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Cognitive functioning mediates the relationship between self-perceptions of aging and computer use behavior in late adulthood: Evidence from two longitudinal studies

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ABSTRACT

Although information and communication technologies have become an integral part of contemporary societies, substantial proportions of the older population remain distant from these digital tools. This stresses the importance of identifying age-specific factors that facilitate or prevent technology adoption among older age groups. Despite being powerful determinants of behavior and health in late adulthood, little is known about the role of stereotypical perceptions about age and aging in the behavioral engagement with technological devices. Across two longitudinal studies, we examined the relationship between self-perceptions of aging and computer use behavior, as well as the mediating role of cognitive functioning. Study 1 was based on the 2010, 2014, and 2018 waves of the Health and Retirement Study ($n = 3404$). Study 2 was based on the 2014 and 2017 waves of the German Ageing Survey ($n = 4871$). Both studies revealed that more positive self-perceptions of aging were associated with more frequent computer use behavior. Moreover, this relationship was partially mediated by cognitive functioning. This suggests that perceptions about their aging experience can influence how individuals behave towards computer technology by impacting important predictors of use behavior. Interventions promoting positive self-perceptions of aging may thus contribute to the digital inclusion of middle-aged and older adults.

1. Introduction

There is growing evidence that information and communication technology contributes to quality of life in late adulthood. Greater levels of computer and internet use have been associated with better health and well-being, including increased life satisfaction and social support, as well as decreased feelings of loneliness and depression (Chopik, 2016; Hartanto et al., 2020; Heo, Chun, Lee, Lee, & Kim, 2015; for reviews, see Hunsaker & Hargittai, 2018; Wagner, Hassanein, & Head, 2010). Yet, older age groups are less likely to adopt information and communication technology than the general population (König, Seifert, & Doh, 2018; Organization for Economic Cooperation and Development [OECD], 2019; Ryan, 2018), which prevents them from taking advantage of these potential benefits. This age-based digital divide underscores the importance of identifying and addressing age-specific barriers to technology uptake in late adulthood. Research exploring age differences in technology use has focused primarily on individual characteristics, with older age groups consistently reporting lower self-efficacy and higher anxiety or discomfort with technology, lower perceived ease of use, perceived usefulness, and behavioral intention to use technology, as well as lower cognitive abilities (Czaja et al., 2006; Czaja & Sharit, 1998b; Lee et al., 2019; for reviews, see Hauk, Hüffmeier, & Krumm, 2018; Wagner et al., 2010).

Surprisingly, little is known about the role of societal factors, such as stereotypical views of age and aging, in how individuals engage with information and communication technology. Older age groups are often stereotyped as having less technological ability than younger individuals. Older adults are considered less likely and less capable of performing technology-related activities, such as taking and completing a computer course (Ryan, Szechtman, & Bodkin, 1992; Swift, Abrams, &

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Marques, 2013), and older workers are perceived as less skilled and less experienced with technology (McGregor & Gray, 2002; Van Dalen, Henkens, & Schippers, 2009). Stereotypical beliefs about age and aging have been consistently found to influence older individuals' actions or behaviors (for reviews, see Meisner, 2011; Westerhof et al., 2014), suggesting that negative stereotypes about the technological competence of older age groups may reinforce their lower rates of technology adoption.

The present research sought to understand whether and how stereotypical views of age and aging may impact technology use in late adulthood. According to the stereotype embodiment theory (Levy, 2009), culturally shared beliefs about older people and the aging process are internalized since childhood and reinforced throughout adulthood. However, as individuals grow older, these stereotypical perceptions about age and aging become perceptions about themselves and their own aging experience, or self-perceptions of aging (Kornadt & Rothermund, 2012; Kornadt, Voss, & Rothermund, 2017). This implies that age stereotypes about technological inability may be internalized, causing older individuals to doubt their own ability to use technology and consequently undermining its adoption in their daily lives. This is consistent with evidence that older age groups report lower technology self-efficacy, which is associated with lower technology use (Czaja et al., 2006; Lee et al., 2019; Mitzner et al., 2019).

Still, this may not be the only mechanism through which negative perceptions about age and aging may preclude technology use in late adulthood. An extensive body of research has documented the beneficial and detrimental impacts of positive and negative age stereotypes and self-perceptions of aging across multiple health domains (for reviews, see Chang et al., 2020; Westerhof et al., 2014), including cognitive functioning (Levy, Zonderman, Slade, & Ferrucci, 2011; Robertson, King-Kallimanis, & Kenny, 2016; Seidler & Wolff, 2017; Siebert, Wahl, & Schröder, 2018). Interacting with information and communication technology is cognitively demanding, as suggested by evidence that cognitive functioning is an important predictor of performance (Czaja & Sharit, 1998a; Czaja, Sharit, Ownby, Roth, & Nair, 2001; Sharit, Taha, Berkowsky, Profita, & Czaja, 2015) and usage (Czaja et al., 2006; Mitzner et al., 2019; Tun & Lachman, 2010). This suggests that, by compromising cognitive functioning, negative age stereotypes and self-perceptions of aging may indirectly undermine technology use behavior.

Few studies have explored these potential relationships. Lagacé, Charmarkeh, Laplante, and Tanguay (2015) found that older adults who held more negative beliefs about older people used information and communication technologies for fewer activities than those with more positive age stereotypes. Cody, Dunn, Hoppin, and Wendt (1999) showed that older adults with more positive self-perceptions of aging were more likely to complete an internet training program and spend more time online during its four-month duration. In contrast, Yoon, Jang, and Xie (2016) found no significant relationship between self-perceptions of aging and computer use when controlling for relevant health and demographic factors. Although inconclusive, these findings tend to suggest the existence of positive associations from age stereotypes and self-perceptions of aging to technology use behavior. Nonetheless, they do not fully clarify the directionality and causality of the relationships, nor identify potential mediating mechanisms.

