Technology in Healthy Aging

Cognitive Enrichment in Old Age

Web-Based Training Programs

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Abstract. Lifestyles with high levels of cognitive activity have been linked to weaker declines in cognitive abilities with aging. Hence, computer-based cognitive training programs that facilitate intense, daily, cognitive practice may help older adults to maintain and improve their cognitive functioning. We present the rationale for and implementation of an internet-based training environment that includes tasks of perceptual speed, episodic memory, and working memory. It was implemented as platform-independent internet-based testing software and used in the COGITO study to investigate intraindividual variability and plasticity in 101 younger (age 20–31) and 103 older (age 65–80) adults across an average of 100 daily practice sessions. Observations from this study and retrospective self-report evaluations demonstrate the program's feasibility and acceptance among participants.

Keywords: aging, technology, cognitive training, cognitive aging, internet

Plasticity of Cognitive Functioning in Older Age

For a growing number of older adults, the decline in cognitive abilities across the adult lifespan can lead to everyday functioning becoming impaired and threaten independent living. Any kind of intervention that could reverse or at least protract cognitive decline would, therefore, have great potential for improving older peoples' everyday competencies and delaying the onset of care dependency (Kramer & Willis, 2002). Consequently, there are a growing number of endeavors, both of a scientific and commercial nature, being made to develop successful interventions for enhancing cognitive functioning in older age. For almost three decades, one important line of research has been concerned with investigating behavioral plasticity as a result of cognitive training. Early approaches delineated the potential and limitations of instructing and practicing strategies for improving episodic memory and fluid intelligence. These attempts successfully demonstrated the considerable potential for improving performance up to very old age, but largely failed to show any transfer to tasks for which participants had not received training and to which the strategies previously practiced could be applied (Ball et al., 2002; Baltes & Lindenberger, 1988; Noack, Lövdén, Schmiedek, & Lindenberger, 2009; Verhaeghen, Marcoen, & Goossens, 1992).

More recent approaches can be loosely categorized into attempts targeting specific cognitive functions that are of presumed importance for many cognitive activities, and attempts to encompass a broader set of cognitive functions selected to represent the broad spectrum of different cognitive abilities. The first of these approaches comprises the development of training programs that aim at improving working memory capacity (e.g., Dahlin, Stigsdotter Neely, Larsson, Bäckman, & Nyberg, 2008; Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Karbach & Kray, 2009; Klingberg et al., 2005), sensory discrimination abilities (Mahncke et al., 2006), or visual processing speed (Ball, Edwards, & Ross, 2007). Some of these approaches have already produced promising findings, but there is still no conclusive empirical evidence as to whether these approaches are actually capable of enhancing important underlying mechanisms to a degree that leads to improvements at some general level of cognitive functioning.

The second of these approaches is based on evidence that lifestyles with a high level of cognitive activity are associated with smaller cognitive declines in old age (e.g., Ghisletta, Bickel, & Lövdén, 2006; Hertzog, Kramer, Wilson, & Lindenberger, 2009; Lövdén, Ghisletta, & Lindenberger, 2005). These approaches are characterized by the idea of simulating the cognitive components of such active lifestyles by using tasks that represent several different cognitive abilities or tasks that show activation in several different brain regions in imaging studies (e.g., Nintendo's

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BrainAge®, n.d.). Most of these approaches use computerized tasks that participants can practice over a large number of sessions. The goal of this article is not to further evaluate the effectiveness of the different existing training programs, but, rather, to outline some general principles for developing such programs, to argue for the benefits of developing internet-based approaches, and to present some results of a large study intended to demonstrate several aspects of feasibility of such web-based cognitive enrichment programs.

