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Comparing the Effectiveness of Two Theory-Based Strategies to Promote Cognitive Training Adherence

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This study compared the effectiveness of two theory-based strategies to promote cognitive training adherence among older adults (M_{age} = 70 years, *SD* = 4.42, range = 64–84). Strategies incorporated either (a) elements of implementation intention formation or (b) positive message framing, both of which have been found to promote adherence to health behaviors in other domains. Participants (*N* = 120) were asked to engage in technology-based cognitive training at home comprised of seven gamified neuropsychological tasks. In Phase 1 (structured), participants were provided a schedule that required engagement in 1 hr of cognitive training 5 days each week over 2 months. In Phase 2 (unstructured), participants were instructed to engage with the intervention as much as they desired for 1 month. Contrary to expectations, neither the implementation intention nor positive message framing produced greater adherence relative to control as measured by the total number of training sessions completed in each phase. However, exploratory analysis indicated a greater likelihood of intervention engagement for participants assigned to the implementation intention condition on many days of the intervention, though the trajectory of engagement decline was similar for all three groups. Measures of cognition, attitudes/personality, and technology proficiency also did not predict adherence over either phase.

Public Significance Statement

Discovering effective strategies to boost adherence can aid in ensuring maximal benefit is derived from effective interventions, both for the individual and for society. Regardless of the debated efficacy of cognitive training, the present study is relevant to our understanding of adherence to technology-based interventions in general and behavioral approaches to address cognitive decline. Adaptive, technology-based reminder systems may hold more promise compared to traditional behavioral interventions to promote adherence.

Keywords: adherence, cognition, implementation intention, positive message framing, technology

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A growing body of evidence suggests that behavioral and lifestyle interventions might improve cognition and preserve everyday functioning later in life (Corbett et al., 2015; Kramer & Colcombe, 2018; Ngandu et al., 2015; Rebok et al., 2014; Smith-Ray et al., 2014; Wolinsky et al., 2015). Building a better understanding of the factors that shape adherence to these types of interventions has significant implications. The discovery of effective strategies to boost adherence can aid in ensuring maximal

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benefit is derived from effective interventions, both for the individual (improved cognition and functional independence) and for society (fewer resources needed to support individuals with declining ability). Further, the ability to predict adherence at the individual level has additional benefits: for individuals predicted to struggle with adherence, targeted support can be provided, and prediction also allows for better forecasting of the benefits individuals will experience.

Cognitive training has been of particular interest to both scientists and the public as a potential method to improve cognition later in life. Bold claims have been made that cognitive training can prevent automobile crashes (Ball et al., 2010) and reduce dementia risk (Edwards et al., 2017) among older adults. Others, on the other hand, have outright rejected the potential of cognitive training based on advanced meta-analytic techniques indicating no effect (Gobet & Sala, 2023) and methodological flaws present in many studies (Simons et al., 2016). Even though cognitive training efficacy is uncertain (e.g., Basak et al., 2020; Butler et al., 2018; Nguyen et al., 2019; Sala et al., 2019), studying adherence to home-based cognitive training can serve as a useful test bed for a broader understanding of methods to boost and predict adherence to technology-based interventions, including interventions aimed at reducing social isolation, increasing physical activity (e.g., exergaming), or improving health through telehealth technology, areas that have grown in importance since the COVID-19 pandemic. Using a cognitive training paradigm to advance understanding of adherence to technology-based and behavioral interventions to boost cognition is desirable in that, if critics of cognitive training efficacy are right, missed cognitive training sessions are of little consequence to the health, safety, and well-being of participants (as the treatment is essentially inert). For these reasons, the current article focused on boosting and understanding adherence to cognitive training.

It is generally recognized that there are multiple barriers to adherence. Inadvertent forgetfulness, inability to follow recommendations due to a lack of comprehension, and negative attitudes regarding intervention efficacy are a few examples. However, adherence is also related to an individual's ability to develop adequate habitual routines and is associated with automatic behaviors triggered by environmental cues (Strack & Deutsch, 2004). Thus, this study compares the effectiveness of two theory-based strategies to promote adherence to cognitive training related to these barriers—the use of implementation intention to strengthen habit and positive message framing to enhance motivation.

