Internet use by middle-aged and older adults: Longitudinal relationships with functional ability, social support, and self-perceptions of aging

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Abstract

In an increasingly digital world, those who remain offline may face greater challenges across multiple contexts of everyday life. Besides being less likely to be internet users, older age groups go online less frequently and for fewer activities. Understanding which factors facilitate or prevent internet use in later life is therefore essential to minimize existing age-based digital inequalities. Based on the 2014 and 2017 waves of the German Ageing Survey, comprising 3,479 respondents aged 40 years and older, this study examined the longitudinal relationships of a wide range of often overlooked, yet potentially relevant factors related to functional ability, social support, and self-perceptions of aging with general internet use and seven specific online behaviors. As the only factors relating to general use and a considerable number of specific uses, cognitive functioning and competence-related self-perceptions of aging emerged as the most important correlates of internet use in middle and late adulthood. Better cognitive functioning preceded contacting friends, acquaintances, and relatives, searching for information, banking, and shopping more frequently three years later. In turn, competence self-perceptions of aging preceded contacting others, searching for new social contacts, seeking information, banking, engaging in online entertainment, and creating contents more frequently three years later. Reciprocal relationships were also found between each factor and general use, suggesting mutual influences. Additionally, physical functioning and received informational support preceded greater use for specific activities. These findings elucidate which factors to consider when developing effective strategies to promote general and specific internet use among middle-aged and older adults.

Keywords: technology, cognitive function, social support, perceptions of aging, stereotype.

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Information and communication technologies have progressively shaped almost every aspect of everyday life over the past few decades. A key driver of this digital transformation, the internet has fundamentally changed how individuals communicate with each other, access and share information, purchase products and services, or spend their free time. Inevitably, those who remain offline are likely to face greater challenges across different social spheres. The COVID-19 pandemic is perhaps the most striking example of the overlap between digital and social inequalities, with digitally excluded individuals experiencing more difficulties in adapting to rapid social changes (Beaunoyer, Dupéré, & Guitton, 2020; Seifert, Cotten, & Xie, 2021). Age remains an important dimension of digital inequality. Despite substantial increases in adoption rates over the years, older age groups are less likely to be internet users, besides going online less frequently and for fewer activities (Brandtzæg, Heim, & Karahasanović, 2011; König, Seifert, & Doh, 2018; Organization for Economic Cooperation and Development [OECD], 2020; Pew Research Center, 2017). Identifying the factors facilitating or preventing internet use in later life is thus critical to inform interventions and policies aiming to minimize existing digital inequalities between generations.

Theoretical models, such as the technology acceptance model (TAM; Davis, Bagozzi, & Warshaw, 1989) and the unified theory of acceptance and use of technology (UTAUT; Venkatesh, Morris, Davis, & Davis, 2003), have been widely applied to understand technology use in general (e.g., Macedo, 2017; Mariano et al., 2021b) and internet use in particular (e.g., Pan & Jordan-Marsh, 2010; Ramón-Jerónimo, Peral-Peral, & Arenas-Gaitán, 2013) among older age groups (for reviews, see Chen & Chan, 2011; Ma, Chan, & Teh, 2021). However, TAM and UTAUT have also been criticized for overlooking biophysical and psychosocial characteristics, abilities, and problems experienced by aging individuals that likely influence their use behaviors (Chen & Chan, 2011). This led to theoretical extensions, such as the senior technology acceptance model (STAM, Chen & Chan, 2014), which propose that, in addition to sociodemographic factors and TAM and UTAUT core constructs, factors related to health status (e.g., functional ability), social relationships (e.g., social support), and attitudes towards aging (e.g., self-perceptions of aging) also influence technology use in later life. Despite receiving some support as relevant correlates of general use of everyday technology (Chen & Chan, 2014; Gell, Rosenberg, Demiris, LaCroix, & Patel, 2015; Kamin, Beyer, & Lang, 2020; Mariano, Marques, Ramos, & de Vries, 2021a), the role of functional ability, social support, and self-perceptions of aging on internet engagement in middle and late adulthood remains largely overlooked and understudied, with existing evidence being mostly based on cross-sectional designs and global assessments of multidimensional factors. To overcome these limitations, the present study investigated the longitudinal relationships of multiple dimensions of functional ability, social support, and self-perceptions of aging with internet use among middle-aged and older adults.

Functional Ability

Interacting with information and communication technology involves the coordination of cognitive, physical, and perceptual abilities (Charness & Boot, 2009; Rogers, Stronge, & Fisk, 2005b). For this reason, age-related changes in functioning have long been acknowledged as potential barriers to internet engagement in later life (Becker, 2004). Among these functional domains, cognitive functioning is perhaps the most studied correlate of internet use (Czaja et al., 2006; Freese, Rivas, & Hargittai, 2006). Multiple studies have shown that cognitive abilities, such as working memory and processing speed, are important predictors of internet-based task performance, such as information searching (Czaja et al., 2013; Sharit, Hernández, Czaja, & Pirolli, 2008; Sharit, Taha, Berkowsky, Profita, & Czaja, 2015). Longitudinal evidence further indicates that better cognition is reciprocally related to greater use, suggesting that internet use is both determined by and a determinant of cognitive functioning (Kamin & Lang, 2020; Yu & Fiebig, 2020). Reciprocal relationships have also been found between cognitive functioning and general use of information and communication technology (Choi, Wisniewski, & Zelinski, 2021; Hartanto et al., 2020; Mariano et al., 2021a).

Compared to cognition, the roles of physical and perceptual functioning have been considerably less studied. Declines in motor control and coordination, coupled with the propensity to develop disabling conditions, may compromise how individuals physically interact with technology, for example, when using a computer mouse or a touch screen (Rogers, Fisk, McLaughlin, & Pak, 2005a; Smith, Sharit, & Czaja, 1999). However, existing evidence on the relationship between physical functioning and internet use is mixed. Gell et al. (2015) found that those with better physical functioning were more likely to use the internet for online activities related to communication, health, shopping, and banking. In contrast, Choi and DiNitto (2013a, 2013b) observed that physical functioning was unrelated to internet use for similar purposes. Perceptual ability may also be essential in learning and maintaining the regular use of information and communication technology. Regarding internet use, existing evidence suggests that visual functioning plays an important role, with better vision being consistently associated with greater use (Choi, DiNitto, Lee, & Choi, 2020; Echt & Burridge, 2011; Gell et al., 2015). Overall, better functional ability in its various domains should relate to greater internet use.

