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The Mediating and Moderating Effects of Types of Internet Use in the Relationship between Age and Cognitive Function among Community-Dwelling Older Adults

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Abstract

Background: This paper examines whether various types of internet use mediated or moderated the relationship between age and cognitive function.
Methods: Using 2020 National Survey of Older Koreans, the data of 8,639 adults aged 65 or over were analyzed by complex sample analysis using chi-square test, t-test, multiple regression analysis, and Sobel's test.
Results: All types of internet use were significantly associated with cognitive function and played a significant mediating effect in the relationship between age and cognitive function. Internet use for information searching was the most protective for cognitive function (β=1.902, *P*<0.001), while Internet use for interpersonal communication exhibited the greatest mediating effect in the relationship between age and cognitive function (Age: β=–0.131, *P*<0.001→ β=–0.079, *P*<0.001). The influence of age on cognitive function moderated by all types of internet use.
Conclusions: This underscores the need to consider various types of internet use when creating nonpharmacological interventions aimed at delaying age-associated cognitive decline in community-dwelling older adults.

Keywords: Internet, Cognition, Aging, Elderly

INTRODUCTION

With increased life expectancy, decline of cognitive functioning has been of growing concern because of the potential to influence their quality of life, as well as the threat to autonomy and independence that older adults fear [1]. Thus, how to delay cognitive decline has become a focus in public health research [1]. Gaining knowledge on nonpharmacological strategies for slowing cognitive decline will have a beneficial effect on older adults, given the ongoing increase in the aging population.

A growing body of evidence revealed that cognitive function declines gradually with age [2], primarily as a result of structural and functional alterations in the aging brain [3]. As age increases, the brain undergoes a series of changes, including volume loss of gray and white matter, neurochemical alterations, blood flow reductions, and synaptic loss [3]. Meanwhile, research has demonstrated that it is possible to compensate for changes in the aging brain. The brain is capable of adapting to environmental demands and stimuli, especially when it comes to learning new processes, because of its capacity for neuroplasticity [4]. Some

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scenarios such as learning second language [5], formal education or exam preparation [6] have been reported to induce long term changes in the neuronal structures of the human brain. Recently, an increasing number of empirical studies have found that internet use may also entail cognitive advantages [7,8]. Using the internet can help older adults practice specific skills, enabling them to avoid losses and foster maintenance, which could bring about neural changes. In a study with large longitudinal datasets across 14 countries in Europe, internet use predicted positive change in cognitive functioning over the course of 2 years [7]. A systematic review examining clinical studies reported that use of the internet, including online training programs, may have a positive effect on the improvement of cognitive function in healthy older adults [8]. According to research, the influence of Internet use on the health outcomes of older adults varies depending on the types of internet use [9,10]. It is possible that different activities on the Internet are differently related with cognitive functioning (e.g., watching videos vs. interacting with others). Therefore, it is necessary to examine the impact of internet use on health outcomes based on different types of internet use.

Age differences in internet use among older adults have been well confirmed by many previous literature [11]. In the studies conducting age comparisons of older adults, a linear relationship is observed, with Internet use decreasing as age increases [12]. Age differences in Internet use may be attributed to age-related cognitive, physical, and perceptual changes, such as changes in cognitive processing speed, reduced ability to allocate attention effectively, decreased spatial abilities, diminished visual acuity, impaired hearing acuity, and declining motor skills [13]. Hence, online activities that demand advanced cognitive abilities, such as internet banking, online games, and commerce, may be more difficult for older adults than for young adults with higher cognitive functioning.

Given the previous literature, age is a significant determinant of both cognitive function and Internet usage. Moreover, it is plausible that internet usage among older adults may serve as a cognitive stimulant, potentially enhancing cognitive performance or even mitigating the progression of cognitive impairments [7,8]. The impact of internet usage on cognitive function of older adults may differ based on the specific types of internet activities they engage in. However, there is a dearth of research investigating the relationship among age, cognitive function, and internet usage across different types of online activities. Building on prior research, the hypothesis was that internet use could play a significant role in the relationship between aging and cognitive function. Importantly, it was anticipated that the strength of this influence would vary depending on the types of internet use. To improve understanding of the dynamics among age, cognitive function, and internet usage, the investigation focused on discerning the effects of diverse internet activities on cognitive function. Additionally, the aim was to elucidate the mediating and moderating effects that different types of internet use played in the relationship between age and cognitive function in older adults.

