains such as speed of processing, episodic memory, verbal fluency, attention and executive functions clearly show major decline with aging. As cognitive functions play a key role in health, well-being and quality of life across lifespan, hence it is important to understand the relationship between aging and cognition. In a time period when the advancement of science and medicine has increased the life expectancy of people; understanding processes of aging that affect cognitive functioning and new interventions to maintain cognitive performance in older age (including making judgements, decision to work, retire, spend or save money and making decision on health and medical issues) is highly essential. Moreover, variances in patterns of cognitive aging are crucial to know its relationship among socio-cultural, economic, racial, educational, gender and health.

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Recent decades have witnessed an increase in research literature concerning the relationship between aging and cognitive functioning. According to the National Research Council's (NRC's) Research on Aging, featured in the Aging Mind: Opportunities in Cognitive Research, "Now is a time of great promise for learning more about the aging mind and turning that knowledge to the advantage of older people" (NCR, 2000). The committee reported that in research on cognitive aging in the area of behavioural science has made progress in "classifying types of cognitive functioning, measuring them, tracking changes in particular functions over the life cycle and documenting declines, maintenance and improvement in these functions over the lifespan" (NCR, 2000). It also observed that, "researches in cognitive sciences are developing detailed models and theories of cognitive processes that can help make sense of observed patterns of changes in neural systems (NCR, 2000).

Many significant advancement in developing theories and models of cognitive aging have taken place in last 5 decades. Though the study of aging mind has intrigued interest of behavioural scientists since long back but a systematic accumulation of data and development of theories occurred during 1960s. According to the article 50 Years of Cognitive Aging Theory published in the Journal of Gerontology: Psychological Sciences (Anderson & Craik, 2017), "Empirical proof of cognitive aging appeared in the 1930s, when Miles evaluated the perceptual, motor, and cognitive abilities of 1600 people aged 6 to 95 years old, and reported declines after age 30 in these skills, including learning ability (e.g., Miles, 1933). Age-related slowing emerged as a salient feature in the 1930s; the fact that most intelligence tests were speeded led Lorge (1940) to correct intelligence test data for speed of processing, finding that intelligence did not, in fact, decline with age. Lorge's discovery of the relationship between speed and intellectual capacity reminds us of Salthouse's later and more encompassing theory that age related changes in speed underlie changes in a number of cognitive domains (e.g., Salthouse, 1996)" (J Gerontol B Psychol Sci Soc Sci, 2017). It also states that, "1965 marked the beginning of a sea change in cognitive aging theory. This was the year that Welford and Birren (1965) published Behavior aging and the nervous system, a collection of chapters on slowing, attention, memory and their relationship with biological and health factors that together provide a strong foundation for cognitive aging theory" (J Gerontol B Psychol Sci Soc Sci, 2017). Understanding of the dynamics of cognitive aging has witnessed a tidal change in last 50 years. Many empirical studies have been conducted and theories have been developed which have given us an insight into the what, how and why of the changing components of aging mind. This paper is an attempt to assimilate and assess different theories of cognitive aging that have been pivotal in providing a coherent framework for scientific observation and explanation of changing faculties of cognition in aging population.

Environmental Changes: Historical Processes and Cultural Differences

Human development in part is a result of its interaction with its environment. And environment is not a static object, it changes over time. A comprehensive understanding of cognitive aging cannot be achieved isolating the effect of changing environment on cognition in aging population. Advocates of this viewpoint maintain that many age differences are a result of obsolescence and rapid environmental changes and not a true reflection of deterioration occurring within the individual e.g. G.V. Laboevie 1973; Laboevie-Vief,1976, 1977,1985; Laboevie-Vief, W.F. Hoyer, M.M. Baltes, & P.B. Baltes,1974; Schaie, 1974,1975,1980a, 1980b, 1984a; Schaie & Laboevie-Vief, 1974; Schaie & Strother,1968b (Salthouse,1991). The earliest study of time-lag reported by Tuddenham (1984) was a comparative study between 768 enlisted soldiers tested during

World War II in 1944, with the scores of 48102 enlisted soldiers tested in World War I. The study reported an estimate of .96 standard deviation of higher score performance in soldiers of 1944 than the soldiers in 1918, an apparent increase in intelligence of .037 standard deviation per year due to time-lag effect (Salyhouse,1991). In another study of time-lag effect conducted by Owens (1966) between the scores of 96 male college freshmen tested in 1919 with the scores of 101 male college freshmen tested in 1966. The result showed an average of .44 standard deviation higher performance among 1966 freshmen than 1919, noting an estimated increase of .010 standard deviation units over the 42 year period (Salthouse, 1991).