Social Support

Although help and support offered by family, friends, and other members of their social network can facilitate individuals' engagement with information and communication technology (Peek et al., 2016), social support remains an understudied correlate of internet use in later life. Greater perceptions of social support have been shown to be associated with higher levels of technology use in general and internet use in particular (Chan, 2018; Erickson & Johnson, 2011; Heo, Chun, Lee, Lee, & Kim, 2015); (for a review, see Fuss, Dorstyn, & Ward, 2019). Yet, these findings are mainly interpreted and discussed in terms of the potential of technological tools to foster supportive relationships through online interactions, even though their predominantly cross-sectional nature does not clarify this assumed directional influence. Although some intervention studies corroborate the argument that internet use enhances perceptions of social support (Cody, Dunn, Hoppin, & Wendt, 1999; Czaja, Boot, Charness, Rogers, & Sharit, 2018), there is also evidence of mutual influences. Cody et al. (1999) found that older adults with higher perceived social support were more likely to complete an internet training program and that these perceptions further improved over its four-month duration. Nonetheless, social support did not relate to time spent online nor use frequency for various online activities, suggesting that its role as an antecedent may be limited.

Furthermore, existing research does not fully elucidate how different types of social support relate to internet use. A distinction is often made between support received in the past and support perceived as available in the future (Schwarzer & Knoll, 2007). Kamin et al. (2020) found that received technology-related support was directly associated with using more technological devices while perceived support was only indirectly associated, indicating that actually receiving social support may be more influential than its perceived availability. Among other relevant distinctions (Cohen, 2004), social support is also differentiated into informational support (e.g., giving advice and guidance) and emotional support (e.g., offering empathy and caring). Informational support, for example, in the form of advice on which online activities one should try or guidance on how one should perform certain tasks, has been suggested as an important facilitator of technology use in later life (Francis, Kadylak, Makki, Rikard, & Cotten, 2018; Luijkx, Peek, & Wouters, 2015). Overall, greater social support should relate to greater internet use, although some types of support may be more influential than others.

Self-Perceptions of Aging

Stereotypical perceptions of age and aging are important determinants of behavior and health in late adulthood (Meisner, 2012; Westerhof et al., 2014). The aging process is commonly expected to entail losses and declines (Heckhausen, Dixon, & Baltes, 1989) and older people are generally considered less competent than other groups (Cuddy & Fiske, 2002). This also applies to the technological domain. Older age groups are perceived as less capable of engaging in computer- and internet-related activities, such as shopping online, and these views are held by older individuals themselves (McGregor & Gray, 2002; Ryan, Szechtman, & Bodkin, 1992; Swift, Abrams, & Marques, 2013). According to stereotype embodiment theory (Levy, 2009), stereotypical perceptions of age and aging become increasingly self-relevant as individuals age, eventually being internalized as perceptions about themselves and their own aging, or self-perceptions of aging (Kornadt & Rothermund, 2012; Kornadt, Voss, & Rothermund, 2017). The internalization of incompetence stereotypes into self-perceptions of aging, particularly those associated with technological inability, may thus undermine individuals' perceptions about their ability to use technology successfully and ultimately compromise their use behaviors.

Although some studies found positive self-perceptions of aging to be generally associated with greater use of information and communication technology (Chen & Chan, 2014; Mariano et al., 2021a), existing evidence on internet use is mixed, with studies suggesting that self-perceptions of aging determine, but are not determined by, internet use (Cody et al., 1999) and studies indicating the exact opposite (Köttl, Cohn-Schwartz, & Ayalon, 2020). Since Cody et al. (1999) found self-perceptions of aging to be associated with time spent online and internet use for news but not for other activities, a more detailed look at the relationships between different dimensions of self-perceptions of aging and different purposes of internet use may help clarify these divergent findings. Overall, positive self-perceptions of aging, particularly those associated with competence, should relate to greater internet use, as their influence is stronger when the stereotypical perceptions match the behavioral outcomes (Levy & Leifheit-Limson, 2009) and technology-related behaviors are perceived as requiring high competence (Ryan & Heaven, 1988).

The Present Study

Based on the 2014 and 2017 waves of the German Ageing Survey, this study aimed to investigate the longitudinal relationships of relevant dimensions of functional ability, social support, and self-perceptions of aging with general internet use among individuals aged 40 years and older, controlling for known sociodemographic predictors of use behavior. Overall, we hypothesized that better functional ability (i.e., better cognitive, physical, and visual functioning; hypotheses 1.1, 1.2, and 1.3, respectively), higher social support (i.e., higher informational and emotional received support and higher perceived support; hypotheses 2.1, 2.2, and 2.3, respectively), and positive self-perceptions of aging (i.e., positive competence, physical, and social self-perceptions of aging; hypotheses 3.1, 3.2, and 3.3, respectively) would be associated with greater internet use three years later.

As secondary goals, this study sought to address several limitations of past research on factors influencing internet use in later life. First, most studies have opted for cross-sectional designs, which preclude inferences about directionality and causality. Alternatively, longitudinal designs permit describing the temporal and directional relationships between factors over long time periods. To clarify previous cross-sectional findings and identify potential mutual influences, we conducted an autoregressive cross-lagged panel analysis to test reciprocal relationships. Second, most studies have relied on general indicators of use behavior, often comparing users with nonusers, which limit a more nuanced understanding of its predictors. Besides having lower levels of general use, older age groups tend to engage in fewer online activities (Brandtzæg et al., 2011; Czaja et al., 2006). To identify the factors relating to internet use for different purposes, we further examined the longitudinal relationships with seven specific online behaviors: contacting friends, acquaintances, and relatives; searching for new social contacts; searching for information; banking; entertainment; shopping; and creating own contents. Third, most studies have focused on older adults, despite evidence that middle-aged individuals also report lower levels of internet use compared to younger groups (Brandtzæg et al., 2011; Czaja et al., 2006). Middle-aged adults also experience age-related changes in functional ability (Salthouse, 2009), value social support as an important facilitator of technology use (Morris & Venkatesh, 2000), and tend to be negatively stereotyped regarding their technological competence, especially in the workplace (Sharit, Czaja, Hernandez, & Nair, 2009). Given the wide age range of the study sample and the possible relevance of functional ability, social support, and self-perceptions of aging to internet engagement in middle and late adulthood, we conducted multigroup analyses to examine potential differences between middle-aged and older adults.