Principles of Cognitive Enrichment Programs

At a general level, the question of how to develop cognitive training software beneficial to older adults can be approached by applying the three principles of successful aging technologies put forward by Lindenberger, Lövdén, Schellenbach, Li, and Krüger (2008). These authors propose evaluating aging technologies using the criteria of *net resource release*, *person specificity*, and *proximal versus distal frames of evaluation*. The first criterion of net resource release, which states that technology for older people should free more cognitive resources than are needed for its operation, applies to cognitive training programs in more than one way. On the one hand, most cognitive training programs intentionally require the investment of cognitive effort. In this sense, they are a special case of aging technology, as resources are consumed rather than released. However, this consumption of cognitive resources should be under experimental control, that is, confined to task performance and controlled by parameters defining task difficulty. For instance, the instructions for any such tasks and the general handling of the software should be as easily accessible and as straightforward as possible, so that available cognitive resources can be fully devoted to task performance.

The second criterion of person-specificity states that aging technologies need to provide idiosyncratic support structures based on cues of the user's behavior. It applies to the demands made by cognitive enrichment programs. Given the huge individual differences in available cognitive resources and plastic capacities, training software needs to be able to adjust task difficulty to individual ability levels, preferably in an adaptive manner so as to accommodate within-subject changes with regard to practice and fluctuations in performance. Specifically, cognitive task performance needs to make sure that each individual participant is constantly in a state of mental activity that is at a clear but still manageable distance from the default state. This is the case because cognitive systems that can respond effortlessly to a change in demand (i.e., the task is too easy) as well as systems that are not capable of experiencing altered environmental demands (i.e., the task is too difficult) will not perform with sufficient mental activity to allow for plastic changes (Lövdén, Lindenberger, Bäckman, Schaefer, & Schmiedek, in press).

The third criterion of proximal versus distal frames of evaluation points to the need to evaluate long-term benefits as well as risks of aging technologies. Regarding cognitive enrichment programs, the desired outcome of enduring improvements in cognitive abilities is a long-term one. It needs to be emphasized, however, that the question of whether any cognitive training program fulfills the promise of providing such long-term improvements in cognitive abilities that are of significance in real-life settings needs to be addressed empirically and has not been answered conclusively thus far (Hertzog et al., 2009). If no such real-life effects can be demonstrated, the opportunity costs arising from not having spent the amount of time invested into such training on alternative, more helpful activities become a serious issue.

At a more specific level, these principles, together with the data provided by research on cognitive training interventions, can be used to put forward several characteristics of cognitive enrichment programs that are desirable, in our view. First, we hold that cognitive enrichment via practicing computerized tasks needs to be both intensive and extensive in order to have the potential to improve cognitive functioning at some general level. Thus, task performance needs to be challenging and continued over many sessions. This leads to the need for large, preferably unlimited, numbers of items with tight control over item difficulty and the development of adaptive algorithms that determine individual difficulty levels.

Second, training should comprise several different tasks. Whether these tasks should target one or several abilities and which abilities should be targeted are questions that can only be answered by experimental intervention studies. It is necessary to operationally define the targeted abilities with different kinds of paradigms and tasks, however, in order to prevent training from being merely about the development of task-specific strategies. One way to achieve this is to use tasks based on different paradigms; another approach is to use similar tasks with different content material, as strategies are often highly context- and content-bound.

As a third important feature, it is important to include immediate feedback within the training program to satisfy participants' need for information about training progress and foster their self-concept by making this progress transparent (see Lachman, 2006). Feedback may also be crucial for directing effort, as it allows appropriate behavior (e.g., investing lots of effort) to be reinforced and suboptimal behaviors (e.g., investing little effort) to be identified and corrected (Butler & Winne, 1995).

Web-Based Technology for Cognitive Enrichment

While the principles outlined above could all be achieved with stand-alone software, choosing an internet-based approach for developing cognitive enrichment programs has some major advantages. It allows new tasks and task versions to be introduced in a continuous fashion without the need to install new versions of the program. For scientific purposes, it also allows data to be stored in a central database, allowing it to be used to evaluate and optimize the effectiveness of the program. Furthermore, it has the potential for the creation of web communities that can exchange information about their training experiences. As a potential disadvantage, limited internet access might be an issue. In our view, it is likely, however, that those older people who have a personal computer will probably also have access to the internet.