To investigate the interplay between self-perceptions of aging, cognitive functioning, and technology use behavior, we conducted two longitudinal studies including middle-aged and older adults from different countries, different domains of cognitive functioning, and different measures of use behavior. We focused on computers for being potentially more cognitively demanding than other types of technology (Tsai, Shillair, Cotten, Winstead, & Yost, 2015). Overall, we predicted that cognitive functioning would mediate the relationship between self-perceptions of aging and computer use behavior over time. Specifically, we hypothesized a direct positive association between self-perceptions of aging and computer use behavior (Hypothesis 1), such that more positive self-perceptions would relate to higher levels of use behavior. Additionally, we hypothesized an indirect positive association between self-perceptions of aging and computer use behavior through cognitive functioning (Hypothesis 2), such that positive self-perceptions would relate to better cognitive functioning (Hypothesis 2a), which would then relate to greater computer use (Hypothesis 2b). We tested these predictions in both studies while also controlling for relevant health, well-being, and demographic correlates of computer use behavior, cognitive functioning, and self-perceptions of aging (for reviews, see Hertzog, Kramer, Wilson, & Lindenberger, 2008; Marques et al., 2020; Wagner et al., 2010). Given the wide age range in our study samples, potential age differences between middle-aged and older adults were also investigated.

2. Study 1

Based on the Health and Retirement Study, our first study examined the relationships between self-perceptions of aging, cognitive functioning, and computer use behavior over eight years among individuals aged 50 or older from the United States of America. Given the stereotypical beliefs about memory and aging, we focused on memory performance as an indicator of cognitive functioning. Memory decline is widely assumed to be an inevitable part of the aging process, with older age groups being commonly stereotyped as forgetful (Hummert, Garstka, Shaner, & Strahm, 1994; Ryan, 1992). Age stereotypes have been found to be important predictors of both short-term and long-term memory performance (Levy, 1996; Levy et al., 2011). Although longitudinal research looking specifically at the interplay between self-perceptions of aging and memory functioning is scarce, some findings suggest a positive association over time (Robertson et al., 2016; Siebert et al., 2018). Longitudinal evidence for the relationship between memory functioning and computer use is mixed, with one study providing support for this relationship over six years (Slegers, van Boxtel, & Jolles, 2012) and another study showing no association over nine years (Hartanto et al., 2020). Overall, we expected the relationship between self-perceptions of aging and computer use behavior to be mediated by cognitive functioning as indicated by memory performance.

2.1. Method

2.1.1. Participants

The Health and Retirement Study (HRS, Sonnega et al., 2014) is a biennial longitudinal survey of a nationally representative sample of the United States population aged over 50 years and their spouses of any age. The HRS is sponsored by the National Institute on Aging (grant number NIA U01AG009740) and is conducted by the University of Michigan. A "leave-behind" self-completed psychosocial questionnaire has been administered to a rotating half of the sample every four years since 2006. The present study is based on all respondents aged 50 years or older who completed the core interview and the psychosocial questionnaire in 2010, 2014, and 2018 (Time 1 [T1], Time 2 [T2], and Time 3 [T3], respectively; $n = 3404$), the most recent waves that included the same measures of self-perceptions of aging, cognitive functioning, and computer use behavior.

2.1.2. Measures

Self-perceptions of Aging. Five items derived from the Attitude Toward Own Aging subscale of the Philadelphia Geriatric Center Morale Scale (Lawton, 1975) assessed self-perceptions of aging: (1) "Things keep getting worse as I get older", (2) "I have as much pep as I did last year", (3) "The older I get, the more useless I feel", (4) "I am as happy now as I was when I was younger", and (5) "As I get older, things are better than I thought they would be". Response options ranged from 1 (*strongly disagree*) to 6 (*strongly agree*). Negatively phrased items (1 and 3) were reverse coded so that higher values reflected more positive self-perceptions of aging (Cronbach's alpha: $\alpha_{T1} = 0.73$, $\alpha_{T2} = 0.73$, $\alpha_{T3} = 0.74$).

Cognitive Functioning. Episodic memory was chosen as an indicator of cognitive functioning and assessed with two free recall tasks (McArdle, Fisher, & Kadlec, 2007). A list of 10 nouns was read to participants, who were asked to recall as many words as possible: (1) immediately after their presentation – immediate word recall; and (2) after a delay of approximately five minutes – delayed word recall. Memory performance on each task was coded as the total number of correctly recalled words, ranging from 0 to 10, with higher scores indicating better cognitive functioning (Spearman-Brown coefficient: $\rho_{T1} = 0.82$, $\rho_{T2} = 0.86$, $\rho_{T3} = 0.85$).

Computer Use Behavior. A single item from a list of different activities assessed general frequency of computer use: "Please tell us how often you do each activity. (...) Use a computer for e-mail, Internet or other tasks?". Response options ranged from 1 (*daily*) to 7 (*never/not relevant*), which were reverse coded so that higher values indicated more frequent computer use.