Method

Participants

The German Ageing Survey (DEAS, Klaus et al., 2017) is a nationally representative survey of the German population aged 40 years and older. The DEAS is organized by the German Centre of Gerontology (DZA) and funded by the German Federal Ministry for Family Affairs, Senior Citizens, Women, and Youth (BMFSFJ). Data collection comprises a computer-assisted personal interview and a self-completed drop-off questionnaire. In the 2014 and 2017 drop-off questionnaires, respondents who indicated having access to the internet subsequently reported their frequency of use for specific activities. Thus, the present study is based on all respondents aged 40 years and older who completed the drop-off questionnaire and reported having internet access at both waves (2014=Time 1 [T1] and 2017=Time 2 [T2]; n=3,479).

A logistic regression was performed to examine potential differences between those with and without internet access among respondents aged 40 years and older who completed the drop-off questionnaire at 2014 and 2017 (n=4,871). The dependent variable was coded 1 (*with internet access at both waves*) and 0 (*without internet access in at least one wave*). All covariates were included as independent variables. Age (b=-0.12, Wald $\chi^2(1)$=363.57, p<.001), gender (b=-0.27, Wald $\chi^2(1)$=9.81, p=.002), marital status (b=0.30, Wald $\chi^2(1)$=4.36, p=.037), living arrangements (b=0.33, Wald $\chi^2(1)$=4.24, p=.040), region (b=-0.73, Wald $\chi^2(1)$=62.68, p<.001), education (b=0.99, Wald $\chi^2(1)$=150.66, p<.001), and income (b=3.22, Wald $\chi^2(1)$=179.33, p<.001) were significant predictors, with individuals who were younger, male, married, living alone, in West Germany, and had higher income and education levels being more likely to have internet access. Nonetheless, the majority of respondents reported having internet access at both waves (71.42%). Among them, almost all had access at home (98.68%) and almost one third had access at work (34.49%) at baseline.

Measures

Unless otherwise indicated, responses were reverse coded as appropriate so that higher values reflected greater levels of the corresponding construct.

Functional Ability

Cognitive functioning was assessed with the Digit Symbol Substitution Test (Wechsler, 1955), a measure of processing speed that is indicative of age-related changes in global cognition (Hoyer, Stawski, Wasylyshyn, & Verhaeghen, 2004; Salthouse, 1996). Based on a code pairing symbols with digits 1 to 9, participants were asked to copy the symbol matching each digit presented on a list within 90 seconds. Cognitive functioning was coded as the total number of correct responses, ranging from 0 to 93, divided by 93 to facilitate interpretation.

Physical functioning was assessed with the corresponding subscale of the 36-item short-form health survey (SF-36; Ware & Sherbourne, 1992). Participants reported whether and how their health limited their activities of daily living across ten items (e.g., "bathing or dressing yourself"; α_{T1}=.88, α_{T2}=.90) and three response options: (1) *yes, limited a lot*; (2) *yes, limited a little*; (3) *no, not limited at all*. A single item assessed visual functioning ("Do vision problems cause you trouble reading the newspaper (possibly even when using a vision aid)?"), with response options ranging from 1 (*no difficulties*) to 4 (*impossible*).

Social Support

Two types of received social support were assessed with single items: informational ("How often in the past 12 months have you asked someone for advice in making an important decision?) and emotional ("How often in the past 12 months did someone comfort you or cheer you up?"). Response options ranged from 1 (*often*) to 4 (*never*). For each support type, responses from participants who reported having no one to ask for support were coded as 4 (*never*). Perceived social support ("How do you think you could get help from persons in your social environment in difficult situations?") was assessed with seven items (e.g., "If I have a problem, there is someone who can tell me how to handle it"; α_{T1}=.87, α_{T2}=.87). Response options ranged from 1 (*strongly agree*) to 4 (*strongly disagree*).

Self-Perceptions of Aging

Three dimensions of self-perceptions of aging were assessed with the AgeCog scale (Steverink, Westerhof, Bode, & Dittmann-Kohli, 2001; Wurm, Tesch-Römer, & Tomasik, 2007). The four-item subscales of ongoing development (e.g., "Ageing means to me that I can still learn new things"; α_{T1}=.77, α_{T2}=.79), physical loss (e.g., "Ageing means to me that I am less energetic and fit"; α_{T1}=.77, α_{T2}=.79), and social loss (e.g., "Ageing means to me that I feel lonely more often"; α_{T1}=.71, α_{T2}=.71) were used as measures of competence, physical, and social self-perceptions of aging, respectively. Response options ranged from 1 (*strongly agree*) to 4 (*strongly disagree*).

Internet Use

Participants who first indicated having internet access (“Do you have access to the Internet?”) then reported their frequency of internet use (“How often do you use the internet for the following purposes?”) for seven different online activities, from 1 (*daily*) to 6 (*never*): (1) “Contact with friends, acquaintances, and relatives (e.g., e-mail, Facebook, chat, video telephony)”; (2) “Search for new social contacts (e.g., friends, partner, like-minded persons)”; (3) “Search for information (e.g., news, advisers, Wikipedia)”; (4) “Banking business (e.g., online banking)”; (5) “Entertainment (e.g., listening to music, watching films, playing games, watching television)”; (6) “Shopping (e.g., Amazon, eBay, online pharmacy)”; (7) “Create own contents (e.g., texts, photos, music, uploading videos for blogs, websites, online selling)”. Specific internet uses were based on each item, while general internet use was based on the mean score of the seven items (α_{T1}=.69, α_{T2}=.70).

Covariates

As known predictors of internet use in later life (for reviews, see Hunsaker & Hargittai, 2018; Wagner, Hassanein, & Head, 2010), age, gender (1=*female*), marital status (1=*married*), occupational status (1=*employed*), living arrangements (1=*alone*), region (1=*East Germany*), education, and income assessed at baseline were included as covariates. Age, gender, and region were included also because the German Ageing Survey sample is stratified according to these factors (Klaus et al., 2017). Region was reported as East or West Germany. Education was based on the International Standard Classification of Education (ISCED; United Nations Educational, Scientific and Cultural Organization [UNESCO], 1997) with three levels: low (ISCED 0-2), medium (ISCED 3-4), and high (ISCED 5-6).

Income was based on the monthly net household income in euros, which was log transformed to correct skewness.