Positive-Framed Messages

The premise that altering how health communication information is framed can affect people's behavioral decisions was originally motivated by prospect theory (Tversky & Kahneman, 1985). The message-framing literature has often focused on the different effects of positive- and negative-framed messages; positive-framed messages focus on the benefits of engaging in a certain behavior, whereas negative-framed messages often focus on the consequences of not engaging in the behavior. Therefore, the risks and uncertainties associated with health behavior can be expected to influence the form of framing that is most likely to motivate or promote behavior (Rothman & Salovey, 1997; Updegraff & Rothman, 2013). As a recent example, Mikels et al. (2020) showed that positive-framed messages can generate positive affect, in turn increasing intention as well as actual engagement in physical exercise. This demonstrates that motivational engagement due to positive message framing can occur without the individual even being aware of conscious involvement or intention (Michaelsen & Esch, 2021). Similar to implementation intention, positive-framed messages have been used to shape behaviors related to skin cancer prevention, smoking cessation, and physical activity engagement (Gallagher & Updegraff, 2012). Moreover, research has shown that older people appear to prefer, attend to, and remember positive information better than negative information (Löckenhoff & Carstensen, 2007; Mather et al., 2005), making this approach especially suitable in the context of cognitive training. Older adults also find positive messages to be more motivating (Reed & Carstensen, 2012), which suggests that positive framing can aid goal attainment by promoting behavior change when an intervention in and of itself is not influential enough to maintain adherence. In a recent study, Harrell et al. (2021) demonstrated that message framing can impact adherence to technology-based cognitive interventions under certain conditions. Notably, Harrell et al. (2021) found that while positive-framed messages encouraged greater adherence over negative-framed messages, this effect was only seen when participants were not exposed to social pressure in the form of a predetermined schedule designating a frequency and duration with which they were expected to engage in the intervention. This finding shows that study conditions and other antecedents to information processing such as individual difference and attitudinal variables should also be considered as impression motivations (e.g., social pressure) can play a role in the effectiveness of message framing (Nan et al., 2018). In fact, past research has shown that often health behaviors like adherence are shaped by implicit emotions and autonomous, noncognitive motives rather than cognitive willpower (Hall & Fong, 2007; Kahneman & Tversky, 1982; Strack & Deutsch, 2004). For example, if there is a match between an individual's motivation orientation and framing of the message, it can lead to a sense of "feeling right" (Cesario et al., 2008) when one evaluates the message and engages in the behavior. Thus, while gain-framed messaging may be helpful in improving reflective behavior, if adherence failure is resulting from automatic behavior failure, implementation intention formation may be a better resource to promote behavior change.

Implementation Intention

An implementation intention is a self-regulatory strategy in the form of an "if-then plan" that can lead to better goal attainment by specifying when, where, and how a person will instigate responses that promote goal realization (Gollwitzer & Sheeran, 2006). Implementation intentions have the structure of "When situation x arises, I will perform response y" and thus link anticipated opportunities with goal-directed responses (Gollwitzer, 1999). Take, for example, an older adult who has the goal intention of engaging in cognitive training. Implementation intention formation helps to specify when, where, and how ~~of~~ responses ~~that~~ will lead to attaining this goal (e.g., After each meal at home, I will use my tablet for 20 min to improve my cognition). In the example mentioned above, when an initially goal-directed behavior becomes habitual (engaging in 20 min of cognitive training on his/her tablet), the initiation of the action transfers from conscious motivational

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processes to context-cued impulse-driven mechanisms (Gardner & Rebar, 2019). Since goal-directed behavior usually involves an intention or plan, the upper limbic level (i.e., the orbitofrontal and ventromedial cortex) is involved when stimuli are processed and goals are formed (Michaelsen & Esch, 2021). As a result, the stimulus or context cue can activate automatic processes and lead to the desired behavior without the individual consciously being aware of involvement (Michaelsen & Esch, 2021) increasing the odds that the behavior will be maintained.

The overarching benefit of implementation intention formation is that it is a self-regulatory tool unaffected by age-related cognitive decline that has been shown to be effective at increasing adherence to health behaviors in older adults over sustained periods of time (Liu & Park, 2004). The effectiveness of implementation intention formation in promoting adherence to health behaviors has been demonstrated in studies of (a) smokers (Webb et al., 2009), (b) stroke survivors (Liu & Park, 2004), (c) individuals with epilepsy (Brown et al., 2009), and (d) medication-taking routines (Chambers et al., 2011). Additionally, implementation intentions have been shown to be helpful in increasing adherence to medication and health behaviors in which patients wanted to adhere as well as in situations in which patients were already exhibiting noncompliance (Alhalaiqa et al., 2012).

Individual Difference and Attitudinal Variables

Aside from being impacted by reflective and automatic factors, adherence is also likely due to a host of individual difference and attitudinal factors, some of which may be moderated by repetition and habit development (Gardner & Rebar, 2019). Numerous studies have shown that the mental associations that underlie habits tend to develop most strongly or quickly where actions are intrinsically rewarding and are completed in response to cues that are salient and consistently encountered (Lally & Gardner, 2013; McDaniel & Einstein, 1993; Radel et al., 2017). This is in alignment with the theory of planned behavior in that the more favorable a behavior is, the more likely one is to perform the behavior (Ajzen, 1987).

Even though older adults may intend to adopt positive health behaviors, they may be reluctant to commit to doing so if they perceive the distance between goal setting and goal attainment as being far (Gollwitzer, 1990). This may be particularly relevant for cognitive training as it is often delivered via technology. Technology-based barriers to adherence can exist for older adults due to lower rates of technology use and adoption and relatedly lower amounts of technology proficiency relative to younger adults. For example, according to a Pew Research Center survey of U.S. adults conducted in 2021, approximately 96% of adults ages 18–49 said they owned a smartphone, compared to only 61% of adults ages 65 and older (Pew Research Center, 2021). Older adults, on average, have lower levels of, and more varied, technology proficiency compared to younger adults for a range of technologies (Boot et al., 2015; Roque & Boot, 2018). Therefore, from a motivational perspective, technology use may also be influenced by both intrinsic and extrinsic reasons (Davis et al., 1992). While motivation was anticipated to play a large role in decision making and adherence, so were other constructs such as memory, self-efficacy, and general cognitive functioning. A systematic review of health behavior change theories conducted by Kwasnicka et al. (2016) identified five common themes relevant to adherence: maintenance motivation, self-regulation, resources, habits, and environmental and social influences, except for habit, all of the themes involved cognitive awareness, which is why measures such as the General and Technology Self-Efficacy Scales, Perceived Deficits Questionnaire, and Brain Training and Independence Survey were included among other measures of cognitive functioning in our battery (see Table 1).