Many evidences suggest that culture influences cognitive behavioural function e.g. Nisbett, 2003; Nisbett, Peng, Choi, & Norenzayan, 2001 (Park, 2008). In his essay, 'Developing a Cultural Cognitive Neuroscience of Aging', Park (2008), has referred to the work of Nisbett while describing life experiences and culture sculpt neurocognitive function. According to Nisbett (2003), the fundamentally different philosophical views of Western and Eastern world from ancient times which still continues to persist have subtly shaped perception, memory, higher order cognition and social relationship (Nisbett & Masuda, 2003). It suggests that, Western thoughts are individualistic in nature which focuses on objects and its properties where as the Eastern thoughts have a holistic approach that views object as part of a greater whole. In the Work on perceptual processes using the Witkin Rod and Frame test, Ji, Peng, and Nisbett (2000) reported that East Asians were more dependent on field than the Westerners (Witkin & Berry, 1975). In a similar experiment Kitayama, Duffy, Kawamura, and Larsen (2003) found the difference between Japanese and Americans in the use of context to judge line length (Park, 2008).

Many facets of environment change with time and it is hence possible that these changing environments could have its influence on cognitive functioning of aging population. However, researches on time-lag effect and environmental and cultural change perspective only provides an idea of "why" the differences occur, where as the answer to "what" developmental changes occur in relation to environmental and cultural changes, what dimensions of environment influence these changes and "how" do they influence change still remains to be answered.

Neuropsychological factors

New advancements and research in neuroimaging studies have allowed us to understand and examine the relationship between cognition and the structural and functional role of brain in it. Like all other organs of the body, the brain also undergoes wear and tear throughout life. These structural changes on the brain affect its underlying function qualitatively and quantitatively. Since cognitive processes depend on brain anatomy and physiology, any age-related changes in the integrity of cerebral architecture and function are evidently observed in behavioural differences in aging. With the availability of high-resolution neuroimaging methods such as Positron Emission Tomography (PET), Magnetic Resonance Imaging (MRI) and Functional MRI (fMRI) researchers are able to understand the neural basis of cognitive aging. These neuroimaging studies indicate that while the brain undergoes significant structural change with age, age-related atrophy differs across and within regions (Dennis & Cabeza, 2008). Resting neuroimaging studies in volumetric measures of gray matter shows that the frontal lobes undergo the steepest rate of decline followed by parietal lobes, temporal lobes and occipital lobes. In a correlational study of structure and function of certain parts of the brain, Rodrigue and Raz (2004) studied the volumetric measures of prefrontal cortex (PFC), hippocampus (HC) and entorhinal cortex (EC) and measures of episodic memory in the age group of 26-83 years across 5 years interval. Multiple measures of episodic memory were administered at follow-up. Results indicated that the volume of HC and PFC (but not EC) correlated with age at baseline and follow-up. Another study by Persson and colleagues (2006) revealed reduced hippocampal volume in a group of older adults who suffered decline in episodic memory compared to older adults whose performance in episodic memory remained stable across a decade. Many of the research assessing the role of neurotransmitter in aging have focused on the role of dopamine (DA) and the findings are remarkably consistent (Dennis & Cabeza, 2008). The frontal lobe hypothesis of cognitive aging proposes that cognitive functions associated with frontal lobes specifically with Prefrontal Cortex (PFC) are more vulnerable to effect of aging than the functions associated with other area of the brain (Luszcz & Lane, 2008). MRI studies show that the structure of frontal lobes undergoes progressive change with advancement in age compared to others areas of the brain (Daigneault, Braun & Whitaker, 1992; West, 1996). Batteries designed by neuropsychologists to detect frontal lobe and executive dysfunctions in clinical patients have also shown poor performance among older adults in comparison to younger ones. Studies found similarities between the types of cognitive impairments in healthy older adults and patients with frontal lobe damage (Moscovitch & Winocur, 1992; Perfect, 1997). Similarly many PET and fMRI cognitive aging studies in the domains of visual perception (fischer et al., 2005; Gunning-Dixon et al., 2003; Iidaka et al., 2002), attention (Cabeza et al., 2004), language (Madden et al., 1996,2002), working memory (Cabeza et al., 2004; Reuter-Lorenz et al., 2000), executive function (Milham et al., 2002; nielson, Langenecker & Garavan, 2002; Smith et al., 2001), episodic memory, encoding (Dennis et al., 2006) and retrieval (Cabeza et al., 2004) have revealed two consistent patterns of brain activity related to aging i.e. a posterior-anterior shift in activity in older adults (PASA) (Grady et al., 1994) and a general reduction in the asymmetry of brain activity (HAROLD) (Cabeza, 2002). Both activation patterns exhibit same conclusions i.e. increased activation in prefrontal regions acts as a compensatory mechanism for age related deficits in other brain regions (occipital region in PASA and prefrontal cortex in HAROLD studies).