On a technical level, there are different ways to implement such an internet-based program. One solution is to create a website that encompasses all the components, such as session generation, community features, and task presentation on the computer screen. The main advantages of this approach are platform independence because the program is realized as a web application, consistency of visual design, and ease of use as the result of a unified framework. The main disadvantage is the lack of control over the client computer, especially the screen, timing, and input devices. This can be avoided by installing a program on the local computer that displays the tasks on the computer screen. One particularly elegant approach to meet all of these criteria is to use *Java,* a platform-independent programming language, combined with the *Java WebStart* technology. Using this platform, the *Java* program is installed on the website, with *WebStart* automatically updating the local version of the program whenever a modification is detected. In this manner, the advantages of an internet-based application and local execution on the client computer can be combined.

Development of a Cognitive Training Environment: The COGITO Study

The central aim of the COGITO study was to investigate different levels of intraindividual variability in cognitive functioning in a broad multivariate way (Lindenberger, Li, Lövdén, & Schmiedek, 2007). The goal of exploring systematic relationships between plasticity and day-to-day variability in different cognitive domains, as well as interindividual and age differences in these relationships, required the development of a testing environment that fulfilled several of the principles outlined above. Specifically, it was necessary to represent the cognitive ability space in a broad way, to develop algorithms to generate an unlimited number of items for each task automatically, to have control over task parameters that influence task difficulty, to individualize task difficulties, and to provide feedback on daily performance. Furthermore, it was decided to create the testing environment using internet-based technology in order to allow it to be developed further into a widely accessible cognitive enrichment program in the near future.

Task Development

In the COGITO study, we tried to use tasks that cover important parts of the ability space as described by research on the structure of human cognitive abilities (see Carroll, 1993, for a comprehensive review of this research) and implemented these tasks in different content modalities. In addition to the abilities of episodic memory and perceptual speed, we decided to include working memory tasks because working memory is closely related to fluid intelligence (Kane, Hambrick, & Conway, 2005; Oberauer, Schulze, Wilhelm, & Süß, 2005; Schmiedek, Hildebrandt, Lövdén, Wilhelm, & Lindenberger, 2009), a central ability for all sorts of problem solving and cognitively demanding activities in everyday life, while item generation is more convenient for working memory tasks than for tests of fluid intelligence. In addition, promising results from working memory training have recently been published by several research groups (e.g., Dahlin et al., 2008; Jaeggi et al., 2008; Karbach & Kray, 2009; Klingberg et al., 2005).

Regarding the selection of tasks, a facet structure cross-classifying perceptual speed, episodic memory, and working memory with the content domains of verbal, numerical, and figural-spatial task material was chosen (see Guilford, 1956; Jäger, 1982). This resulted in 12 tasks (1 working memory, 1 episodic memory, and 2 perceptual speed tasks for each content domain; see Figure 1). Given the close relation of interindividual differences in working memory and the broad ability of fluid intelligence, this selection of tasks represented a broad sample from the space of cognitive abilities. Furthermore, this set of tasks enabled participants to alternate between the more complex episodic and working memory tasks and the simpler speed tasks, and

	Verbal	Numerical	Figural-Spatial
Perceptual Speed	Comparison tasks Choice reaction tasks		
Episodic Memory	Word lists	Number-noun pairs	Object position memory
Working Memory	Alpha Span	Memory Updating	N-Back

Figure 1. Theoretical facet structure of the daily practiced tasks in the COGITO Study.

supported participants' motivation to work repeatedly on the tasks by taking into consideration the fact that people differ with regard to their preference for different processing operations and content domains.

For each task, considerable attempts were made to control the parameters that influence task difficulty. The reason for this was twofold. First, some parameters needed to be fixed across sessions to allow performance scores to be derived that are comparable across days. For example, word lists in the verbal episodic memory task were assembled in a way that controlled for word frequency, word length, emotional value, and imageability across lists. In this way, it was also possible to give more valid feedback to participants at the end of each session than if words had been chosen at random. Secondly, some parameters were used to adapt difficulty to individual ability levels. This was achieved by adjusting the presentation times of the episodic and working memory tasks based on time-accuracy functions (Kliegl, Mayr, & Krampe, 1994), which were assessed for each participant at pretest sessions, so that accuracy levels were above chance levels but still low enough to allow for a high level of improvement without a ceiling being reached. Individualized presentation times were kept constant across the 100 sessions of the study to obtain an individual time series that could be analyzed as a whole (Figure 2). In order to optimize training gains in the future, it will be necessary to further develop the individualization of difficulty levels to dynamically follow individual improvements and keep the cognitive demands at a constantly high but still manageable level.