Covariates. Age (in years), education (in years), gender (1 = *female*), marital status (1 = *married*), employment status (1 = *working*), income, subjective health, physical conditions, depressive symptoms, and loneliness assessed at baseline were included as covariates. Income was based on an imputed measure of total household income provided by the HRS, which was log transformed to correct skewness. Subjective health ("Would you say your health is excellent, very good, good, fair, or poor?") was rated from 1 (*excellent*) to 5 (*poor*). Physical conditions were scored as the sum of seven illnesses (hypertension, diabetes, cancer, lung disease, heart condition, stroke, and arthritis). Depressive symptoms were scored as the sum of eight items from the Center for Epidemiologic Studies Depression Scale (CES-D; Radloff, 1977; $\alpha = 0.80$). Loneliness was scored as the mean of three items from the short version of the Revised University of California, Los Angeles Loneliness Scale (R-UCLA; Hughes, Waite, Hawkley, & Cacioppo, 2004; $\alpha = 0.81$). Responses were reverse coded as appropriate so that higher values indicated greater levels of the corresponding construct.

2.1.3. Analysis

A three-wave autoregressive cross-lagged panel design was used to test longitudinal mediation (Cole & Maxwell, 2003; Little, Preacher, Selig, & Card, 2007). Structural equation modeling was performed using Mplus 8 (Muthén & Muthén, 1998–2017) with maximum likelihood estimation (ML). Mediation was examined using percentile bootstrapping with 10,000 resamples to generate estimates and 95% confidence intervals (CI) that indicate the significance of indirect effects. 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 0.90 or higher and RMSEA and SRMR values of 0.08 or lower were considered indicative of acceptable fit (Browne & Cudeck, 1993; Hu & Bentler, 1999). Model fit comparisons were based on the chi-square difference test ($\Delta\chi^2$).

As the first step of the longitudinal analysis, we tested the measurement model. Self-perceptions of aging and cognitive functioning were modeled as latent factors with their respective items serving as observed indicators. Residuals of corresponding indicators were correlated across waves. To ensure that the same constructs were measured across time, longitudinal measurement invariance was tested by specifying a series of increasingly constrained models representing various degrees of invariance: configural (equal structure), weak (equal loadings), and strong (equal intercepts). Due to the large sample of the current study, CFI differences of 0.010 or lower ($\Delta CFI \leq 0.010$) were considered indicative of no substantial difference in model fit, therefore demonstrating measurement invariance (Cheung & Rensvold, 2002). At least partial strong invariance was demonstrated and equality constraints were applied consistently with the appropriate level of invariance (Little et al., 2007). As the second step, we tested the structural model. Computer use behavior and all covariates were modeled as observed variables. Autoregressive paths were specified between the same constructs across waves, while cross-lagged paths were established between different constructs across waves. Stationarity was tested by constraining autoregressive and cross-lagged paths to be equal across waves (Cole & Maxwell, 2003). Differences between an association (e.g., from self-perceptions of aging at T1 to computer use behavior at T3) and its reverse pattern (e.g., from computer use behavior at T1 to self-perceptions of aging at T3) were examined based on the chi-square difference test ($\Delta\chi^2$). A constrained model in which the associations were constrained to equality was compared to an unconstrained model in which they were allowed to differ.

Lastly, multigroup analysis was conducted to identify potential age differences by comparing middle-aged adults (50 to 64 years) and older adults (65 years or older). Multigroup measurement invariance was also tested to ensure that the same constructs were measured across groups, demonstrating at least partial strong invariance. A constrained model in which cross-lagged paths were equated across age groups was compared to an unconstrained model in which these paths were allowed to differ.

2.2. Results

2.2.1. Descriptive analysis

Sample characteristics at baseline are shown in Table 1. Age ranged from 50 to 93 years ($M = 64.41$). Education ranged from 0 to 17 years ($M = 13.44$). Most participants were female (60.16%) and married (66.48%). Less than half were working (42.98%). Subjective health averaged between *good* and *very good* ($M = 3.44$). Participants reported low levels of physical conditions ($M = 1.74$), depressive symptoms ($M = 1.13$), and loneliness ($M = 1.44$).

Table 2 presents the correlations between the main variables across the three waves. Self-perceptions of aging were moderately positive, cognitive functioning was close to the midpoint, and computer use was moderately frequent. Self-perceptions of aging were significantly and positively related to use behavior across all waves. Cognitive functioning was significantly and positively associated with both, although more strongly with computer use.

2.2.2. Longitudinal analysis

Firstly, we tested the measurement model. The modification indices suggested correlating the residuals of items 1 and 3 within the self-perceptions of aging latent factors to improve model fit. Because both items were reverse coded and part of the same measure, their residuals

Table 1
Sample characteristics at baseline in Study 1 (n = 3404) and Study 2 (n = 4871).

Variables	Study 1			Study 2		
	M (*n*)	*SD* (%)	*Range*	*M* (*n*)	*SD* (%)	*Range*
Age	64.41	8.93	50–93	63.92	10.58	40–94
Education	13.44	2.71	0–17	2.41	0.58	1–3
Gender (*female*)	(2048)	(60.16)	0–1	(2474)	(50.79)	0–1
Marital status (*married*)	(2263)	(66.48)	0–1	(3564)	(73.17)	0–1
Employment status (*working*)	(1463)	(42.98)	0–1	(1812)	(37.20)	0–1
Income (log)	4.65	0.59	0–6.32	3.42	0.25	2.09–4.70
Subjective health	3.44	1.00	1–5	3.58	0.79	1–5
Physical conditions	1.74	1.26	0–6	2.50	1.81	0–11
Depressive symptoms	1.13	1.76	0–8	6.25	5.72	0–40
Loneliness	1.44	0.52	1–3	1.76	0.54	1–4
Region (*East Germany*)	–	–	–	(1607)	(32.99)	0–1

Table 2
Means, standard deviations, and correlations between the main variables across the three waves in Study 1.