Analysis

A two-wave autoregressive cross-lagged panel design was used to test the reciprocal relationships of factors related to functional ability, social support, and self-perceptions of aging with internet use (Little, Preacher, Selig, & Card, 2007). Structural equation modeling was performed using Mplus 8 (Muthén & Muthén, 1998-2017) with robust maximum likelihood estimation (MLR), which provides standard errors and chi-square test statistics that are robust to nonnormality. Model fit was examined based on the Chi-Square Test (χ^2), the Comparative Fit Index (CFI), the Tucker-Lewis Index (TLI), the Root Mean Square Error of Approximation (RMSEA), and the Standardized Root Mean Square Residual (SRMR). CFI and TLI values of .90 or higher and RMSEA and SRMR values of .08 or lower were considered indicative of acceptable fit (Browne & Cudeck, 1993; Hu & Bentler, 1999).

As the first step of the longitudinal analysis, we tested the measurement models. Constructs assessed with multiple items, namely physical functioning, perceived social support, and competence, physical, and social self-perceptions of aging, were modeled as latent factors with their respective items serving as observed indicators. Residuals of corresponding indicators were correlated across waves. Modification indices suggested correlating the residuals of items 7-8 and 8-9 within the physical functioning latent factors to improve model fit. Since these items belonged to the same measure and referred to similar activities (i.e., walking), their residuals were correlated at each wave. To ensure that the same constructs were measured across time, longitudinal measurement invariance was tested by specifying increasingly constrained models representing various degrees of invariance: configural (equal structure), weak (equal loadings), and strong (equal intercepts). Given the large sample size, CFI differences of .010 or lower were considered indicative of no substantial difference in model fit, therefore demonstrating measurement invariance (Cheung & Rensvold, 2002). Because strong invariance was demonstrated, loadings and intercepts were equated across waves in subsequent analyses (Little et al., 2007). All models had acceptable fit to the data (see Supplementary Table S1).

As the second step, we tested the structural models. Constructs assessed with single items, general use, specific uses, and covariates were modeled as observed variables. In each model, cross-lagged paths were established between the nine constructs related to functional ability, social support, and self-perceptions of aging at T1 and the internet constructs at T2, as well as between the internet constructs at T1 and the nine constructs at T2. Autoregressive paths were specified between each construct at T1 and the corresponding construct at T2. An independent model was specified for general internet use (Model 1), based on the mean score of the seven items representing specific uses, demonstrating acceptable fit to the data: $\chi^2(2586)=10494.63$, CFI=.919, TLI=.912, RMSEA=.030 (90% Confidence Interval (CI) [.029, .030]), SRMR=.042. A single independent model was then specified for specific internet uses (Model 2), also demonstrating acceptable fit: $\chi^2(3252)=11873.79$, CFI=.924, TLI=.911, RMSEA=.028 (90% CI [.027, .028]), SRMR=.038.

Finally, multigroup analyses were conducted to identify potential age differences by comparing middle-aged and older adults. Following common classifications adopted in previous studies (e.g., Kornadt et al., 2017; Mariano et al., 2021a) and international reports (e.g., Pew Research Center, 2017; United Nations [UN], 2020) on aging, which usually apply the age cutoff at 65 years to differentiate between age groups, we categorized middle-aged adults as those aged 40 to 64 years and older adults as those aged 65 years and older. Multigroup measurement invariance was tested to ensure that the same constructs were measured across groups, demonstrating strong invariance (see Supplementary Table S1). Comparisons were based on the Wald chi-square test (Wald χ^2).

Results

Descriptive Analysis

Table 1 presents the sample characteristics at baseline. Age ranged from 40 to 87 years (*M*=61.12). Education averaged between *medium* and *high* (*M*=2.51), with slightly over half of participants having high education (53.09%). Almost half were female (48.61%). A similar proportion was employed (47.54%). The majority was married (77.21%) and few lived alone (15.12%). Close to one quarter lived in East Germany (28.77%). Regarding specific internet uses, searching for information (*M*=4.47) and contacting friends and relatives (*M*=3.85) were the most frequently performed activities, followed by banking (*M*=2.68), entertainment (*M*=2.59), and shopping (*M*=2.25). Creating contents (*M*=1.77) and searching for new social contacts (*M*=1.48) were the least performed. Supplementary Table S2 presents the means, standard deviations, and correlations between the main variables at both waves.

Insert Table 1 here

Longitudinal Analysis

To control the inflated probability of Type I errors (i.e., false positives) due to the simultaneous estimation of numerous paths in each model (i.e., multiple testing), we followed the Bonferroni-type controlling procedure proposed by Benjamini and Hochberg (1995) and recommended by Cribbie (2000, 2007) for structural equation modeling, using α = .05 as the baseline significance level. Overall, estimates with $p \leq .025$ were considered significant in the general internet use model (Model 1, see Supplementary Table S3) and estimates with $p \leq .018$ were considered significant in the specific internet uses model (Model 2, see Supplementary Table S4). Results for the autoregressive, cross-lagged, and covariate paths of each model are presented in Supplementary Tables S3 and S4.

Table 2 presents the unstandardized (*b*) and standardized (β) estimates of the cross-lagged associations of nine factors related to functional ability, social support, and self-perceptions of aging at baseline (T1) with general use and specific uses three years later (T2). Figure 1 presents the autoregressive cross-lagged panel model of general internet use with standardized estimates (β). Cognitive functioning and competence self-perceptions of aging (T1) were the only factors significantly and positively associated with general internet use (T2), supporting hypotheses 1.1 and 3.1, respectively. Overall, individuals who exhibited better cognitive functioning ($\beta=.040$, $b=.268$, $p=.004$) and more positive self-perceptions of aging about competence ($\beta=.056$, $b=.099$, $p=.010$) reported using the internet more frequently three years later.