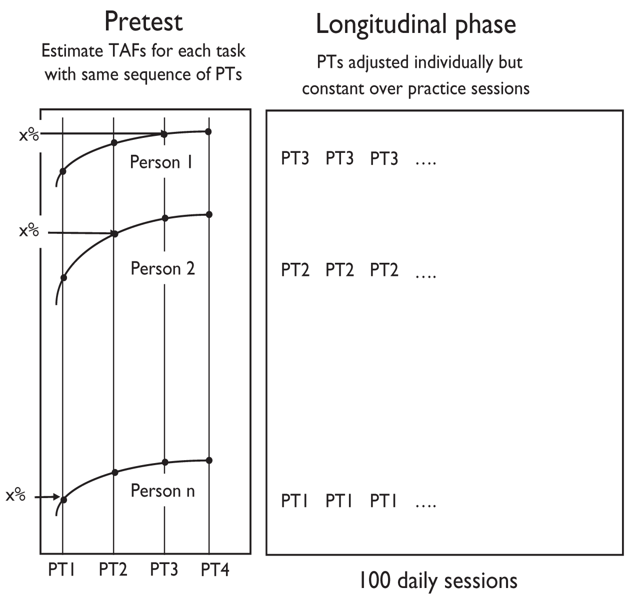

Figure 2. Illustration of the procedure for adjusting individual presentation times (PTs) for the episodic and working memory tasks using time-accuracy functions (TAFs). The TAFs were fitted to each participant's performance at different PTs at pretest and individual PTs were chosen to achieve a high but manageable level of difficulty.

Technical Realization

The software consisted of two different components for reasons previously mentioned: a website-managing task for session creation and a *Java* application for the presentation of the stimuli on the screen. The website was built on a freely available content management system (CMS) written in *PHP* called *e107* (downloadable from e107.org; Version 0.6175). We expanded the CMS with our own plug-ins to control the creation of tasks and stimuli, the generation of sessions, and participant management. The second component was a program written in *Java* (Sun Microsystems, http://java.sun.com; Version 1.5) that displayed the sessions on the screen. The program was executed on the client computer using *Java WebStart* (Sun Microsystems), a technology that downloads Java applications from a website and executes them as local programs. Both components communicated through a common database, with the website storing the generated stimuli, and the *Java* program loading the respective sessions and stimuli as well as storing the data generated by the participants. The database was run by a *MySQL* server (Sun Microsystems, http://www.mysql.com; Version 4.1.8), a freely available open-source database.

Study Design, Procedure, and Sample

Participants were recruited through newspaper advertisements, word-of-mouth recommendation, flyers distributed in university buildings, community organizations, and local stores. The advertisements were aimed at people interested in practicing cognitive tasks for 4–6 days a week for a period of about 6 months. Financial remuneration was mentioned, but no details were given regarding amounts. Several steps were required for inclusion in the study. First, interested people were given information about the study in a telephone interview and checks were made as to whether the requirements for participation in the study, in particular the time investment, could be met. Potential candidates for participation were then called back and invited to join a 1-hour "warm-up" group session to get more information about the study. The general aims of the study were explained and detailed information on incentives was given. The digit-symbol substitution test and a questionnaire on sociodemographic variables were then completed. At the end of this session, individuals were able to decide to take part in the study. Participants underwent 10 days of pretesting held in group-sessions (2–2.5 h, including a large number of self-report questionnaires), and behavioral testing with tasks included in the daily protocol as well as a number of covariates and transfer tasks. During the longitudinal training phase, participants scheduled daily sessions (1–1.5 h) on an individual basis on up to 6 days a week (including Saturdays). Participants worked on the tasks individually in rooms with three to six workstations. At the end of each session, participants received feedback on their performance on all tasks, including average accuracies and reaction times. They were also able to receive printouts of these results to take home.