Study Aims

Considering the importance of adherence in shaping intervention success, the present study explored the novel approach of combining implementation intention support (Gollwitzer & Sheeran, 2006) with cognitive training to improve adherence and compared adherence in this condition to the effect of positive-framed messaging (Harrell et al., 2021; Notthoff & Carstensen, 2014). These comparisons were used to further investigate the following hypotheses: (a) Participants who received positive-framed motivational messages that emphasized the benefits of engaging in cognitive training would exhibit greater adherence than participants in the control condition who did not receive these messages; (b) Participants who were encouraged to develop implementation intentions (if-then planning strategies) would have higher adherence rates than participants who received positive messages or were in the control group; and (c) Higher scores on individual difference and attitudinal predictors like memory, self-efficacy, cognitive functioning, and technology proficiency would be associated with greater adherence.

To explore the effectiveness of these two approaches and the influence of individual difference and attitudinal factors on adherence in the presence and absence of social pressure, the intervention was divided into two phases. During the first phase (8 weeks), a training schedule was provided to create the presence of social pressure, whereas during the second phase (4 weeks), participants were told that they could conform to their own schedule (i.e., play as much as little as they wanted).

Method

Transparency and Openness

This study was preregistered with the Open Science Framework (OSF; https://osf.io/h4nv9).

Data

Data are not publicly available as the authors plan to conduct further analyses. In the future, subsets of the data may be approved by request.

Analytic Methods

The analytic codes to produce the analyses are available as Jamovi, JASP, and RMarkdown files at https://osf.io/ybhp5.

Sample

Power analysis performed in Gpower predicted that a sample size of 120 participants would be needed to detect a medium effect (Cohen's $f = .25$; medium effect) with a power of .80 for three

Table 1
Individual Difference Predictor Measures Used in Analyses

Construct	Measures	Sources
Demographics	Background Questionnaire	Adapted from a survey developed by the Center for Research and Education on Aging and Technology Enhancement
Objective cognition, vocabulary (crystallized intelligence)	Shipley Vocabulary	Shipley (1940)
Objective cognition, memory	Hopkins Verbal Learning Test and Hopkins Delayed Recall	Brandt and Benedict (2001)
Objective cognition, reasoning ability	Letter Sets	Ekstrom et al. (1976)
Self-efficacy	General Self-Efficacy Questionnaire	Schwarzer and Jerusalem (1995)
	Technology Self-Efficacy	Adapted from the General Self-Efficacy Scale by Schwarzer and Jerusalem (1995)
Technology proficiency	CPQ-12	Boot et al. (2015)
	MDPQ-16	Roque and Boot (2018)
Perceived benefits	Brain Training Belief Scale	Rabipour and Davidson (2015)
	Brain Training and Independence (motivation) Survey	Harrell et al. (2019)
Subjective cognition	Perceived Deficits Questionnaire	Adapted from the MSQLI by Sullivan et al. (1990)

Note. CPQ = Computer Proficiency Questionnaire; MDPQ = Mobile Device Proficiency Questionnaire; MSQLI = Multiple Sclerosis Quality of Life Inventory.

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groups and two measurement time points. This effect size is slightly conservative compared to the medium-to-large effect (Cohen's $d = .65$ or Cohen's f of approximately 0.325) observed in a meta-analysis conducted by Gollwitzer and Sheeran (2006) examining the impact of implementation intention strategies on goal attainment. One hundred twenty adults aged 64 years and older were recruited from Leon County, Florida, and the surrounding area and completed written informed consent prior to beginning the study. The research was conducted in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki): Human Subjects Committee No. 2018:25270.

Prescreening ensured that participants were cognitively healthy and able to provide consent. Competency was determined by the score (two or fewer errors) on the Short Portable Mental Status Questionnaire in addition to the required recall of six or more items from Story A or four or more items from Story B on the Wechsler Memory Scale–III. The most common reasons for exclusion were not passing the Weschler Memory Scale screening or reporting current involvement in a cognitive training program such as Lumosity or CogniFit.

Of the 120 participants recruited, only 116 completed the structured phase of the study, including the cognitive measures that were given at baseline and after 8 weeks of structured gameplay. Participant age ranged from 64 to 84 years with an average of 70 years ($SD = 4.42$ years). Seventy-seven participants were female (64.2%) and 43 were male (35.8%). The majority (90%) identified as being White/Caucasian, and all participants had completed at least high school or passed the General Educational Development test signifying that the individual possesses the equivalent knowledge of a person who completed a traditional high-school education.

While the intent was for participants to complete both phases of the study, the second phase of the study did not require that participants engage with the gaming intervention for any predetermined length of time. Data were analyzed independently for each phase with comparisons between both phases only including those participants who completed the structured phase and agreed to keep the tablet computer in their possession for the unstructured phase ($N = 87$).