Existing evidence for age related changes in the structure and function of brain in neuroimaging studies are compelling. Advancement in neuroimaging methodologies and cognitive aging theories could be more explanative and predictive of not only what changes occur but also why these changes take place and how do these changes affect cognitive functioning of older adults.

Reduced Processing Resources

According to Salthouse (1991), the essence of reduced processing resources perspective is the hypothesis that many age differences in cognitive performance may be attributable to age related changes in a few relatively general factors or mechanisms. He classified the processing resources into three categories based on dominant characteristics used for processing resources. These categories of resources are (i) limitation of time, in the form of speed of processing; (b) limitation of space, in the form of reduced working memory capacity; (c) limitations of energy, in the form of limited attentional capacity.

Reduced Speed Processing

Cognitive processing speed is defined as the ability to process information rapidly. It is closely related to the ability to perform higher-order cognitive tasks (Lichtenberger and Kaufman, 2012). Deficit in speed of processing is therefore assumed to be the core issue responsible for deficits in performance on complex cognitive measures in aging populations (Salthouse, 1996; Salthouse and Ferrer-Caja, 2003). According to this theory, a major factor contributing to age-related differences in memory and other aspects of cognitive functioning is a reduction in the speed with which many cognitive operations can be executed (Salthouse, 1985). Salthouse (1996) explained low processing speed and impaired cognitive performance with two mechanisms: (i) limited time mechanism in which time required for the execution of earlier task reduces the available time required for later tasks, (ii) simultaneity mechanism in which products of early operations or tasks is lost or become irrelevant by the time later processing is completed. The fundamental principle behind the limited time mechanism is that slow processing might lead to incomplete operation of tasks and the underlying idea behind the simultaneity mechanism is either a high rate of errors or time-consuming repetitions of critical operations could occur as a result of impairments of critical operations, when all the relevant information are not available due to slow processing (Salthouse, 1996).

Recent theories of age and processing speed are the Sensory Deprivation hypothesis, the Common-Cause hypothesis, and the Information Degradation hypothesis (Ebaid et al, 2017). These theories suggest the age interaction between slow cognitive processing speed and declines in sensory function such as, visual and auditory. Baltes and Lindenberger (1997) had explained the link between sensory and cognitive decline as the "physiological architecture of the aging brain". Previous study of Lindenberger and Baltes (1994) had reported sensory motor variables such as visual acuity, balance-gait, and auditory acuity, predicted 59% of total reliable variance in general intelligence. As sensory functions, particularly vision and hearing are more likely to decline to age; the Sensory Deprivation hypothesis states that a lack of adequate sensory input over a prolonged period is likely to result in cognitive deterioration due to the prior neuronal atrophy (Oster, 1976; Valentijn et al., 2005). The Information Degradation hypothesis states that when perceptual signals are weakened or degraded, either due to experimental manipulations or age-related impaired perception, higher order cognitive processes are in turn affected (Schneider and Pichora-Fuller, 2000). The Common-Cause hypothesis suggests that concurrent peripheral and central decline occur simultaneously with declines in aspects of cognition, such as memory and processing speed (Fozard, 1990; Lindenberger and Baltes, 1994). Slower rates of processing have also been related to other cognitive phenomena in older adults such as, problem in divided attention due to slower alteration between simultaneous activities (Talland, 1968) and difficulty in comprehension due to slower rates of reception, perception and integration of new and stored information (Birren & Riegel, 1962; Salthouse & Kali, 1983). Several studies on processing speed and measures of memory performance including working memory, associative learning and free recall have also shown. In a meta analysis of cross sectional studies by Verhaeghen & Salthouse (1997), it was found that speed accounted for 70% of age related variance in episodic memory.