At the posttest section of the study, another 10 group sessions (1.5–2 h) were held, with the pretest cognitive tasks and additional self-report measures being conducted again. These posttest sessions included retrospective evaluations of the study itself and its perceived effectiveness regarding real-life criteria. The results of these subjective evaluations come from the sample of participants who completed the longitudinal phase of the study: 101 younger (51.5% women; age: 20–31, M = 25.6, SD = 2.7) and 103 older (49.5% women; age: 65–80, M = 71.3, SD = 4.1) adults who completed an average of 101 practice sessions over an average total period of 192 days.

Tasks

Perceptual Speed: Choice Reaction Tasks (CRTs)

In the CRTs, participants had to make quick decisions as to whether presented numbers were odd or even, letters were consonants or vowels, and combinations of lines were symmetric or asymmetric, by pressing corresponding left and right buttons on the keyboard. All three CRTs were based on the same stimulus layout, the seven lines of the number “8” as displayed on pocket calculators. Stimuli were masked with a stimulus that combined this “calculator 8” with extending lines in all 10 possible directions. Possible masking times were 2, 4, or 8 screen cycles (24, 47, or 94 ms). Depending on pretest performance, two of these masking times (one fast and one slow condition) were chosen for each participant. Each CRT trial consisted of 40 stimuli, 20 for the fast and 20 for the slow condition, with randomly chosen stimuli from the two response categories. Two trials of each CRT were included in each daily session.

Perceptual Speed: Comparison Tasks

For the numerical version of the comparison task, two strings of five digits each appeared on the left and right of the screen, with participants having to decide as quickly as possible whether both strings were exactly the same or different. The verbal version of this task was equivalent to the numerical one, using strings of five consonants. In the figural version, two “fribbles” (courtesy of Michael J. Tarr, Brown University, Providence, RI, USA, http://www.tarrlab.org), that is, three-dimensional colored objects consisting of several connected parts, were shown to the left and right of the screen, with participants having to decide as quickly as possible whether the two objects were exactly the same or differed in some part. In each session, two trials of 40 items were included for each of the verbal, numerical, and figural tasks.

Episodic Memory: Word Lists

Lists of 36 nouns were presented sequentially with presentation times individually adjusted based on pretest performance. Presentation times were 1000, 2000, or 4000 ms. The interstimulus interval (ISI) was 1000 ms. Word lists were assembled in such a way that word frequencies, word lengths, emotional valence, and imageability were balanced across lists. After presentation, the first three letters of each word had to be entered in the correct order using the keyboard. Two trials were included in each daily session.

Episodic Memory: Number-Noun Pairs

Lists of 12 two-digit numbers and nouns in plural case pairs (e.g., “22 dogs”) were presented sequentially with presentation times individually adjusted based on pretest performance. Presentation times were 1000, 2000, or 4000 ms. The ISI was 1000 ms. After presentation, the nouns appeared in random order and the corresponding numbers had to be entered. Two trials were included in each daily session.

Episodic Memory: Object Position Memory

Sequences of 12 colored photographs of real-world objects were displayed at different locations in a 6 × 6 grid with presentation times individually adjusted based on pretest performance. Presentation times were 1000, 2000, or 4000 ms. The ISI was 1000 ms. After presentation, objects appeared at the bottom of the screen and had to be moved in the correct order to the correct locations by clicking on the objects and the locations with the computer mouse. Two trials were included in each daily session.

Working Memory: Alpha Span

Ten upper-case consonants were presented sequentially together with a number below the letter. For each letter, participants had to decide as quickly as possible whether the number corresponded to the position of the current letter in the alphabet within the set of letters presented up to this step. Five of the ten items were targets. The presentation time for the letters was individually adjusted based on pretest performance. The possible presentation times were 750, 1500, and 3000 ms. The ISI was 500 ms. Eight trials were included in each daily session.