Participants received a total of $75.00 in cash for being in the study with payment based on the completion of planned sessions. Participants received $25 after completing their first two sessions (baseline testing and tablet and game training). They received another $25 after completing their second two sessions following 2 months of at-home training. The remaining $25 was distributed when participants returned for the final session, completed an exit interview, and returned the tablet.

Materials and Design

Surveys and cognitive tests were administered before the start of the intervention to establish baseline characteristics. Demographic information, personality variables, technology experience, computer and mobile device proficiency, and belief in the efficacy of cognitive training measures were collected using similar measures as Harrell et al. (2019), who found both attitudinal and cognitive abilities to be important for predicting hypothetical willingness to engage in technology training. All measures can be found in Table 1 with a description of what was assessed.

The intervention was delivered to all participants via 10-in. Lenovo tablets utilizing an Android operating system that was version six or higher. Three types of tablets were used: TB2 A10-70F, TB-X304F, and TB3-X70F. All tablets used the Clyd Kiosk[1] software to restrict participants to the Mind Frontiers application, a Wild West-themed suite of games, that was used for cognitive training. While previous studies have used the Mind Frontiers application (see Harrell et al., 2021; Souders et al., 2017), this study used Mind Frontiers Version 2.4.11. It should be noted that while this study was investigating the effectiveness of theory-based adherence strategies, the Mind Frontiers application was chosen as the cognitive training intervention due to it comprising seven different gamified neuropsychological tasks aimed at

[1] Clyd Kiosk Standalone is a free Kiosk solution that allows users to lock down the screen to restrict the use of applications. Clyd Kiosk blocks the user from being able to download content, install applications, access the internet, or access or modify any of the preset system settings.

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exercising working memory, processing speed, executive control, and spatial reasoning (a full description of each of the games can be found in Harrell et al., 2021).

Participants were randomized into one of three conditions (implementation intention messages, positive-framed messages, no messages). Participants in the message conditions would receive messages coinciding with their respective condition (implementation intention or positive frame; see Supplemental Material A) each time they logged into the tablet to engage in training. Participants randomized to the positive-framed message condition were given motivational messages (e.g., "Studies have found that people who engage in mentally stimulating activities have better memory later in life") to emphasize the benefit of their participation, while those in the implementation intention condition received messages encouraging them to develop a plan that matched their needs for the duration of the study (e.g., "Form a plan! People who plan when and where they will engage in training are less likely to miss a session"). Implementation intention participants were also provided with a handout adapted from Brown et al. (2009) to help them plan how they would facilitate adherence by linking training sessions to another activity in their daily schedule. For participants in the message conditions, the message would appear on the screen for 20 s to allow ample time for reading the message. Participants randomized to the control or no-message group did not receive a message when they engaged in training.

All participants, regardless of condition, were given a packet of information, including (a) Mind Frontiers-specific information, that is, information about each game and its overarching purpose including which cognitive skill(s) was being targeted; (b) tablet-specific information (e.g., how to power on/off the device and adjust the volume); and (c) support-specific information (i.e., the phone number to contact the lab for more information). This take-home packet also included a copy of the recommended games to be played during each of the five training sessions per week and emphasized that training should last for 60 min per session, which participants would be responsible for planning and tracking.

Procedure

Participants who passed the prescreening and consented to participate were scheduled to complete baseline testing and game training across 2 days on a tablet similar to the one that they would be asked to use for the duration of the intervention. Each session lasted 1–2 hr. During the first session, participants would complete article and electronic surveys as well as cognitive assessments (see Table 1). On the second day, participants received one-on-one standardized tablet and game training to become familiar with the tablet hardware and game software. After the training was completed, participants were given a take-home packet which included a recommended schedule of gameplay (5 hr-long sessions across 5 days each week for 8 weeks) for a total of 40 hr. Participants then received a tablet to take with them that had been preprogrammed to one of the experimental conditions (control, positive-framed messaging, or implementation intention messaging).

If participants were randomized to the implementation intention condition, they also received a worksheet with their tablet (see Supplemental Material B). The experimenter would review the worksheet and inform the participant that this was being provided to help them set up a schedule for their gameplay so they would be less likely to forget to engage in their training. Participants were not required to complete the worksheet while with the experimenter but could do so at that time if they wanted. If they were not ready to complete the worksheet in the laboratory, they were told to take the worksheet with them and complete it at home before beginning their training. They were also instructed to update the worksheet if at any time the original schedule they set up was no longer feasible as a result of changes in personal commitments or life demands. Cognitive training from that point forward took place in participants' homes.

One week into the study, participants received a call to verify that they did not have any questions about the games and confirm they had been able to successfully charge the tablet. During this call, participants were reminded they would not receive any additional contact from the research team until it was time for them to return to the lab for their 8-week follow-up appointments. Individuals were instructed to call the lab if technical support issues arose prior to their follow-up appointments scheduled at the end of Phase 1.

After participants completed Phase 1, they returned to the lab and completed the same measures given at baseline minus demographics. Participants were asked to bring their tablets so that logs of gameplay could be collected and to confirm that the tablet device was still charging properly. During this follow-up visit, participants were informed they would now begin the second phase of the study in which they would continue to have access to the Mind Frontiers cognitive training program for an additional month but would not be provided with the adherence schedule they received during the first phase of the study. Instead, participants were instructed to engage in as much or as little training as they liked for the remaining 4 weeks of the study. The motivation for dividing the intervention into two phases was to obtain estimates of adherence both when there is strong external motivation to train (when a specific amount of training is expected by experimenters) and when this motivation is absent. During both periods, training time, training activities, and performance metrics were logged by the Mind Frontiers game system to estimate training intervention adherence.