Insert Figure 1 here

Consistently, cognitive functioning and competence self-perceptions of aging (T1) were significantly and positively associated with multiple specific internet uses (T2). Those with better cognitive functioning reported contacting friends, acquaintances, and relatives ($\beta=.061$, $b=.770$, $p<.001$), searching for information ($\beta=.075$, $b=.764$, $p<.001$), banking ($\beta=.032$, $b=.418$, $p=.007$), and shopping ($\beta=.047$, $b=.385$, $p=.001$) more often. In turn, those with more positive self-perceptions of aging about competence reported contacting others ($\beta=.099$, $b=.332$, $p<.001$), searching for new social contacts ($\beta=.128$, $b=.265$, $p<.001$), seeking information ($\beta=.086$, $b=.232$, $p=.002$), engaging in online entertainment ($\beta=.098$, $b=.358$, $p=.001$), and creating contents ($\beta=.148$, $b=.332$, $p<.001$) more often. Other factors, such as physical functioning and received informational support (T1), were significantly and positively associated with considerably less online behaviors (T2). Searching for information ($\beta=.081$, $b=.253$, $p<.001$) was more frequent among those with better physical functioning, while contacting others ($\beta=.059$, $b=.106$, $p<.001$) and shopping ($\beta=.042$, $b=.049$, $p=.004$) were more frequent among those who received informational support more often. Inversely, perceived social support and physical self-perceptions of aging (T1) were significantly and negatively related to internet use, although exclusively for information seeking (T2). Using the internet to search for information was more frequent among individuals with lower perceptions of social support (β=-.050, b=-.144, p=.010) and more negative physical self-perceptions of aging (β=-.137, b=-.464, p<.001). Moreover, those with more negative social self-perceptions of aging were more likely to look for new relationships online (β=-.095, b=-.205, p=.014). Visual functioning and received emotional support (T1) had no significant associations with internet use for any purpose (T2).

Insert Table 2 here

The multigroup analyses revealed no significant differences between middle-aged and older adults in the cross-lagged associations of the nine factors (T1) with internet use (T2), neither with general use, Wald $\chi^2(9)$=10.39, p=.320, nor with specific uses, Wald $\chi^2(63)$=58.58, p=.634.

Table 3 presents the unstandardized (b) and standardized (β) estimates of the cross-lagged associations of general use and specific uses at baseline (T1) with nine factors related to functional ability, social support, and self-perceptions of aging three years later (T2). General internet use (T1) was significantly and positively associated with cognitive and physical functioning (β=.031, b=.005, p=.018 and (β=.030, b=.016, p=.017, respectively), perceived social support (β=.031, b=.016, p=.022), competence and social self-perceptions of aging (β=.067, b=.040, p<.001 and β=.047, b=.027, p=.001, respectively) three years later (T2). Because cognitive functioning and competence self-perceptions of aging were reciprocally related to general internet use, potential differences in the cross-lagged associations were tested for each factor. The cross-lagged association of cognitive functioning (T1) with general use (T2) was significantly different and stronger than the cross-lagged association of general use (T1) with cognitive functioning (T2), Wald $\chi^2(1)$=8.00, p=.005 (β=.040, b=.268, p=.004 and β=.031, b=.005, p=.018, respectively). This difference was nonsignificant for competence self-perceptions of aging, Wald $\chi^2(1)$=2.23, p=.135.

Several specific online behaviors (T1) were also significantly associated with different factors (T2). Contacting friends, acquaintances, and relatives was significantly and positively associated with received social support, both informational and emotional (β=.066, *b*=.034, *p*<.001 and β=.065, *b*=.032, *p*<.001, respectively). Searching for new social contacts was significantly and negatively associated with cognitive and physical functioning (β=-.045, *b*=-.006, *p*=.001 and β=-.037, *b*=-.018, *p*=.012, respectively). Searching for information and banking were significantly and positively associated with competence self-perceptions of aging (β=.048, *b*=.018, *p*=.005 and β=.047, *b*=.014, *p*=.006, respectively). Entertainment was significantly and negatively associated with received informational support (β=-.044, *b*=-.022, *p*=.012). Shopping was significantly and positively associated with cognitive functioning (β=.048, *b*=.006, *p*=.005). Creating contents had no significant associations with internet use for any activity.

Insert Table 3 here

The multigroup analyses revealed no significant differences between middle-aged and older adults for general use, Wald $\chi^2(9)$=14.98, *p*=.092. However, significant differences were found for specific uses, Wald $\chi^2(63)$=97.92, *p*=.003, namely in the cross-lagged associations of contacting friends, acquaintances, and relatives (T1) with perceived social support (T2), Wald $\chi^2(1)$=6.84, *p*=.009 (middle-aged: β=.073, *b*=.019, *p*=.001; older: β=-.019, *b*=-.005, *p*=.482), with competence self-perceptions of aging (T2), Wald $\chi^2(1)$=4.52, *p*=.034 (middle-aged: β=.013, *b*=.004, *p*=.566; older: β=-.062, *b*=-.019, *p*=.028), and with physical self-perceptions of aging (T2), Wald $\chi^2(1)$=3.92, *p*=.048 (middle-aged: β=.043, *b*=.010, *p*=.069; older: β=-.032, *b*=-.008, *p*=.276); as well as in the cross-lagged associations of searching for information (T1) with visual functioning (T2), Wald $\chi^2(1)$=5.53, *p*=.019 (middle-aged: β=-.056, *b*=-.019, *p*=.030; older: β=.040, *b*=.013, *p*=.207).

Discussion

To understand which factors relate to internet engagement in later life, this study examined the longitudinal relationships of multiple dimensions of functional ability, social support, and self-perceptions of aging with internet use over three years among middle-aged and older adults. As the only factors relating to general use and wide ranges of specific uses, cognitive functioning and competence self-perceptions of aging emerged as the most important correlates of internet use in middle and late adulthood. Importantly, these findings were consistent across age groups. Corroborating the notion that navigating the internet is cognitively demanding and can be hindered by age-related cognitive declines, better cognitive functioning preceded contacting friends, acquaintances, and relatives, searching for information, banking, and shopping more frequently three years later. This complements past cross-sectional and longitudinal evidence linking better cognitive performance with greater general internet use (Czaja et al., 2006; Freese et al., 2006; Kamin & Lang, 2020; Yu & Fiebig, 2020) and elucidates which online activities may be particularly dependent on cognitive functioning. Although experimental studies have indeed shown that better cognition predicts better information seeking performance (Czaja et al., 2013; Sharit et al., 2008; Sharit et al., 2015), future research should also confirm its predictive role for tasks related to communication, banking, and shopping. Overall, designing web interfaces and training programs that minimize cognitive demands, for example, by presenting website contents and instructional materials written in plain language, should facilitate internet engagement among middle-aged and older adults, especially for this set of activities (for reviews, see Berkowsky & Czaja, 2018; Rogers et al., 2005b).