METHODS

Study design and participants

This was a cross-sectional study with secondary data from the 2020 National Survey of Older Koreans and was officially approved by the Institutional Review Board (IRB) of the Korea Institute for Health and Social Affairs (KIHSA IRB Number: 2020-36) [14]. The 2020 Living Profiles of Older People Survey involved a sample of community-dwelling older adults aged ≥65 years residing in 17 regions in both urban and rural areas of South Korea. A total of 10,097 adults aged ≥65 years participated in the survey, conducted between September 14 and November 20, 2020. A trained investigator visited the participant's home and collected data through tablet-based personal interviews. Those who responded via proxy or had missing data on cognitive impairment, household income, and internet usage were excluded from the analysis (i.e., cognitive impairment, household income, depressive symptoms, and internet use). Finally, 3,575 men and 5,064 women aged ≥65 years were included in the analysis.

Measurement

Cognitive function

Cognitive function was assessed using the Korean version of the Mini-Mental State Examination for Dementia Screening (MMSE-DS) [15]. The MMSE-DS consists of 19 items measuring general cognitive function, including time and place orientation, memory, attention, command execution, naming, copying interlocking pentagons, and judgement. The total score is calculated by summing all items, ranging from 0 to 30. Participants were classified into the categories "cognitively intact" and "cognitively impaired" using the criterion score based on sex, age, and educational level. Cognitive impairment was iden-

tified as scores falling 1.5 standard deviations (SDs) below those expected for the age and education levels of older Korean adults [15]. This standardized test has demonstrated reliability and validity for screening cognitive impairment, including dementia. The Cronbach's alpha coefficients of this scales were 0.826 [15], and Cronbach's alpha in this study was 0.82.

Types of internet use

Based on previous literature [10], types of internet use were divided into four categories: instrumental use, interpersonal communication, entertainment, and information searching. Each participant was presented with examples of 11 types of internet activities using a Personal computer, smartphone, or tablet and asked to respond to each one. Internet use for instrumental purposes was assessed through three questions and coded as 1 if the respondent used it for shopping, internet banking, and application installations. Internet use for interpersonal communication was measured through three questions, with a score of 1 assigned if the respondent used it for sending and receiving messages and various social network services (SNS) activities. Internet use for entertainment was evaluated via four questions, with a score of 1 assigned if the respondent reported using the internet for activities such as watching videos/movies, listening to music, playing games, and taking photos. Internet use for information searching was measured using one question and coded as 1 if the respondent used it for searching for information like news and daily weather. Total internet usage was calculated by the sum of the scores across all types of internet use.

Covariates

Sex (male, female), living arrangement (living alone or not), residence (urban or rural), education, equivalent annual household income, economic activity (yes, no), self-rated health (SRH), and Instrumental Activities of Daily Living (IADL) [16], depressive symptoms were included as covariates. Education level was classified as uneducated, elementary school, middle school, high school or above. Equivalent annual household income (total household income divided by the square root of the number of household members) was calculated and divided into quartiles to detect a nonlinear relationship. IADL was measured using the Korean-version of IADL scale. This scale includes 10 items with scores of 1 point for complete independence, 2 point for partial help, and 3 point for complete help), which higher scores indicate greater dependence. Participants requiring assistance with any of the 10 items were categorized as 'IADL dependent,' whereas those who were completely independent were categorized as 'IADL independent.' Depressive symptoms were evaluated using the Short-form of Geriatric Depression Scale-Korean version (SGDS-K). The Geriatric Depression Scale was developed by Sheikh and Yesavage [17] and translated into South Korean by Bae and Cho [18]. Its 15 items include five positive and 10 negative feelings for the previous week, where each is scored as negative (1) or positive (0); the total score ranges from 0 to 15. The five items with positive feelings are inverted, and higher summed scores indicate more severe depression. The SGDS-K has demonstrated high reliability (Cronbach's alpha of 0.90) and validity [19]; Cronbach's α coefficient in this study was 0.827. A Korean community-based study identified an optimal SGDS-K cut-off score of 8 or higher for the screening of major depressive disorders [19]. SRH was measured using the question "How would you rate your health in general?" (1=very good, 2=good, 3=fair, 4=poor, and 5=very poor), and then coded dichotomously (0=very good/good, 1=fair/poor/very poor).