Statistical Approach

All data were cleaned and prepared for analyses using R Version 4.0.2. (R Core Team, 2020). The results presented include preregistered confirmatory analyses of primary outcomes. Correlational analyses are also presented to explore the influence of individual difference and attitudinal variables on adherence. To conserve space, secondary preregistered analyses (i.e., regressions) are made available on the OSF at https://osf.io/ybhp5.

Results

Primary Confirmatory Analyses

For confirmatory analyses, the primary outcome variable was the number of unique days of gameplay participants engaged in (i.e., per each study phase). Days of unique gameplay were extracted from log files output from the Mind Frontiers mobile application, excluding all records prior to the tablet setup appointment date. Based on the training schedule, participants were provided during the structured phase (Phase 1) perfect adherence would have resulted in 40 playdays. Primary outcome analyses leveraged one-way analysis of variances to determine if there was an effect of condition on the number of days played in each phase.

Contrary to predictions, results indicated that there was no significant difference in number of playdays between conditions in the structured phase, $F(2, 113) = 1.73$, $p = .182$; $BF_{incl} = 0.336$. To further examine the evidence for the inclusion of each effect in the model, Bayesian factor inclusion (BFincl) was used. The Bayes factor for the inclusion of the study condition was 0.336, indicating anecdotal evidence against its inclusion in the model. Game days were statistically equivalent for the control group ($M = 24.9$ days, $SD = 14.0$), positive-framed condition ($M = 24.2$ days, $SD = 13.4$), and implementation intention condition ($M = 29.3$ days, $SD = 10.9$). Large standard deviations, however, indicated a higher degree of variability among participants. Further, on average, adherence in all groups was far from the goal of 40 sessions over the initial 8-week period. In the unstructured phase (Phase 2) where participants were not given a schedule to adhere to, there was a similar lack of difference between conditions, $F(2, 84) = 0.564$, $p = .571$; $BF_{incl} = 0.159$. The Bayes factor for the inclusion of the study condition was 0.159, indicating anecdotal evidence against its inclusion in the model. Game days were statistically equivalent for the control group ($M = 9.04$ days, $SD = 6.16$), positive-framed condition ($M = 10.69$ days, $SD = 6.58$), and implementation intention condition ($M = 9.27$ days, $SD = 5.93$).

Post hoc tests (including Bayesian analysis of variance and post hoc t tests conducted in JASP) revealed no significant condition differences in adherence for the structured phase, positive-framed condition versus implementation intention: $t(113) = -1.73$, $p = .2$, Cohen's $d = 0.42$, $BF_{10} = 0.969$; positive-framed condition versus control: $t(113) = -0.744$, $p = .965$, Cohen's $d = 0.05$, $BF_{10} = 0.241$; implementation intention versus control: $t(113) = 1.473$, $p = .308$, Cohen's $d = 0.35$, $BF_{10} = 0.626$, or unstructured phase, positive-framed condition versus implementation intention: $t(84) = 0.873$, $p = .659$, Cohen's $d = 0.23$, $BF_{10} = 0.365$; positive-framed condition versus control: $t(84) = 0.980$, $p = .591$, Cohen's $d = 0.26$, $BF_{10} = 0.400$; implementation intention versus control: $t(84) = 0.149$, $p = .988$; Cohen's $d = 0.04$, $BF_{10} = 0.264$. However, these comparisons shown in Table 2, at least according to the Bayes factors obtained, only provide anecdotal to moderate evidence for the null hypothesis (Andraszewicz et al., 2015).

Individual Difference and Attitudinal Predictors

All individual difference and attitudinal measures were Z-scored, and correlations were explored to uncover predictors of adherence during Phases 1 and 2. Replicating Harrell et al. (2019), belief in the efficacy of cognitive training was weakly correlated with self-reported motivation to engage in cognitive training as measured by the Brain Training and Independence Survey (see Table 3). Belief in the efficacy of training was also weakly correlated to adherence during Phase 2. It is worth noting that constructs such as self-efficacy and perceived susceptibility seen in protection motivation theory have been proposed as moderators of message framing (Rogers, 1983; Witte, 1992).

Exploratory Analyses

Although our primary, a priori outcome of interest focused on the total number of sessions played, this may have been too crude of a measure to pick up more subtle differences in adherence behavior. An exploratory analysis considered engagement with the intervention over time, with a focus on the likelihood that a participant within each group would engage with the intervention each day over time (i.e., for each day, the proportion of participants from each group who engaged in a training session).

Figure 1 depicts this analysis, with 95% confidence intervals (CIs) depicted in gray. As illustrated in Figure 1, the trajectories of the observed adherence drop for participants were similar for all three groups.