Variables	*M*	*SD*	*Range*	1	2	3	4	5	6	7	8
1. Self-perceptions of aging 2010	4.18	1.07	1–6	–							
2. Self-perceptions of aging 2014	4.12	1.06	1–6	.59***	–						
3. Self-perceptions of aging 2018	4.04	1.08	1–6	.56***	.63***	–					
4. Cognitive functioning 2010	5.32	1.47	0–10	.15***	.13***	.14***	–				
5. Cognitive functioning 2014	5.20	1.55	0–10	.17***	.18***	.19***	.57***	–			
6. Cognitive functioning 2018	5.12	1.64	0–10	.16***	.16***	.18***	.55***	.58***	–		
7. Computer use behavior 2010	5.07	2.54	1–7	.17***	.16***	.17***	.33***	.34***	.37***	–	
8. Computer use behavior 2014	5.16	2.52	1–7	.17***	.17***	.19***	.33***	.35***	.37***	.83***	–
9. Computer use behavior 2018	5.09	2.54	1–7	.17***	.18***	.19***	.35***	.37***	.41***	.77***	.82***

*$p < .05$. **$p < .01$. ***$p < .001$.

were allowed to correlate at each time point. Because strong longitudinal invariance was demonstrated (see Supplementary Table 1), loadings and intercepts were equated across waves. The resulting measurement model had good fit to the data: χ^2 (170) = 1094.71, CFI = 0.967, TLI = 0.959, RMSEA = 0.040 (90% Confidence Interval (CI) [0.038, 0.042]), SRMR = 0.049. Secondly, we tested the structural model. Stationarity was demonstrated, $\Delta\chi^2$ (7) = 11.86, p = .105, so path coefficients were equated across waves. The resulting structural model had adequate fit to the data: χ^2 (447) = 3091.05, CFI = 0.935, TLI = 0.925, RMSEA = 0.042 (90% CI [0.040, 0.043]), SRMR = 0.050. Fig. 1 presents the autoregressive cross-lagged panel model with standardized path coefficients (β), while the unstandardized path coefficients (b) are reported below.

The autoregressive associations of self-perceptions of aging (b = 0.76, $p < .001$), cognitive functioning (b = 0.67, $p < .001$), and computer use behavior (b = 0.79, $p < .001$) were all significant, substantial, and positive. Supporting Hypothesis 1, the direct association from self-perceptions of aging at T1 to computer use behavior at T3 was significant and positive (b = 0.10, p = .021). Also supporting Hypothesis 2, the indirect association from self-perceptions of aging at T1 to computer use behavior at T3 was significant and positive (b = 0.017, $p < .001$, 95% CI [0.010, 0.025]). The cross-lagged associations from self-perceptions to cognitive functioning (b = 0.09, $p < .001$) and from cognitive functioning to use behavior (b = 0.20, $p < .001$) were all significant and positive, consistently with Hypotheses 2a and 2b, respectively. Lastly, the total association from self-perceptions of aging at T1 to computer use behavior at T3 was also significant and positive (b = 0.12, p = .007). Taken together, these results indicate that cognitive functioning partially mediates the relationship between self-perceptions of aging and computer use behavior over eight years.

In turn, although the direct and total associations from computer use behavior at T1 to self-perceptions of aging at T3 were both nonsignificant, the indirect association via cognitive functioning was significant and positive (direct: $b < 0.01$, p = .517; indirect: b = 0.002, p = .005, 95% CI [0.001, 0.003]; total: $b < 0.01$, p = .225). Still, all these associations were significantly different and weaker than their corresponding reverse patterns, that is, from self-perceptions at T1 to use behavior at T3 (direct: $\Delta\chi^2$ (1) = 6.67, p = .010; indirect: $\Delta\chi^2$ (1) = 14.93, $p < .001$; total: $\Delta\chi^2$ (1) = 8.84, p = .003). The cross-lagged associations from use behavior to cognitive functioning (b = 0.08, $p < .001$) and from cognitive functioning to self-perceptions (b = 0.02, p = .005) were also significant and positive, although significantly different and weaker than their corresponding reverse associations ($\Delta\chi^2$ (1) = 44.52, $p < .001$ and $\Delta\chi^2$ (1) = 9.97, p = .002, respectively). Although these results provide some evidence of reciprocal relationships between constructs, the associations from self-perceptions at T1 to use behavior at T3 were consistently stronger.

2.2.3. Multigroup analysis

Finally, we tested whether the relationships between self-perceptions of aging, cognitive functioning, and computer use behavior differed between middle-aged adults (50–64 years, M_{age} = 57.27, SD_{age} = 4.01, n = 1816) and older adults (65–93 years, M_{age} = 72.58, SD_{age} = 5.27, n = 1588). Partial strong multigroup invariance was demonstrated (see Supplementary Table 1), so loadings and intercepts were equated accordingly across groups. The constrained model did not differ