In turn, perceiving the aging process as involving maintained or increased capabilities preceded contacting others, searching for new social contacts, seeking information, banking, engaging in online entertainment, and creating contents more frequently three years later. Besides corroborating existing evidence that general self-perceptions of aging relate to general internet and computer use (Cody et al., 1999; Mariano et al., 2021a), these findings identify competence-related self-perceptions of aging as the most relevant to internet engagement and clarify which online behaviors are more likely to be facilitated by these perceptions. As implied by stereotype embodiment theory (Levy, 2009), internalizing beliefs that aging entails competence gains may enhance individuals' perceptions about their own capabilities, including their ability to use the internet, thus increasing the likelihood of going online for multiple purposes. This is consistent with evidence that self-perceptions of aging indirectly relate to health behaviors via self-efficacy beliefs (Klusmann, Sproesser, Wolff, & Renner, 2019). Stereotype embodiment theory (Levy, 2009) further proposes that self-perceptions of aging become embodied, ultimately influencing functioning and health (Brothers, Kornadt, Nehrkorn-Bailey, Wahl, & Diehl, 2021), including cognition (Levy, Zonderman, Slade, & Ferrucci, 2012; Robertson, King-Kallimanis, & Kenny, 2016; Seidler & Wolff, 2017). This suggests that positive self-perceptions of aging may indirectly facilitate internet use by contributing to better cognitive functioning (Mariano et al., 2021a). Future studies should therefore examine self-efficacy and cognition as potential mediating mechanisms. Because stereotypical beliefs about older people and the aging process shape how they perceive themselves as aging individuals (Kornadt & Rothermund, 2012), interventions aiming to promote internet use among middle-aged and older adults should consider countering negative age stereotypes, particularly those related to competence (Brothers & Diehl, 2017; Levy, Pilver, Chung, & Slade, 2014); (for reviews, see Burnes et al., 2019; Marques et al., 2020). For example, Levy et al. (2014) found that implicitly exposing older individuals to positive age stereotypes over four weeks improved age stereotype endorsement, which subsequently improved self-perceptions of aging.

Besides cognitive functioning and competence self-perceptions of aging, social support may also contribute to internet use for certain purposes. Receiving informational support preceded contacting others and shopping more frequently three years later. This suggests that obtaining support in the form of advice on what to do or guidance on how to do it may facilitate internet use for some activities, consistently with past qualitative findings on social support and technology use in later life (Francis et al., 2018; Luijkx et al., 2015). Interestingly, the mere belief that support is available may not be enough for individuals to go online (Kamin et al., 2020; Luijkx et al., 2015). In fact, lower expectations about the availability of social support preceded more information seeking, perhaps as a way of coping with the perceived lack of help from others. This seemingly counterproductive influence of perceived support may stem from individuals' reluctance to ask for support to avoid burdening others, even if they perceive this support to be available (Luijkx et al., 2015). Nonetheless, perceiving its availability may be a precondition to request and receive social support (Kamin et al., 2020). Interventions should ensure that informational support is readily available

Other functional domains seem considerably less relevant than cognition. Only better physical functioning preceded greater internet use for information searching, possibly for being more physically challenging to perform successfully. Navigating the internet may be less affected by physical and perceptual limitations, as access is possible through various devices, requiring distinct forms of interaction with different functional demands. Indeed, older age groups are increasingly going online primarily through mobile devices (Pew Research Center, 2019), which tend to be seen as easier to use (Tsai, Shillair, & Cotten, 2017; Tsai, Shillair, Cotten, Winstead, & Yost, 2015). Future studies should thus take into consideration the different types of devices and modes of interaction that individuals choose when going online. Apart from competence, other dimensions of self-perceptions of aging were also less determinant. Those who perceived their own aging as involving social losses were more likely to search for new relationships, while those who perceived physical declines as part of their aging experience engaged in information searching more often. Taken together, these findings suggest that individuals may perform certain activities to cope with losses and declines perceived to be associated with their aging process. For instance, perceiving social losses as part of their aging experience may motivate them to go online to seek meaningful social ties. Nonetheless, our findings indicate that competence-related self-perceptions of aging are the primary drivers of internet use in middle and late adulthood.

Being online also has the potential to influence functional ability, social support, and self-perceptions of aging. Middle-aged and older adults who reported more frequent general use exhibited better cognitive and physical functioning, higher perceptions of social support, and more positive competence and social self-perceptions of aging three years later. Internet use may improve cognitive and physical outcomes by enabling individuals to participate in diverse social and leisure activities, thus contributing to their active and healthy aging (Kamin, Seifert, & Lang, 2021). Specifically, our findings indicate that learning and engaging in online shopping can be particularly helpful in preserving cognitive functioning. Similarly to general use, those using the internet for information searching and online banking more often expressed more positive self-perceptions of aging about competence three years later. Given its potential to support users in a multitude of ways (Czaja, 2017a), the internet may contribute to their sense of competence as aging individuals, with important benefits to their health and well-being (Westerhof et al., 2014). Adding to past cross-sectional (Fuss et al., 2019) and intervention studies (Cody et al., 1999; Czaja et al., 2018), our findings suggest that general use may enhance perceptions of social support. Moreover, those who contacted family, friends, and others over the internet more frequently were more likely to receive informational and emotional support three years later, as well as to perceive support to be available in middle adulthood. This reinforces the argument that higher levels of social support are primarily attributable to the internet's potential to facilitate communication and enable supportive relationships between individuals and their social networks (Czaja, 2017b). Finally, besides complementing previous longitudinal studies (Choi et al., 2021; Hartanto et al., 2020; Kamin & Lang, 2020; Mariano et al., 2021a; Yu & Fiebig, 2020), the reciprocal relationships of general internet use with cognitive functioning and competence self-perceptions of aging point to an ongoing positive feedback loop, through which increasing general internet use subsequently improves cognitive functioning and competence self-perceptions of aging, which in turn lead to further increases in future use.

Some limitations should also be acknowledged. Firstly, although our study comprised an ample range of relevant factors expected to predict internet use, including many sociodemographic covariates, the potential influence of unknown confounders cannot be entirely ruled out, so causal inferences should be made with caution. Secondly, only individuals with internet access reported their internet use behaviors, which limits the generalizability of our findings. Nonetheless, the majority of potential participants (i.e., more than two thirds) indicated having internet access and were therefore included in the sample. Thirdly, given the residual number of participants who became online or offline over three years, we were unable to examine the correlates of the transition from nonuse to use and from use to nonuse. Future studies should explore the role of functional ability, social support, and self-perceptions of aging on internet adoption and abandonment in middle and late adulthood. Fourthly, considering the evolving nature of technology and the pressures posed by the COVID-19 pandemic for the rapid adoption of digital tools (Golinelli et al., 2020), future research should replicate this longitudinal study with more recent data. Lastly, some measures may have been insufficiently comprehensive to fully grasp the role of their corresponding constructs. For example, although dexterity difficulties can be expected to be particularly detrimental to internet use (Rogers et al., 2005b), the physical functioning measure assessed both fine and gross dimensions of motor ability. Unlike received support, perceived support could not be broken down into different types, thus limiting their direct comparison. Domain specific measures assessing internet-related social support would also be informative (Kamin et al., 2020). These and other measures would benefit from greater specificity and multidimensionality in future studies.