To understand if any of these differences observed were statistically significant, we fitted two mixed-effects logistic regression models, using the glmer function from the lme4 package in R, predicting if the daily engagement was observed (1 = played, 0 = did not play), as a function of day in study, one model for each experimental condition comparison (Model 1: implementation intention vs. control; Model 2: positive-framed vs. control, estimated using machine learning and Bound Optimization BY Quadratic Approximation optimizer). Ninety-five percent CIs and p values were computed using a Wald z-distribution approximation. Additionally, the model includes a random intercept term (specified in lme4 as 1 | experiment_tag) that allows the intercept to vary across different participants (i.e., each unique experimenter assigned ID).

The explanatory capability of both models is significant, with Model 1 having a conditional R^2 of 0.30 and Model 2 having a conditional R^2 of 0.33. Additionally, when considering only the fixed effects, the marginal R^2 is 0.09 for Model 1 and 0.08 for Model 2. For both models, the effect of day in study is statistically significant and negative (Models 1 and 2: odds ratio: 0.97, 95% CI [0.97, 0.98], $p < .001$). We observed no significant differences in engagement by condition over time (see Tables 4 and 5).

Table 2
Table Reporting the Post Hoc Tests

Phase	Comparison	T test	Cohen's d	Bayes $factor_{10}$
Structured	Positive-framed condition versus implementation intention	$t(113) = -1.73$, $p = .2$	0.42	0.969
	Positive-framed condition versus control	$t(113) = -0.744$, $p = .965$	0.05	0.241
	Implementation intention versus control	$t(113) = 1.473$, $p = .308$	0.35	0.626
Unstructured	Positive-framed condition versus implementation intention	$t(84) = 0.873$, $p = .659$	0.23	0.365
	Positive-framed condition versus control	$t(84) = 0.980$, $p = .591$	0.26	0.400
	Implementation intention versus control	$t(84) = 0.149$, $p = .988$	0.04	0.264

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Table 3
Correlation Matrix Examining the Relationship Between Z-Scores and Phases 1 and 2 Adherence

Measures and Phases	Age	Z: TSE	Z: GSE	Z: CPQ	Z: PDQ	Z: MDPQ	Z: Belief in Brain Training	Z: Brain Training Motivation	Z: Shipley	Z: Hopkins (delayed)	Z: Hopkins (immediate)	Z: Letter Sets	Phase 1	Phase 2
Age	—													
Z: TSE	−0.11	—												
Z: GSE	0.06	0.42****	—											
Z: CPQ	−0.32***	0.54****	0.23*	—										
Z: PDQ	−0.10	−0.12	−0.27**	0.04	—									
Z: MDPQ	−0.48****	0.45****	0.15	0.72****	0.00	—								
Z: Belief in Brain Training	−0.01	0.10	0.26**	0.14	−0.07	0.03	—							
Z: Brain Training Motivation	−0.08	0.02	0.07	0.16	0.01	0.08	0.30***	—						
Z: Shipley Vocabulary	−0.00	−0.16	−0.13	0.01	−0.07	−0.01	−0.08	−0.20*	—					
Z: Hopkins VLT (delayed)	−0.39****	0.01	0.04	0.24**	0.06	0.30***	0.02	0.02	0.30***	—				
Z: Hopkins VLT (immediate)	−0.36***	−0.04	−0.05	0.19*	0.12	0.23*	−0.04	−0.01	0.37****	0.83****	—			
Z: Letter Sets	−0.20*	−0.04	−0.05	0.15	0.09	0.20*	0.03	−0.06	0.46****	0.37****	0.43****	—		
Phase 1	0.08	−0.05	0.11	−0.10	−0.01	−0.06	0.04	0.01	0.00	−0.01	−0.03	0.12	—	
Phase 2	−0.16	0.08	0.17	−0.07	0.07	0.00	0.25*	0.20	−0.18	−0.02	−0.07	−0.02	0.56****	—

Note. Z = *z*-score; TSE = Technology Self-Efficacy; GSE = General Self-Efficacy; CPQ = Computer Proficiency Questionnaire; PDQ = Perceived Deficits Questionnaire; MDPQ = Mobile Device Proficiency Questionnaire; Hopkins VLT = Hopkins Verbal Learning Test.
* $p < .05$. ** $p < .01$. *** $p < .001$. **** $p < .0001$.

Discussion

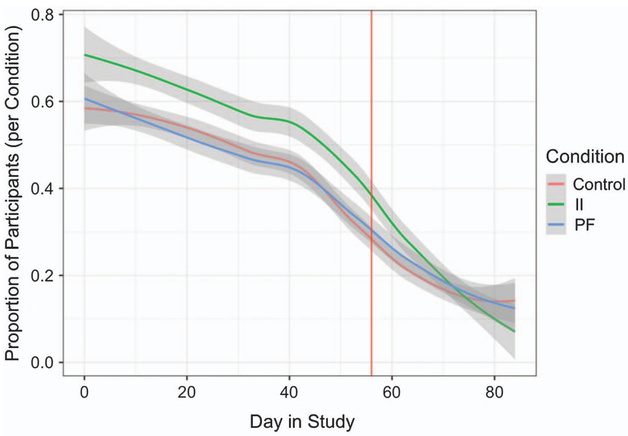
In the domain of cognitive training adherence, the present study compared the effectiveness of two theory-based strategies found to improve adherence in other domains. Digital messaging was used to present older participants with messages encouraging the use of an implementation intention strategy or positive-framed messages, about the benefits of engaging in regular cognitive training. Relative to a control condition that received no messages, we expected these messages to bolster adherence by encouraging habit formation (implementation intention) or by enhancing motivation to engage with training (message framing). Habit formation, targeted by the implementation intention strategy, was expected to be particularly useful in the unstructured phase of the study when social pressure was removed—motivations often fade with time, but well-defined habits should be less susceptible to the removal of external pressure. However, contrary to expectations, adherence did not differ between the three groups in either the structured or unstructured phase. An exploratory analysis of intervention engagement over time did suggest some benefits for the implementation intention condition; however, the decline in intervention engagement over time was similar for all the groups. If the implementation intervention condition was effective, it did not appear to be protective of adherence drop-off. Although this apparent benefit is consistent with a longitudinal approach being more sensitive to condition effects, it should be emphasized as well that this was an exploratory rather than planned analysis and results should be interpreted with caution.