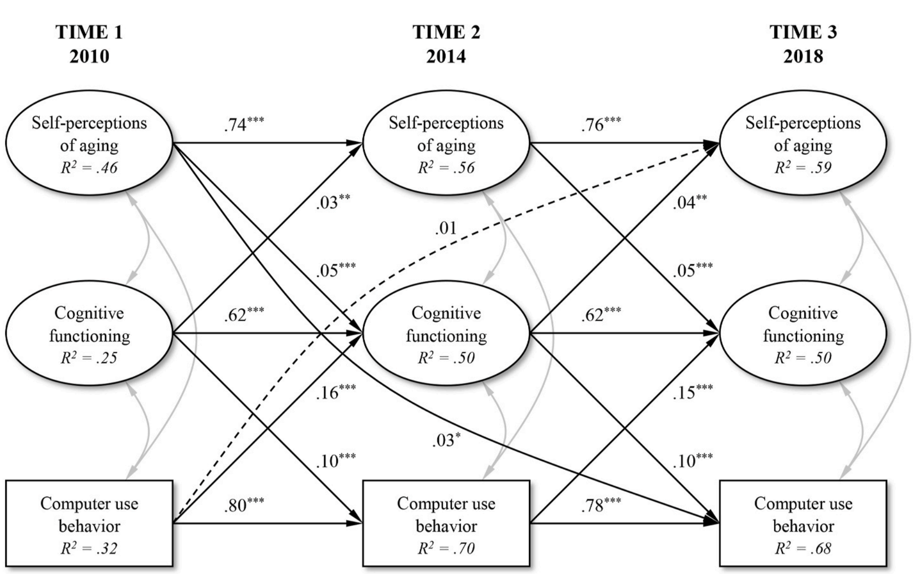

Fig. 1. Autoregressive cross-lagged panel model tested in Study 1. *Note.* All path coefficients and significance levels are standardized. The dotted lines indicate nonsignificant paths. R^2 represents the proportion of explained variance. *$p < .05$. **$p < .01$. ***$p < .001$.

significantly from the unconstrained model, $\Delta\chi^2$ (14) = 18.69, p = .177, indicating comparable cross-lagged associations across age groups.

2.3. Discussion

Study 1 suggests that individuals' beliefs about their aging experience influence their behavior toward technology in late adulthood. As predicted, self-perceptions of aging were associated with computer use behavior over eight years, with more positive self-perceptions being related to higher levels of use behavior. Moreover, cognitive functioning partially mediated this relationship, such that positive self-perceptions were associated with better cognition, which was then related to greater computer use.

Nonetheless, some limitations should be noted. Firstly, despite controlling for employment status, we were unable to fully account for potential confounding effects of computer use in the workplace due to the general measure of use frequency. Secondly, we focused solely on episodic memory as an indicator of cognitive functioning, which limits the generalizability of these results to other domains of cognition. Study 2 aimed to address these limitations, while also extending the findings of Study 1.

3. Study 2

Based on the German Ageing Survey, our second study further explored the relationships between self-perceptions of aging, cognitive functioning, and computer use behavior over three years among individuals aged 40 or older from Germany. To avoid potential confounding effects of computer use for work activities, we focused on use behavior during individuals' free time. Moreover, we focused on processing speed, an important contributor to age differences in cognitive functioning (Salthouse, 1996). Self-perceptions of aging have been found to be reciprocally related to processing speed over time (Seidler & Wolff, 2017). Although processing speed is an important predictor of computer-based task performance (Czaja et al., 2001; Czaja & Sharit, 1998a; Sharit et al., 2015), longitudinal evidence for an association between processing speed and computer use is lacking (Slegers et al., 2012). Overall, we expected the relationship between self-perceptions of aging and computer use behavior to be mediated by cognitive functioning as indicated by processing speed.

3.1. Method

3.1.1. Participants

The German Ageing Survey (DEAS, Klaus et al., 2017) is a nationally representative cohort-sequential survey of the German population aged 40 years or over. The DEAS is funded by the German Federal Ministry for Family Affairs, Senior Citizens, Women and Youth (BMFSFJ; grant number 301-6083-05/003*2) and is organized by the German Centre of Gerontology (DZA). Data collection consists of a computer-assisted personal interview and a "drop-off" self-completed questionnaire. The present study is based on all respondents aged 40 years or older who completed the personal interview and the drop-off questionnaire in 2014 and 2017 (Time 1 [T1] and Time 2 [T2], respectively; n = 4871), the most recent waves that included the same measures of self-perceptions of aging, cognitive functioning, and computer use behavior.

3.1.2. Measures

Self-perceptions of Aging. As in Study 1, five items from the Attitude Toward Own Aging subscale of the Philadelphia Geriatric Center Morale Scale (Lawton, 1975) assessed self-perceptions of aging. Response options ranged from 1 (*strongly agree*) to 4 (*strongly disagree*). Positively phrased items were reverse coded so that higher scores reflected more positive self-perceptions of aging (Cronbach's alpha: α_{T1} = 0.72, α_{T2} = 0.75).

Cognitive Functioning. Processing speed was chosen as an indicator of cognitive functioning and assessed with the Digit Symbol Substitution Test (Wechsler, 1955). The test sheet included a key pairing symbols with digits 1 to 9 and a list of those same digits randomly repeated 100 times with blank spaces underneath. Participants were asked to copy the corresponding symbol under each digit. After completing seven examples as practice, participants filled as many blanks as possible within 90 seconds. Processing speed was coded as the total number of correct responses, ranging from 0 to 93, with higher values indicating better cognitive functioning.

Computer Use Behavior. A single item assessed computer use: "How often do you work with computers in your spare time, i.e., use of internet, e-mails, or playing computer games?". Response options ranged from 1 (*daily*) to 6 (*never*) and were reverse coded so that higher scores indicated more frequent computer use.