Several strengths should also be emphasized. Our study simultaneously tested the relationships of multiple, largely understudied factors with internet use in later life, highlighting the most relevant. In addition to general use, we examined an extensive set of online activities to understand how different factors relate to specific uses. The longitudinal design allowed clarifying past, mostly cross-sectional evidence and identifying reciprocal relationships in some cases. Overall, our findings emphasize the importance of considering stereotypical perceptions of age and aging (Chen & Chan, 2014; Cody et al., 1999; Mariano et al., 2021a; Mariano, Marques, Ramos, Gerardo, & de Vries, 2020) and age-related changes in cognitive functioning (Chen & Chan, 2014; Czaja et al., 2006; Freese et al., 2006; Yu & Fiebig, 2020) when promoting general and specific internet use in middle and late adulthood.

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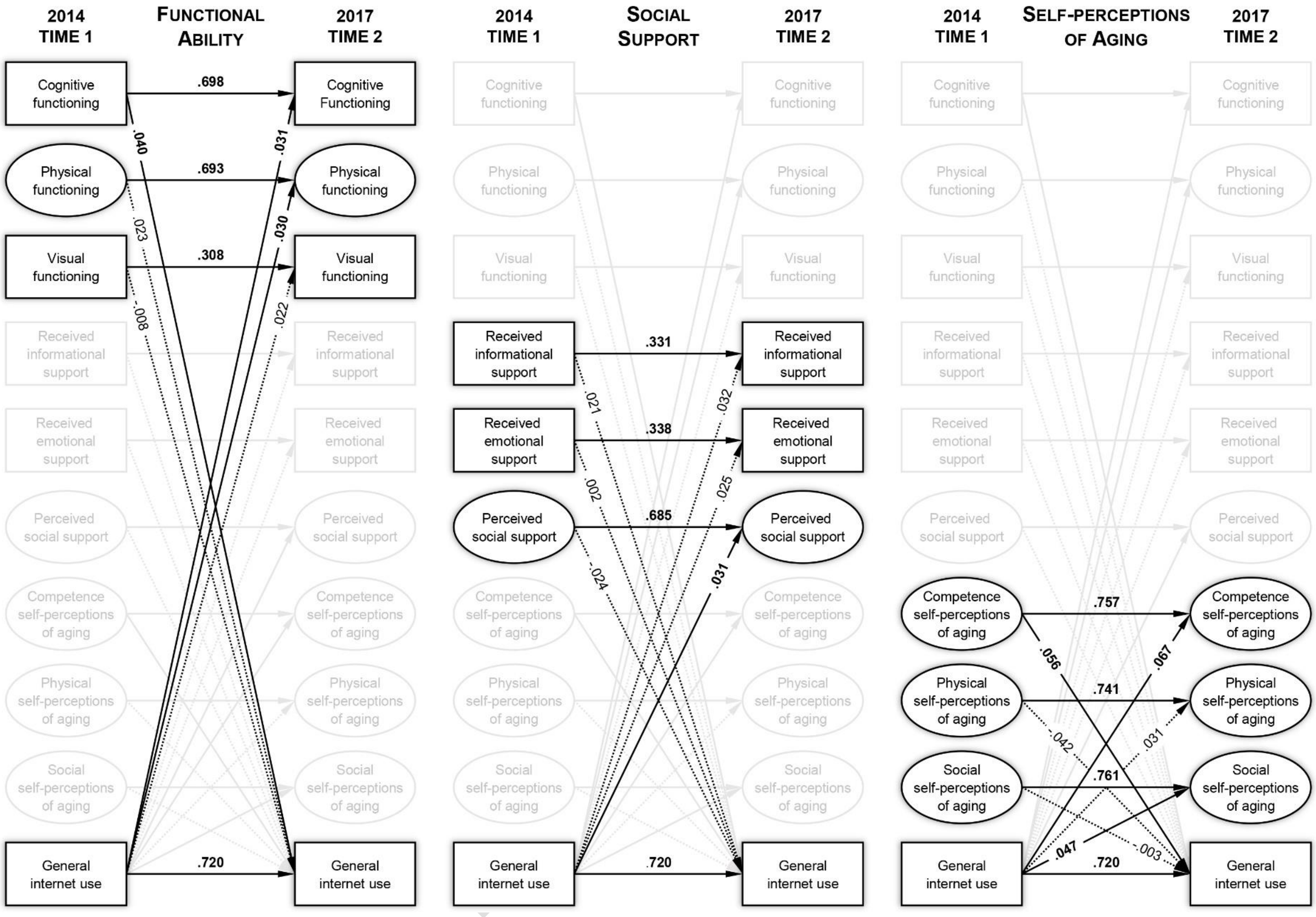
Table 1

Sample characteristics at baseline

Variable	*M* (*n*)	*SD* (%)	*Range*
Age	61.12	9.80	40 – 87
Middle-aged adults	55.03 (2187)	6.26 (62.86)	40 – 64
Older adults	71.42 (1292)	4.84 (37.14)	65 – 87
Education	2.51	0.55	1 – 3
Income (log)	3.48	0.24	2.26 – 4.70
Gender (*female*)	(1691)	(48.61)	0 – 1
Marital status (*married*)	(2686)	(77.21)	0 – 1
Occupational status (*employed*)	(1654)	(47.54)	0 – 1
Living arrangements (*alone*)	(526)	(15.12)	0 – 1
Region (*East Germany*)	(1001)	(28.77)	0 – 1
General internet use	2.73	0.87	1.00 – 6.00
Specific internet uses			
Contacting friends, acquaintances, and relatives	3.85	1.74	1 – 6
Searching for new social contacts	1.48	0.96	1 – 6
Searching for information	4.47	1.38	1 – 6
Banking	2.68	1.78	1 – 6
Entertainment	2.59	1.78	1 – 6
Shopping	2.25	1.11	1 – 6
Creating own contents	1.77	1.20	1 – 6

Figure 1

Autoregressive cross-lagged panel model for general internet use



Note. Path coefficients are standardized. Dotted lines indicate nonsignificant paths. Bold values are significant at $p \leq .025$ based on the multiple testing controlling procedure by Benjamini and Hochberg (1995).