Reduced Working Memory Processing

According to Badeley (1986) Working Memory (WM) is the "total amount of mental energy available to perform on-line mental operations". Working memory can be conceptualised as the amount of cognitive resources available at any given moment to process information. It involves storage, processing and coordination of information which plays a contributing factor in the success of higher cognitive tasks such as planning, problem solving and reasoning. Basically, WM requires storage and processing and coordination of information simultaneously and the reduced WM processing theory suggests that limitation in any of these processes can be a source of age differences in WM (Salthouse, 1991). According to Baddeley (1986), effective encoding of information such as spoken sentences require WM to process previously learned information and simultaneously processing and integrating new information into a cohesive meaningful event. However, studies suggests that older adults lack the control processes required for switching between processing and storage tasks (Light & Albertson, 1988). Hasher & Zacks (1988) have reviewed that functional limitation of storage capacity which is hypothesised to be caused by the interference of irrelevant information are the major cause of age differences in working memory. Other researchers have argued that age related differences in working memory occur as the result of the limitations in the speed of processing (Hasher & Zacks, 1988). Studies on age and memory span also suggests that information coordination is a primary factor responsible for age differences in working memory and other aspects of cognitive functioning (Talland, 1968; Bopp & Verhaeghen, 2005). From overall review of literatures on working memory it could be suggested that the age differences in working memory occurs because of the differences in the limited operational and processing capacities of older adults and the simultaneous requirement of storing information.

Reduced Attention Processing

Attention can be described as a voluntary mental act involving two major aspects i.e. 1) selection of relevant information ignoring or inhibiting the irrelevant ones (selective attention) & 2) simultaneously attend and process information from multimodal environments (divided attention). Plude and Doussard-Rosevelt (1989) demonstrated that the attention-demanding task of conjunction search where two or more features must be searched reliably yields age-related differences in performance. In one of their conjunction task experiment where the subjects were asked to find a Red X in a field of Green Xs and Red Os, search rate was faster for younger adults relative to the older adults. However, these investigations also suggest that the age-related attention may be reduced if older people have previous knowledge or experience with the target and distracter information. For division of attention or attention switching which involves performing two or more tasks at the same time, evidence suggests that for simple tasks, younger and older adults can divide their attention equally well (e.g., Somberg & Salthouse, 1982) but for more complex tasks, the older adult's performance declines (e.g. Mc Dowd & Craik, 1988; Salthouse, Rogan & Prill, 1984). Many dual-task procedure studies have revealed that older adults showed more disruptions in secondary Reaction Time (RT) when tasks were performed simultaneously with primary tasks (Craik & McDowd, 1987; Nestor, Parasuraman & Haxby, 1989).

The reduced processing perspective categorically identifies certain constructs that are responsible for many of the age differences observed in cognitive functioning among younger and older adults. Though the studies reveal the categories of processing recourses, but the reason behind the decline in the resources and how this decline affects the cognitive functioning in older population is still to be discovered.

Executive Function (EF) and Cognitive Aging; A Confluence of Neuropsychology and Cognitive Psychology Approach

As a system of control processes EF may be interpreted to be responsible for planning, assembling, coordinating, sequencing and monitoring of other cognitive operation (Salthouse, Atkinson, & Berish, 2003). Friedman et al. (2017) have defined Executive Function (EF) as "high-level cognitive processes, often associated with the frontal lobes that control lower-level processes in the service of goal-directed behaviour. They include abilities such as response inhibition, interference control, working memory updating, and set shifting". Executive Function (EF) and its associated "frontal hypothesis" or "frontal-executive hypothesis" theory has become the focus of researchers in cognitive aging in recent years. Developments in the study of EF and aging have originated from the confluence of neuropsychology and cognitive psychology. The neuropsychological perspective of EF in aging focuses on the impairment in behaviour and cognitive performance as the consequence of neurological depletion in the frontal lobe and the Cognitive perspective refers EF as a collection of inter dependent higher order strategic mental processes associated with neuro-anatomical integrity of the brain (Luszcz, 2011).