Covariates. Age (in years), education, gender (1 = *female*), marital status (1 = *married*), employment status (1 = *working*), region (1 = *East Germany*), income, subjective health, physical conditions, depressive symptoms, and loneliness assessed at baseline were included as covariates. 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). Region was reported as East or West Germany. Income was based on the monthly household income, which was log transformed to correct skewness. Subjective health ("How would you rate your present state of health?") was rated from 1 (*very good*) to 5 (*very bad*). Physical conditions were scored as the sum of 11 illnesses. Depressive symptoms were scored as the sum of 15 items from the German version of the Center for Epidemiologic Studies Depression Scale (CES-D; Hautzinger & Bailer, 1993; Radloff, 1977; α = 0.85). Loneliness was scored as the mean of six items from the Loneliness Scale by Gierveld and Tilburg (2006; α = 0.83). Responses were reverse coded as appropriate so that higher values indicated greater levels of the corresponding construct.

3.1.3. Analysis

A two-wave autoregressive cross-lagged panel design was used to test longitudinal mediation (Cole & Maxwell, 2003; Little et al., 2007). We followed the same analytical approach as in Study 1, with some exceptions. Only self-perceptions of aging were modeled as latent factors. Cognitive functioning, computer use behavior, and all covariates were modeled as observed variables. Given the two-wave design, stationarity was assumed true as observed in Study 1 (Little et al., 2007). Following the procedure recommended by Cole and Maxwell (2003), the indirect association of self-perceptions of aging on computer use behavior through cognitive functioning was estimated based on the product of path a (i.e., the regression of cognitive functioning at T2 on self-perceptions of aging at T1) and path b (i.e., the regression of computer use behavior at T2 on cognitive functioning at T1). An analogous procedure was used to estimate the indirect association of computer use behavior on self-perceptions of aging through cognitive functioning.

3.2. Results

3.2.1. Descriptive analysis

Table 1 presents the sample characteristics at baseline. Age ranged from 40 to 94 years (M = 63.92). Education averaged between *medium* and *high* (M = 2.41), with slightly under half of participants having high education (45.68%). About half were women (50.79%) and the majority was married (73.17%). Close to one third were employed (37.20%). A similar proportion lived in East Germany (32.99%). Subjective health averaged between *average* and *good* (M = 3.58). Physical conditions (M = 2.50), depressive symptoms (M = 6.25), and loneliness (M = 1.76) were low.

Correlations between the main variables across the two waves are shown in Table 3. Similarly to Study 1, self-perceptions of aging were

Table 3
Means, standard deviations, and correlations between the main variables across the two waves in Study 2.

Variables	*M*	*SD*	*Range*	1	2	3	4	5
1. Self-perceptions of aging 2014	3.01	0.53	1–4	–				
2. Self-perceptions of aging 2017	2.96	0.54	1–4	.64***	–			
3. Cognitive functioning 2014	46.26	13.02	1–92	.18***	.20***	–		
4. Cognitive functioning 2017	45.57	13.70	0–91	.17***	.22***	.73***	–	
5. Computer use behavior 2014	4.04	2.12	1–6	.16***	.18***	.31***	.32***	–
6. Computer use behavior 2017	4.18	2.13	1–6	.16***	.19***	.34***	.36***	.82***

*$p < .05$. **$p < .01$. ***$p < .001$.

moderately positive, cognitive functioning was at the midpoint, and computer use was moderately frequent. Self-perceptions were significantly and positively related to use behavior across waves. Cognitive functioning was significantly and positively associated with both, but more strongly with computer use.

3.2.2. Longitudinal analysis

Firstly, we tested the measurement model. As suggested by the modification indices, the residuals of items 1 and 3 within the self-perceptions of aging latent factors were allowed to correlate at each time point. Strong longitudinal invariance was demonstrated (see Supplementary Table 2). The measurement model had good fit to the data: χ^2 (35) = 499.09, CFI = 0.966, TLI = 0.956, RMSEA = 0.052 (90% CI [0.048, 0.056]), SRMR = 0.036. Secondly, we tested the structural model, which had adequate fit to the data: χ^2 (189) = 2204.23, CFI = 0.931, TLI = 0.911, RMSEA = 0.047 (90% CI [0.045, 0.049]), SRMR = 0.036. Fig. 2 presents the autoregressive cross-lagged panel model with standardized path coefficients (β). The unstandardized path coefficients (b) are reported below.

The autoregressive associations of self-perceptions of aging (b = 0.82, $p < .001$), cognitive functioning (b = 0.73, $p < .001$), and computer use behavior (b = 0.79, $p < .001$) were all significant, substantial, and positive. Supporting Hypothesis 1, the direct association from self-perceptions of aging at T1 to computer use behavior at T2 was significant and positive (b = 0.11, p = .039). Also supporting Hypothesis 2, the indirect association from self-perceptions of aging at T1 to computer use behavior at T2 was significant and positive (b = 0.029, $p < .001$, 95% CI [0.016, 0.042]). The cross-lagged associations from self-perceptions at T1 to cognitive functioning at T2 (b = 2.04, $p < .001$) and from cognitive

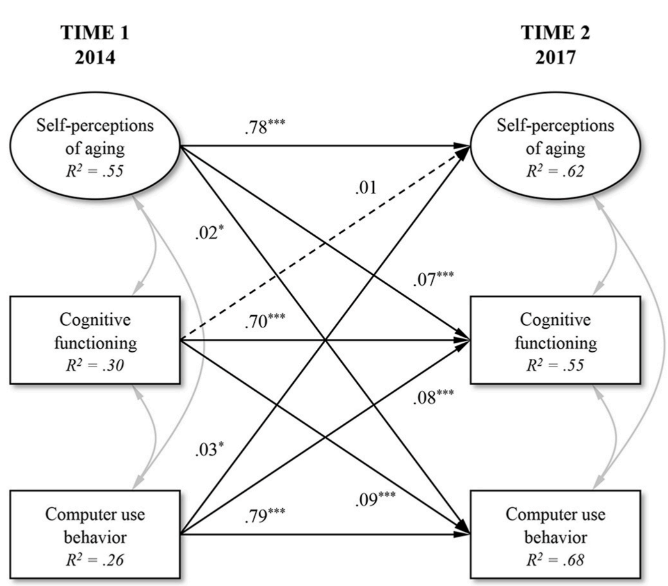

Fig. 2. Autoregressive cross-lagged panel model tested in Study 2. *Note.* All path coefficients and significance levels are standardized. The dotted lines indicate nonsignificant paths. R^2 represents the proportion of explained variance. *$p < .05$. **$p < .01$. ***$p < .001$.