Harrell et al. (2021) conducted a similar study that compared adherence among groups of older adults who received no messages during training, positively framed messages regarding the benefits of cognitive training, or negatively framed messages regarding the benefits of cognitive training. How do the findings of this previous study compare to the present one? Contrary to the present study, Harrell et al. (2021) found a significant benefit for positively framed messages during the unstructured phase of the intervention. It may be important to note that in this previous study, a benefit was only observed when the positively framed condition was compared to the negatively framed condition, and not when compared to the no-message condition. It appeared that differences were due, in part, to the negatively framed messages suppressing adherence. The absence of a negatively framed comparison condition in the present study may help explain the lack of benefit. This previous study was based on a study examining the effect of positively and negatively framed messages in a walking intervention for older adults (Notthoff & Carstensen, 2014). In the most analogous experiment to Harrell et al. (2021; Experiment 1), the same pattern was observed in this walking intervention. The only significant difference observed was between positively and negatively framed message conditions, with the control condition falling in between these two conditions in terms of adherence.

We also anticipated that individual difference and attitudinal factors would, to some degree, predict adherence to cognitive training. While the theory of planned behavior is primarily concerned with the prediction of intentions, attitudes, and subjective norms, perceptions of one's behavior are still at work (Ajzen, 2011). Thus, we reasoned that cognitive ability (objective and subjective) might predict adherence as individuals with lower cognition might feel a greater need for engagement in cognitive training and individuals with greater beliefs in the efficacy of cognitive training might adhere

Figure 1

Time Series of Proportion of Participants by Day in Study



Note. Time series demonstrating the proportion of participants (per condition) who engaged with the intervention each day of the study. The red vertical line represents the expected transition point for the two study phases. Shading represents 95% of CIs. PF = positive-framed condition; II = implementation intention condition; Control = control group; CI = confidence interval.

more. Moreover, low self-efficacy and technology proficiency might also serve as barriers to engagement in a technology-based cognitive intervention, negatively influencing adherence. However, contrary to predictions, we did not observe significant predictors of cognitive training adherence. There are several factors that could have led to this observance. First, is the length of the intervention being 2 months, given that the intention behavior relationship can vary as time passes. Evidence that instability of intentions over time can reduce their predictive validity has been shown in previous studies where observation of behavior (for a period of 5 weeks or less) was associated with stronger correlations than longer time intervals (Conner et al., 2000; Sheeran et al., 1999). Another factor could have been the overall enjoyment of the experience not leading to participants experiencing a flow state in which they became so absorbed in their cognitive training that they lost sense of their surroundings and time. In an online gaming study, Lee and Tsai (2010) found that flow states played a critical role in players' continued intention. The inability to experience a flow state could have been due to a lack of enthusiasm for the games.

Table 4

Exploratory Hierarchical Logistic Regression Results, Model 1, Comparing Implementation Intention Condition and Control Group Condition

Implementation intention versus control			
	Daily adherence threshold met		
Predictors	*OR*	CI	*p*
Intercept	3.29	[2.27, 4.78]	**<.001**
Study day	0.97	[0.97, 0.98]	**<.001**
Condition	1.29	[0.77, 2.18]	.333
Study Day × Condition	1.00	[0.99, 1.01]	.898
Random effects			
σ^2		3.29	
$\tau_{00\ \text{experiment\_tag}}$		0.98	
ICC		0.23	
$N_{\text{experiment\_tag}}$		77	
Observations		4,862	
Marginal R^2/conditional R^2		0.087/0.297	

Note. OR = odds ratios; CI = confidence interval; ICC = The intraclass coefficient. Bold formatting represents statistical significance.

Both the present study and Harrell et al. (2021) found mixed results in regard to the feedback from participants related to game preferences. While some participants reported loving the games and enjoying the challenge of being pushed to achieve new levels, others reported they "became so frustrated with the … games, that they dreaded them." Despite these mixed opinions, there is not enough evidence to say whether participants in this sample chose not to adhere due to simply becoming frustrated with the games. In fact, among those participants who provided reasons for not completing the study, the overwhelming response provided was due to needing to attend to health concerns of their own or a family member. Like the present study, Harrell et al. (2021) also concluded that idiosyncratic barriers such as illness, caregiving duties, and travel likely play a larger role in shaping adherence. However, Harrell et al. (2021) did observe that objective memory performance and self-efficacy had some, but limited, ability to predict overall adherence. Although these findings suggest that belief in efficacy of the training combined with a supportive strategy might have a greater effect on adherence, we were underpowered to test such interactions.