Statistical analysis

The data were expressed as the frequencies, weighted proportions, and mean±SD of the baseline characteristics of cognitive impairment. The chi-square test and t-test were used to compare the distribution of these frequencies and means between older adults who were cognitively intact and those who were cognitively impaired (Table 1). A multiple linear regression analysis was conducted to examine the relationships among age, cognitive function, and internet use and the mediating and moderating effects of the various types of internet use after adjusting for covariates (Table 2). According to Baron and Kenny [20], in step 1, the outcome variable (cognitive function) was regressed on the independent variable (age). In step 2, presumed mediators (types of internet use) were regressed on the independent variable (age), respectively. In step 3, presumed mediators (types of internet use) were added to the model in step 1. The Sobel test was conducted by using an interactive calculation tool for mediation tests (http://quantpsy.org/sobel/sobel.htm). In model 3, we included interaction terms for age and each type of internet usage as a moderator. This was done to examine whether the relationship between age and cognitive function differed depending on the specific type of internet use. In all analysis, a *P*-value of <0.05 was considered to indicate statistical significance. All statistical tests were conducted using the IBM SPSS software ver. 27.0 for Windows (IBM Corp.).

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Table 1. Characteristics of the participants by cognitive impairment

Variable	Total	Cognitively intact	Cognitively impaired	*P*-value
Participant	8,639 (100.0)	6,493 (75.2)	2,146 (24.8)	
Sex				
Male	3,575 (44.2)	2,654 (44.2)	921 (44.1)	0.004
Female	5,064 (55.8)	3,839 (55.8)	1,225 (55.9)	
Age (yr)	73.22±6.26	72.60±6.18	73.96±6.47	<0.001
65–69	3,274 (35.9)	2,599 (37.7)	675 (30.2)	<0.001
70–74	2,189 (23.9)	1,641 (23.8)	548 (24.4)	
75–79	1,661 (22.4)	1,188 (21.6)	471 (24.8)	
≥80	1,515 (17.8)	1,065 (16.9)	450 (20.6)	
Education				
Uneducated	841 (9.0)	684 (9.8)	157 (6.4)	<0.001
Elementary school	2,757 (30.1)	2,077 (30.2)	680 (29.7)	
Middle school	2,059 (23.6)	1,360 (20.7)	699 (32.4)	
High school or over	2,982 (37.3)	2,372 (39.2)	610 (31.4)	
Living arrangement (living alone)				
No	5,951 (59.7)	4,536 (80.8)	1,415 (78.1)	<0.001
Yes	2,688 (40.3)	1,957 (19.2)	731 (21.9)	
Equivalent household income				
Highest 25%	2,262 (28.8)	1,823 (30.4)	439 (24.0)	<0.001
Second 25%	2,165 (26.2)	1,645 (26.1)	520 (26.6)	
Third 25%	2,079 (22.4)	1,467 (21.2)	612 (26.2)	
Lowest 25%	2,133 (22.6)	1,558 (22.4)	702 (23.1)	
Residency area				
Urban	6,236 (76.1)	4,747 (76.7)	1,489 (74.3)	0.08
Rural	2,403 (23.9)	1,746 (23.3)	657 (25.7)	
Economic activity				
No	5,240 (61.1)	3,821 (58.9)	1,419 (67.9)	0.001
Yes	3,399 (38.9)	2,672 (41.1)	727 (32.1)	
Dependence of IADL				
No	780 (9.7)	454 (7.5)	326 (16.7)	<0.001
Yes	7,859 (90.3)	6,039 (92.5)	1,820 (83.3)	
Depressive symptoms				
No	6,153 (71.2)	4,821 (74.2)	1,332 (62.1)	<0.001
Yes	2,486 (28.8)	1,672 (25.8)	814 (37.9)	
Self-rated health				
Good	4,463 (51.2)	3,581 (55.0)	882 (39.6)	<0.001
Fair	2,710 (30.8)	1,934 (29.4)	776 (35.2)	
Bad	1,466 (17.9)	978 (15.6)	488 (25.2)	
Internet use	1.23±1.04	1.35±1.06	0.87±0.87	
Instrumental use	0.10±0.25	0.11±0.27	0.04±0.15	<0.001
Interpersonal communication	0.57±0.34	0.61±0.33	0.47±0.35	<0.001
Entertainment	0.41±0.47	0.46±0.49	0.26±0.40	<0.001
Information seeking	0.46±0.50	0.51±0.50	0.31±0.46	<0.001