Table 2

Unstandardized (b) and standardized (β) estimates of the cross-lagged associations of nine factors related to functional ability, social support, and self-perceptions of aging at T1 with general and specific internet use at T2

	Internet T2: General Use *(Model 1)*		Internet T2: Specific Uses *(Model 2)*													
			Contacting friends, acquaintances, and relatives		Searching for new social contacts		Searching for information		Banking		Entertainment		Shopping		Creating own contents	
	b	(*β*)	*b*	(*β*)	*b*	(*β*)	*b*	(*β*)	*b*	(*β*)	*b*	(*β*)	*b*	(*β*)	*b*	(*β*)
Functional ability																
Cognitive functioning T1 → Internet T2	**.268**	(.040)	**.770**	(.061)	-.306	(-.039)	**.764**	(.075)	**.418**	(.032)	.183	(.013)	**.385**	(.047)	.192	(.023)
Physical functioning T1 → Internet T2	.048	(.023)	.029	(.007)	-.008	(-.003)	**.253**	(.081)	-.055	(-.014)	.115	(.027)	.092	(.036)	.058	(.022)
Visual functioning T1 → Internet T2	-.016	(-.008)	-.027	(-.007)	-.046	(-.020)	.001	(.000)	-.012	(-.003)	.017	(.004)	-.057	(-.023)	-.068	(-.027)
Social support																
Received informational support T1 → Internet T2	.019	(.021)	**.106**	(.059)	.024	(.021)	.045	(.031)	.030	(.016)	-.037	(-.019)	**.049**	(.042)	.031	(.026)
Received emotional support T1 → Internet T2	.002	(.002)	.031	(.016)	-.027	(-.023)	-.001	(-.001)	.024	(.012)	.005	(.003)	-.001	(-.001)	-.031	(-.024)
Perceived social support T1 → Internet T2	-.046	(-.024)	.028	(.008)	-.040	(-.018)	**-.144**	(-.050)	-.096	(-.026)	-.014	(-.004)	-.081	(-.035)	-.084	(-.035)
Self-perceptions of aging																
Competence self-perceptions of aging T1 → Internet T2	**.099**	(.056)	**.332**	(.099)	**.265**	(.128)	**.232**	(.086)	.158	(.046)	**.358**	(.098)	.103	(.048)	**.332**	(.148)
Physical self-perceptions of aging T1 → Internet T2	-.094	(-.042)	-.122	(-.029)	-.022	(-.008)	**-.464**	(-.137)	-.081	(-.019)	-.120	(-.026)	-.173	(-.063)	-.101	(-.035)
Social self-perceptions of aging T1 → Internet T2	-.005	(-.003)	-.157	(-.045)	**-.205**	(-.095)	.147	(.053)	.049	(.014)	-.253	(-.067)	.078	(.035)	-.150	(-.064)

Note. T1 = Time 1 (2014), T2 = Time 2 (2017). Bold values are significant at $p \leq .025$ for general use (Model 1) and at $p \leq .018$ for specific uses (Model 2) based on the multiple testing controlling procedure by Benjamini and Hochberg (1995).

Table 3

Unstandardized (b) and standardized (β) estimates of the cross-lagged associations of general and specific internet use at T1 and nine factors related to functional ability, social support, and self-perceptions of aging at T2

	Internet T1: General Use *(Model 1)*		Internet T1: Specific Uses *(Model 2)*													
			Contacting friends, acquaintances, and relatives		Searching for new social contacts		Searching for information		Banking		Entertainment		Shopping		Creating own contents	
	b	(*β*)	*b*	(*β*)	*b*	(*β*)	*b*	(*β*)	*b*	(*β*)	*b*	(*β*)	*b*	(*β*)	*b*	(*β*)
Functional ability																
Internet T1 → Cognitive functioning T2	**.005**	(.031)	.001	(.015)	**-.006**	(-.045)	.001	(.015)	.002	(.020)	-.001	(-.013)	**.006**	(.048)	.000	(-.004)
Internet T1 → Physical functioning T2	**.016**	(.030)	.006	(.022)	**-.018**	(-.037)	.010	(.030)	.005	(.019)	-.005	(-.020)	.009	(.022)	-.001	(-.003)
Internet T1 → Visual functioning T2	.011	(.022)	.010	(.039)	-.009	(-.018)	-.005	(-.014)	.003	(.011)	.001	(.003)	.009	(.022)	-.005	(-.013)
Social support																
Internet T1 → Received informational support T2	.033	(.032)	**.034**	(.066)	.004	(.005)	-.004	(-.006)	-.007	(-.014)	**-.022**	(-.044)	.017	(.021)	.002	(.003)
Internet T1 → Received emotional support T2	.024	(.025)	**.032**	(.065)	-.018	(-.020)	-.005	(-.009)	-.006	(-.013)	-.004	(-.008)	.017	(.021)	-.010	(-.014)
Internet T1 → Perceived social support T2	**.016**	(.031)	.011	(.040)	-.007	(-.014)	-.006	(-.017)	-.001	(-.003)	-.001	(-.003)	.013	(.031)	.006	(.014)
Self-perceptions of aging																
Internet T1 → Competence self-perceptions of aging T2	**.040**	(.067)	-.006	(-.021)	-.002	(-.004)	**.018**	(.048)	**.014**	(.047)	-.004	(-.015)	.001	(.003)	.004	(.009)
Internet T1 → Physical self-perceptions of aging T2	.015	(.031)	.003	(.012)	-.003	(-.007)	.000	(.002)	.007	(.033)	-.005	(-.020)	.007	(.020)	.000	(-.001)
Internet T1 → Social self-perceptions of aging T2	**.027**	(.047)	.010	(.034)	.004	(.008)	.003	(.007)	.009	(.034)	-.007	(-.026)	.011	(.025)	.000	(.001)

Note. T1 = Time 1 (2014), T2 = Time 2 (2017). Bold values are significant at $p \leq .025$ for general use (Model 1) and at $p \leq .018$ for specific uses (Model 2) based on the multiple testing controlling procedure by Benjamini and Hochberg (1995).