Limitations

While it was our goal to retain all participants for the duration of the study, attrition, and recruitment constraints once the study was underway resulted in our study being slightly underpowered. This resulted in our final sample having four less participants than needed to detect a medium effect size. Another limitation was in the presentation of the messages that appeared to the participants. Although messages (in the two message conditions) were presented for ample time (20 s), when participants initiated each training session, participants may have chosen to ignore these messages, especially as the study progressed and participants saw each message multiple times. It would have been beneficial if we had a mechanism to determine whether participants attended to the messages. Unfortunately, the software was not designed in a way that allowed for attention checks to confirm messages were being read. However, for those individuals who did not engage in the behavior long enough for habits to develop, the messages might not have been enough to promote a contextual association such that when they read the message it would have activated associative stores (Strack & Deutsch, 2004) reminding them of the plan they had set up to engage in the training. When comparing the implementation and positively framed message conditions, another limitation is the difference in message length between conditions; implementation intention messages were longer due to the greater complexity of messages explaining the benefits of planning to increase habit formation. It should also be noted that consistent adherence patterns might have been difficult to identify, given that participants were given the chance to change their scheduled time of play to coincide with changes that took place in their daily routines. We also acknowledge that while our primary focus was on adherence that by providing everyone with an adherence schedule to follow for the first phase of the study, we limited our

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Table 5
Exploratory Hierarchical Logistic Regression Results, Model 2, Comparing Positive-Framed Condition and Control Group Condition

Positive-framed versus control			
	Daily adherence threshold met		
Predictors	*OR*	CI	*p*
Intercept	3.34	[2.23, 4.98]	**<.001**
Study day	0.97	[0.97, 0.98]	**<.001**
Condition	0.98	[0.56, 1.73]	.952
Study Day × Condition	1.00	[1.00, 1.01]	.540
Random effects			
σ^2		3.29	
$\tau_{00\ \text{experiment\_tag}}$		1.19	
ICC		0.27	
$N_{\text{experiment\_tag}}$		78	
Observations		4,715	
Marginal R^2/conditional R^2		0.082/0.326	

Note. *OR* = odds ratios; CI = confidence interval; ICC = The intraclass coefficient. Bold formatting represents statistical significance.

ability to make in-depth evaluations of the effect of social pressure on engagement that could have been explored if phases were counter-balanced, which would be a great direction for future work.

Future Directions and Recommendations

In two studies now (Harrell et al., 2021 and the present study), adherence was far from perfect, yet strategies to improve regular engagement in cognitive training had limited benefit with respect to encouraging a greater number of intervention engagements (here, no significant effect; in the previous study only in the unstructured phase and driven partly by the suppression of adherence in the negative-framed condition). More optimal approaches are clearly necessary to promote adherence to technology-based interventions, including those aimed at improving cognition. To overcome the limitation of messages not being received by those who could benefit most from them, messages external to the technology delivering the training may be necessary (e.g., a phone notification or text message). However, reminder systems may not be enough to promote adherence and reengage participants once adherence has lapsed (Nieuwlaat et al., 2014). Perhaps of greater importance is the similarity between the two activities. For example, studies have shown that despite the intention to act one way, often "bad" habits even when known to be unhealthy such as the case with smoking still win out (Orbell & Verplanken, 2010; Rebar et al., 2014) when individuals find themselves in environments or situations that they generally would smoke in. In essence, if the habit of not engaging in the training was so imbedded and never appropriately linked to the cued behavior to trigger engaging in cognitive training, the habit of not engaging in training on a regular basis may have continually overridden motivational tendencies (Gardner & Rebar, 2019). This suggests the need for larger intervention studies that preselect for people who believe they are experiencing cognitive changes and that the intervention is effective at improving cognitive health.

In our studies, we assumed that motivational messages targeting cognitive health would be effective. However, we did not know whether that was the primary motivator (or a motivator at all) for participants to engage with the cognitive intervention they were assigned; some may have wanted to improve their cognition, some may have wanted to play games, some may have wanted to benefit science, and some may have wanted to earn financial compensation for being in the study. Motivational messages consistent with participants' own motivations (either determined at study entry or predicted by other factors) may have been far more effective at boosting adherence, consistent with the message tailoring literature (Lustria & Cortese, 2020). Finally, in addition to targeting participants with the right message, it may benefit adherence to provide this message at the right time, consistent with principles of just-in-time intervention (e.g., Müller et al., 2017). For example, a smart reminder system might use a participant's own history of intervention engagement to predict the best times for future intervention engagement and provide a motivational message, consistent with their own motivations, at that time once adherence has begun to faulter. This approach is consistent with the one proposed by the Adherence Promotion with Person-centered Technology project funded by the National Institute on Aging.

Like many interventions, cognitive interventions require adequate adherence if they are to effectively combat age-related cognitive decline, benefiting the person, their family, and society as a whole. A greater understanding of predictors of barriers to and methods to improve adherence to cognitive interventions is necessary to fully realize their potential. This understanding has the potential to not only benefit adherence to cognitive training but other technology-based interventions that support the health, well-being, and independence of older adults.

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