Values are presented as number (weighted %) or mean±standard deviation.
IADL, Instrumental Activities of Daily Living.

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Table 2. Mediating and moderating effects of each type of internet use on the relationship between age and cognitive function

Variable	Model 1 (age→cognitive function)		Model 2 (age→types of internet use)		Model 3 (types of internet use →cognitive function)		Model 4 (mediating effect)		Model 5 (moderating effect)	
	B	*P*-value	*B*	*P*-value	*B*	*P*-value	*B*	*P*-value	*B*	*P*-value
Age	−0.131	<0.001	−0.019	<0.001			−0.117	<0.001	−0.108	<0.001
Use for instrumental service					0.841	<0.001	0.724	<0.001	0.964	<0.001
Agexuse for instrumental service									0.049	0.013
Adjusted R^2	0.164		0.149		0.160		0.173		0.173	
Sobel test statistics (*P*)							−8.46	<0.001		
Age	−0.131	<0.001	−0.055	<0.001			−0.079	<0.001	−0.073	<0.001
Use for interpersonal communication					1.097	<0.001	0.936	<0.001	0.915	<0.001
Agexuse for interpersonal communication									0.022	0.008
Adjusted R^2	0.164		0.400		0.179		0.184		0.185	
Sobel test statistics (*P*)							−12.88	<0.001		
Age	−0.131	<0.001	−0.064	<0.001			−0.097	<0.001	−0.072	<0.001
Use for entertainment use					0.638	<0.001	0.528	<0.001	0.654	<0.001
Agexuse for entertainment use									0.047	<0.001
Adjusted R^2	0.164		0.320		0.170		0.178		0.181	
Sobel test statistics (*P*)							−11.22	<0.001		
Age	−0.131	<0.001	−0.026	<0.001			−0.090	<0.001	−0.075	<0.001
Use for information searching					1.902	<0.001	1.559	<0.001	1.707	<0.001
Agexuse for information searching									0.085	<0.001
Adjusted R^2	0.164		0.351		0.171		0.178		0.180	
Sobel test statistics (*P*)							−11.37	<0.001		

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RESULTS

Participants' characteristics

Table 1 shows the descriptive statistics of the participants. Proportions were weighted according to the sample design. Among the study participants, the mean age was 73.22 years. There was a significant difference between the mean ages of the cognitively impaired (73.96 years) and those of the cognitively intact (72.60 years). The percentage of participants with high school education and over was higher among the cognitively intact (39.2%) than among the cognitively impaired (31.4%), and over half of the participants were living with others (59.7%) and lived in urban area (76.1%). The percentage of those who participated in economic activity was higher among the cognitively intact (41.1%) than among the cognitively impaired (32.1%). The majority of the participants were independent in IADL. The incidence of depression was higher among the cognitively impaired (37.9%) than among the cognitively intact (25.8%). Among the cognitively intact, more than half self-reported their health as good (55.0%), whereas among the cognitively impaired, less than half reported it as good (39.6%).