functioning at T1 to use behavior at T2 (b = 0.01, $p < .001$) were both significant and positive, in line with Hypotheses 2a and 2b, respectively. Lastly, the total association from self-perceptions of aging at T1 to computer use behavior at T2 was also significant and positive (b = 0.14, p = .010). Overall, these results show that cognitive functioning partially mediates the relationship between self-perceptions of aging and computer use behavior over three years.

In turn, although the direct and total associations from computer use behavior at T1 to self-perceptions of aging at T2 were both significant and positive, the indirect association via cognitive functioning was nonsignificant (direct: b = 0.01, p = .042; indirect: b = 0.000, p = .405, 95% CI [0.000, 0.001]; total: b = 0.01, p = .033). These associations were significantly different and weaker than those from self-perceptions at T1 to use behavior at T2 (direct: $\Delta\chi^2$ (1) = 4.40, p = .036; indirect: $\Delta\chi^2$ (1) = 90.69, $p < .001$; total: $\Delta\chi^2$ (1) = 7.08, p = .008). The cross-lagged association from use behavior at T1 to cognitive functioning at T2 was significant and positive (b = 0.55, $p < .001$), as well as significantly different and stronger than its reverse association ($\Delta\chi^2$ (1) = 50.49, $p < .001$). The cross-lagged association from cognitive functioning at T1 to self-perceptions at T2 was nonsignificant ($b < 0.01$, p = .397), besides being significantly different and weaker than its reverse association ($\Delta\chi^2$ (1) = 25.52, $p < .001$). These results provide some evidence of reciprocal relationships between constructs.

3.2.3. Multigroup analysis

Finally, we tested whether the relationships between self-perceptions of aging, cognitive functioning, and computer use behavior differed between middle-aged adults (40–64 years, M_{age} = 55.38, SD_{age} = 6.21, n = 2510) and older adults (65–94 years, M_{age} = 73.01, SD_{age} = 5.47, n = 2361). Partial strong multigroup invariance was demonstrated (see Supplementary Table 2). The constrained and unconstrained models did not differ significantly, $\Delta\chi^2$ (6) = 8.49, p = .205, suggesting no age differences in the cross-lagged associations.

3.3. Discussion

Study 2 provides further support for the relationship between self-perceptions of aging and computer use behavior, as well as the role of cognitive functioning. Consistently with Study 1, positive self-perceptions were associated with greater use behavior over three years and this relationship was partially mediated by cognitive functioning. Besides addressing its shortcomings, Study 2 reinforced the findings of Study 1 by extending them to another country sample, cognitive domain, and use measure.

4. General discussion

The present research examined self-perceptions of aging as potential determinants of information and communication technology use in late adulthood. Across two longitudinal studies, more positive perceptions about individuals' aging experience were associated with more frequent computer use over time. This relationship was partially mediated by cognitive functioning, such that more positive self-perceptions of aging were associated with better cognitive performance, which was then associated with higher levels of computer use behavior. Confirming the robustness of these findings, this was replicated across different dimensions of cognitive functioning, different measures of computer use, and two samples from different countries, namely American individuals aged 50 or older over eight years and German individuals aged 40 or older over three years. Although past research exploring this relationship revealed mixed findings (Cody et al., 1999; Yoon et al., 2016), both studies confirmed longitudinally the positive association between self-perceptions of aging and computer use behavior, while also identifying cognitive functioning as an underlying mechanism.

These findings emphasize the importance of considering societal factors to better understand how older individuals relate to information and communication technology (Lagacé et al., 2015; Mariano et al., 2021; Mariano, Marques, Ramos, Gerardo, & de Vries, 2020). The internalization of stereotypical beliefs about age and aging into self-perceptions of aging (Levy, 2009) may positively or negatively impact relevant predictors of use behavior, thus facilitating or compromising technology use. Although the present research focused on cognitive functioning, technology-related self-efficacy may also play a mediating role. Following from the stereotype embodiment theory (Levy, 2009), stereotypes about older age groups as less technologically competent may be internalized, leading older individuals to perceive their own ability to use technology more negatively and consequently avoid using technology. This is consistent with studies showing that older age groups tend to report lower technology self-efficacy (Czaja et al., 2006; Czaja & Sharit, 1998b; Lee et al., 2019). In fact, existing evidence suggests that cognitive performance and self-efficacy are interrelated determinants of use behavior. Czaja et al. (2006) found that fluid cognition and computer self-efficacy mediated the relationship between age and technology use. Specifically, those with better cognitive performance were more likely to have positive beliefs about their computer ability, indicating that older individuals also base their self-efficacy beliefs on their level of cognitive functioning. This suggests that self-perceptions of aging may indirectly influence technology use through multiple interrelated pathways and that interventions targeting perceptions about own aging may simultaneously address different determinants of use behavior. Promoting positive perceptions about age and aging has been shown to reliably improve health-related behaviors and outcomes, namely physical activity and functioning (Brothers & Diehl, 2017; Levy, Pilver, Chung, & Slade, 2014; Wolff, Warner, Ziegelmann, & Wurm, 2014). Future research should examine whether similar interventions would be equally effective in promoting cognitive functioning and technology use among older age groups.