Three analytical approaches have been mostly used to understand the effect of aging on EF and to identify the impact of these effects on other aspects of cognition. They include cross-sectional covariation, neurocognition and the process analysis approach (Braver & West, 2008). Cross-sectional approach studies have attempted to find out whether age related variation in measures of executive function covaries with other age related change in other measure of cognitive functions. Many cross-sectional covariation studies have demonstrated that individual differences in executive functions mediates age related decline in episodic memory, everyday living activities and other measures of cognition (Salthouse et al., 2003; Troyer, Graves, & Cullum, 1994). Neurocognition approach studies have tried to explain the anatomical and biochemical bases of age related decline in executive function. Studies using neuropsychological approach have mostly incorporated two types of scientific inquiry i.e. neuropsychological experimental tasks (e.g., Wisconsin Card Sorting Test (WCST), self order pointing (SOPT), trail making, verbal fluency etc.) and assessment of neurobiological effect on aging brain using non-invasive techniques (e.g., MRI, fMRI etc.). In the study conducted by Fristoe, Salthouse & Woodard (1997), adult age differences in Wisconsin Card Sorting Test (WCST) measures were examined before and after statistical control of age-related differences in measures of feedback usage, working memory, and perceptual-comparison speed and results were consistent with the idea that age-related performance differences in the WCST are partially mediated by adult age differences in feedback usage and that age differences in feedback usage are mediated by age differences in working memory, which are in turn-mediated by age-related reductions in processing speed, indexed by measures of perceptual-comparison speed. Similarly, studies on the relationship between cognitive functions and neuroanatomical and neurochemical have demonstrated that decline in grey matter volume in PFC are associated with cognitive impairments in tasks such as WCST and Tower of Hanoi (Gunning-Dixon &Raz, 2003) and most of the age related variances in tasks such as trail making and self order pointing (SOPT) are correlated to dopamine receptor binding (Cabeza, Nyberg, & Park, 2005; Backman & Farde, 2005). Process analysis studies seek to explain the cognitive processes that cause age-related decline on performances of different measures of executive function. Recent development in executive function studies have focused on the relationship between different cognitive functions related to executive control and their associated neuroanatomical functions. Number of studies on patients with PFC damage have showed disruption in process supporting activation, monitoring, inhibition and initiation (Stuss et al., 2002; Stuss, Floden, Alexander, Levine, & Katz, 2001).

Recent developments in the study of cognitive aging focusing on the effect of executive function on different domains of cognitive functions have been promising. The frontal executive hypothesis provides an understanding of age-related cognitive decline on neurobiological basis. However, further theoretical and empirical development is required to make it more explanative and predictive of brain-behaviour relation.

CONCLUSION

As Salthouse (1991) quotes, "… there is no magical panacea that automatically organizes and supplies insight into complex phenomena, both organisation and direction are primary functions, or at least major goals, of scientific theories i.e., theories are designed to provide a coherent framework within which a large number of observations can be assimilated, and to provide direction for research by imposing a set of priorities about the importance of different topics and issues." Theoretical understandings of different components of cognitive functioning which are affected by aging have witnessed a significant development in the past few decades. Initial cognitive aging researches were mostly descriptive. They focused mainly on the identification of different components of intellectual functioning, which affects older adults compared to younger adults. Mid 1960s, witnessed a widespread change in the approaches towards understanding the aging mind with an increasing interest to understand the dynamics of specific components of cognitive domains that are categorically affected in aging. Rather than focusing on only what changes are taking place, new studies and researches started focusing on the why and how behind the changes in cognitive capacities. Be it the role of environment and culture, neuropsychological factors, reduction in processing speed or the more contemporary Executive Function approach, the theories have provided an insight into the understanding of how and why cognitive functioning changes with age. Growing focus on the neurobiological basis of cognitive aging researches has been emerging to explain the brain-behaviour relationship. Researchers in cognitive science are developing detailed models and theories of cognitive processes that can help make sense of observed patterns of change in functioning and link them to observed changes in neural systems. Theories of cultural and environmental effects demonstrate the significance of life experiences and cultural difference in shaping the cognitive content and process over lifespan. These researches not only help in understanding the basis of changes in cognition in older age but also help making possible to develop interventions to maintain cognitive performance in older individuals and offers great promise for improving the lives of older citizens.

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