As for the assessment of various forms of internet use, each score of internet use was divided by the number of items assessing the types of internet use to compare the amount of each type of internet use. The mean score for interpersonal communication was the highest, while that for instrumental use was the lowest, both among the cognitively intact and the cognitively impaired. The mean score of all types of internet use among cognitively intact older adults (mean, 1.35) was significantly higher than that in cognitively impaired older adults (mean, 0.87) (P<0.001).

Mediating and moderating effects of each type of internet use on the relationship between age and cognitive function

Table 2 shows the results of a multiple linear regression analysis to evaluate the impact of each type of internet use on cognitive function as well as the mediating and moderating effects after controlling for covariates (sex, education, living arrangement, religion, residency area, equivalent household income, economic activity, dependency of IADL, and depression). The results of the three-step regression analysis to identify the mediating effect of each type of internet use between age and cognitive function was presented (Table 2). As a result of regression analysis of step 1, the independent variable, age, had a significant effect on the dependent variable, cognitive function (β=–0.131, P<0.001). In step 2, the significant effects of independent variable, age, on each type of internet use were confirmed. In step 3, it was found that each type of internet use significantly influenced cognitive function. In step 4, it was examined whether the influence of age on cognitive function mediated by each type of internet use disappears or decreases. As a result, although the inclusion of each type of internet use caused the β value for age regarding cognitive function to change, all remained significant, indicating partial mediation. In the Sobel test for the mediating effect of each type of internet use, the absolute value of Z was 1.96 or higher, indicating the significance of the mediating effect of each type of internet use.

We examined whether each type of internet use have a moderating effect on the relationship between age and cognitive function among the elderly (Table 2). When introducing the interaction term between age and each type of internet sue for analysis, it was found that all the interaction term between age and each type of internet use showed a significant relationship, increasing the explanatory power. Therefore, it was confirmed that there is a moderating effect by each type of internet use in the relationship between age and cognitive function.

DISCUSSION

This study explored the varied effects of different types of internet usage on cognitive function, as well as the mediating and moderating effects that various internet activities play in the relationship between age and cognitive function within a representative sample of Korean older adults. In line with previous study [2], all types of internet use were associated with cognitive function, with the greatest influence observed in the use of internet for information searching. Internet searching activates a greater number of brain circuits in older persons compared to reading text pages [21]. According to the technological reserve hypothesis, technology use protects cognitive capacities by offering cognitive stimulation, which may reduce the possibility of developing dementia [22]. That is, the cognitive stimulation facilitated by internet use establishes a cognitive reserve buffer that sustains recovery from functional brain damage and promotes resilience, thereby preventing or delaying the onset of cognitive impairment [23]. Meanwhile, although using the internet for entertainment and instrumental services is a source of constant cognitive stimulation [2], the impact of those activities on cognitive function was even lower than that of interper-

sonal communication use. This finding diverges from a recent meta-analysis in younger samples reporting that cognitively demanding games have larger impacts on cognitive functioning compared to social simulation or puzzle video games [24]. As for internet use for entertainment in this study, most participants engaged in less cognitively demanding activity than playing games (taking photos and videos, 51.9%; watching digital contents on YouTube, 33.2%; listening to music, 25.7%; playing games, 15.3%) (data was not shown). Watching YouTube is an activity of simply getting information by clicking on a link sent via peer-to-peer messengers. Furthermore, using instrumental services like online shopping, banking, booking systems, and so on is more difficult for older adults compared to searching for information like weather, news, and health-related information on Internet portal sites, because using these instrumental services requires more cognitive endeavors (at least in the beginning). In this study, the mean score of instrumental internet use was the lowest among four types of internet use. Therefore, owing to the lower percentage of older adults playing online games and difficulty in the use of instrumental services, we presume that the impacts of internet use for entertainment and instrumental use on cognitive function were lower than those of other types of internet activities.