Despite some inconsistencies between studies, reciprocal relationships were observed between self-perceptions of aging and computer use behavior, indicating that these factors may influence each other mutually over time. More frequent use behavior was directly associated with more positive self-perceptions over three years, but not over eight years. Moreover, greater use behavior was indirectly associated with positive self-perceptions via episodic memory, but not through processing speed. These findings suggest that, to some extent, computer technology may also influence how older individuals perceive their aging experience by contributing to their health and well-being. Nonetheless, the strength of the associations observed in both studies indicates that self-perceptions of aging are primarily an antecedent rather than an outcome of use behavior. Furthermore, Cody et al. (1999) found no support for the impact of technology use on self-perceptions of aging, as older adults' perceptions about their own aging did not significantly change after participating in an internet training program over four months. Given these inconclusive findings, future research should further explore the potential of information and communication technology to improve self-perceptions of aging.

Our studies also contribute to research exploring the relationship between cognition and information and communication technology by corroborating the consistent finding that better cognitive performance is associated with higher use behavior in late adulthood (Czaja et al., 2006; Mitzner et al., 2019; Tun & Lachman, 2010). Although past research has considered cognitive functioning either as an antecedent or an outcome of technology use in isolation, recent studies began to explore their reciprocal relationships over time. Kamin and Lang (2018) found evidence of bidirectional associations between global cognition and internet use over two years among individuals aged 50 or older across 14 European countries. Yu and Fiebig (2020) observed similar reciprocal patterns over four years among Chinese individuals aged 45 or older. Hartanto et al. (2020) also found reciprocal associations between computer use and executive function over nine years among Americans aged 30 or older. Adding to this research, our findings indicate that computer use is reciprocally associated with episodic memory over eight years and processing speed over three years in American and German samples of individuals aged 50 and 40 years or older, respectively. Furthermore, our studies contribute to research on the relationship between self-perceptions of aging and cognitive functioning. Although existing evidence on the longitudinal association from age stereotypes and self-perception of aging to memory performance has been somewhat inconsistent (Levy et al., 2011; Robertson et al., 2016), we found a reciprocal relationship over eight years. Consistently with Seidler and Wolff (2017), self-perceptions of aging were also associated with processing speed over three years, although not reciprocally. Overall, our findings suggest that self-perceptions of aging mainly determine, rather than reflect, cognitive functioning in late adulthood.

Future studies should examine the interplay between self-perceptions of aging, cognitive functioning, and technology use behavior in greater detail. For instance, age stereotypes and self-perceptions of aging are multidimensional constructs (Kornadt & Rothermund, 2012; Steverink, Westerhof, Bode, & Dittmann-Kohli, 2001) and their impact is stronger when the dimensions match the outcome domains (Levy & Leifheit-Limson, 2009). This suggests that specific dimensions that are more closely related to the technological domain, such as individuals' perceptions about cognitive decline as they age, may be particularly influential with regards to their use behavior. Concerning cognitive functioning, existing evidence suggests that self-perceptions of aging influence fluid but not crystallized abilities (Siebert et al., 2018). Although both fluid and crystalized cognition are important correlates of technology use (Czaja et al., 2006), self-perceptions of aging may only influence use behavior to the extent that they positively or negatively impact fluid functioning. Because our studies focused on episodic memory and processing speed, two components of fluid functioning, future research should explore the role of crystallized cognition on the relationship between self-perceptions of aging and use behavior. Future studies should also investigate the generalizability of our findings to different technological devices and activities. By identifying cognitive functioning as a mediating mechanism, our studies suggest that self-perceptions of aging may be particularly beneficial or detrimental in relation to more cognitively demanding devices or activities. Future research should examine this possibility by considering other information and communication technologies and relying on more detailed measures of use behavior that specify which activities are performed with a given device. Lastly, the mutual influence between computer use behavior and cognitive performance raises the interesting hypothesis that self-perceptions of aging may indirectly determine cognition through technology use. Indeed, the stereotype embodiment theory (Levy, 2009) asserts that the internalization of age stereotypes into self-perceptions of aging impacts functioning and health through behavioral pathways. Future studies should explore this possibility while also using more comprehensive indicators of technology use and functional health.

The existing digital divide between generations underscores the need to promote the adoption of technological tools among the older population by addressing the factors that contribute to these inequalities. Stereotypical perceptions about age and aging can be one such factor. Often shaped by societal views of the aging process and older people, negative perceptions about their own aging may deter individuals from engaging with information and communication technology in late adulthood. Support for the longitudinal relationship between self-perceptions of aging and computer use behavior was found among American and German middle-aged and older adults. The mediating role of cognitive functioning further suggests that self-perceptions of aging exert their influence through major determinants of use behavior. Future studies should investigate self-efficacy as another potential mediator. Thus, self-perceptions of aging emerge as an important modifiable factor to consider when promoting technology use among older age groups.

Credit author statement

João Mariano: Conceptualization, Methodology, Formal analysis, Data curation, Writing – original draft; Sibila Marques: Conceptualization, Writing – review & editing; Miguel R. Ramos: Validation, Writing – review & editing; Hein de Vries: Conceptualization, Writing – review & editing.

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Declaration of competing interest

None.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.chb.2021.106807.

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