This study also revealed that all types of internet use mediated the influence of age on cognitive function. Unexpectedly, as opposed to the relationship between types of internet use and cognitive impairment, internet use for interpersonal communication exhibited the greatest mediating effects on cognitive function, compared to other types of internet use. Engaging in non-communicational activities, such as searching for information, internet banking, e-commerce, and online games, is an intellectually stimulating activity that requires higher cognitive ability and advanced digital skills. Conversely, internet use for the interpersonal communication in this study predominantly involved receiving messages (80.1%), sending messages (68.5%), and participating in SNS (22.9%), which typically do not demand higher abilities (data was not shown). There could be possibly two explanations; firstly, using the internet with basic skills may also be cognitively stimulating. Research has demonstrated that even simple interactions with the Internet via the smartphone's touchscreen interface can cause long-lasting neurocognitive alterations due to neural changes in brain areas associated with sensory and motor processing of the hand and thumb [25]. Secondly, staying in touch with family and friends, even when geographically separated, can foster a sense of belonging and social support, which may positively influence cognitive function in older adults. Previous literature found that using the internet for communication purposes was associated with lower depression, better life satisfaction [9], decreased loneliness, and increased social engagement [10], whereas using the internet for information access was associated with lower life satisfaction [9]. It has been known that depression is an important predictor of cognitive decline and greater loneliness is associated with lower cognitive function in older adults [26]. Moreover, those using the Internet for interpersonal contact are likely to have more social connections and social support than those who use it for solitary activities (e.g., Web surfing) [27]. A growing body of literature has described the beneficial impact of social interaction and detrimental impact of social isolation on cognitive function in older adults [28]. The stress buffering theory, which suggests that social relationships may lead to positive health and cognitive outcomes by alleviating the detrimental effects of stress, may explain the beneficial effect of social support on cognition [29]. Therefore, the impact of internet usage for interpersonal communication on cognitive function may not solely result from participating in cognitively demanding activities. Rather, it could be largely influenced by the improved mental well-being and social connections fostered through communication with family and friends.

An examination of the relationship between cognitive function and the interplay of age and internet usage revealed that while older adults typically exhibit lower cognitive function levels, higher levels of internet use moderate this association, such that the difference in cognitive function between older and younger individuals is less among those with more frequent internet use. This suggests that despite the natural neurobiological changes associated with aging, activities like internet use, which demand cognitive engagement, may improve brain function and potentially delay cognitive decline in older individuals by mitigating the adverse effects of aging [7,8]. This finding aligns with prior research indicating positive effects on cognitive function from digital interventions in healthy older adults [30]. The results underscore the potential for various types of internet use to contribute to cognitive plasticity in later life and shed light on the underlying mechanisms linking age, cognitive function, and internet usage. Notably, these findings offer empirical support for the value of digital education for older adults and interventions involving diverse internet activities in promoting cognitive health and offer insights for the development of strategies to preserve cognitive function among older populations.

This study presents several limitations. Firstly, a single-item measure of Internet use restricts the depth of insight into participants' actual online behaviors and may compromise reliability. Future research should consider employing a more comprehensive assessment, encompassing variables such as frequency of use, duration of online activity, and digital proficiency levels. Secondly, this study is its cross-sectional design, which prevents the establishment of causal relationships among age, cognitive function, and internet use. A longitudinal approach would enable a more nuanced understanding of these dynamics, allowing for the assessment of potential causal pathways. Thirdly, although important confounders were controlled in this analysis, the presence of unmeasured confounders could remain due to data limitations. Lastly, it is plausible that the association between different types of internet use and cognitive function varies across specific cognitive domains. Investigating these relationships in future research is imperative for a more thorough understanding of how internet usage impacts cognitive function.

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AUTHOR CONTRIBUTIONS

Dr. Kyungwon CHOI had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. Author reviewed this manuscript and agreed to individual contributions.

Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Writing–original draft, Writing–review & editing: KC.

CONFLICTS OF INTEREST

No existing or potential conflict of interest relevant to this article was reported.

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DATA AVAILABILITY

The data presented in this study are available from: https://data.kihasa.re.kr/kihasa/kor/contents/ContentsList.html

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