Working Memory: Memory Updating

Four single digits (ranging from 0 to 9) were presented simultaneously in four cells situated horizontally for 4000 ms. After an ISI of 500 ms, a sequence of eight updat-

Table 1. Frequencies of dropout by study phase and reason for dropping out

	Study phase				
	After warm-up session	During pretest	After pretest	During daily phase	Total
Illness	1	0	0	4	5
Moved away	0	0	0	5	5
Lack of interest	1	2	1	1	5
Lack of time	2	4	1	4	11
Exclusion because of unreliable participation	0	1	0	2	3
Exclusion for individual reasons	2	1	1	0	4
Participation stopped for unknown reasons	4	2	4	8	18
Total	10	10	7	24	51

ing operations were presented in a second row of four cells below the first one. These updating operations were additions and subtractions within a range of –8 to +8. The updating operations had to be applied to the digits memorized from the corresponding cells above and the updated results had to be memorized. Possible presentation times, based on pretest performance, were 500, 1250, and 2750 ms. The ISI was 250 ms. At the end of each trial, the four end results had to be entered in the four cells in the upper row. Eight trials were included in each daily session.

Working Memory: 3-Back

A sequence of 39 black dots appeared at varying locations in a 4 × 4 grid. Participants were supposed to recognize whether each dot was in the same position as the dot three steps earlier in the sequence or not. Dots appeared at random locations with the constraints that (a) 12 items were targets, (b) dots did not appear in the same location in consecutive steps, (c) exactly three items each were 2-, 4-, 5-, or 6-back lures, that is, items that appeared in the same position as the items 2, 4, 5, or 6 steps earlier. The presentation rate for the dots was individually adjusted based on pretest performance by varying the ISI. The presentation time for the dots was always 500 ms. The ISI was 500, 1500, or 2500 ms. Four trials were included in each daily session.

Feasibility of Extensive Computerized Enrichment: Results

In the following, we report on the feasibility of the training program and its acceptance by participants.

Participation and Completion Rates

One important aspect of a successful cognitive enrichment program is whether it is able to retain participants' interest and motivation to such a degree that extensive amounts of practice can be completed. Completion rates in the COGITO study are one way to evaluate this issue. As the study consisted of several phases, it is possible to differentiate between various kinds of dropout from the study. Table 1 gives an overview of the numbers of participants who dropped out at the different phases of the study. Overall, dropout was small, and the corresponding rates of completion very high. Excluding those who moved away or became ill, only 15 participants quit the study during the longitudinal phase for reasons that were or could be related to lack of interest and motivation. This amounts to a dropout rate as low as 6.8% (15 out of 219) for those who had started the daily sessions.

It should, however, be mentioned that the strong financial incentives for the daily sessions, which increased from 7 EUR for the first to 11 EUR for the last sessions, plus a bonus ranging from 100 to 500 EUR (depending on participation frequency) at the end of the study, makes it difficult to attribute these high participation rates to satisfaction with the training regime alone. However, another observation also supports our general impression that many of the older participants had a strong intrinsic interest in cognitive practice. After completion of the study, we gave participants the opportunity to continue coming to additional testing sessions without financial compensation aside from reimbursement of public transport expenses. A considerable number of older participants continued coming back as a result of this. In total, 37 older participants returned for an average of 21.1 (Range = 1–76) extra sessions.

Study Evaluation

At the posttest session, participants were asked to give retrospective evaluations regarding their enjoyment of the study. Table 2 shows the ratings given for how much fun it was to participate in the study and how much participants liked coming to the daily testing sessions. On average, these ratings were high for all three time-points among older adults, while they were comparatively high for the beginning time-point but lower for the later time-

Table 2. Retrospective evaluations of the COGITO study at posttest (means and standard deviations) by age group

	Younger		Older	
	M (95%-CI)	*SD*	*M* (95%-CI)	*SD*
"How much fun did you have participating in the study?" (0 = none, 7 = extremely)				
. . . at the beginning	5.11 (4.90; 5.32)	1.07	5.51 (5.23; 5.79)	1.43
. . . during the study	4.07 (3.82; 4.32)	1.27	5.62 (5.36; 5.88)	1.33
. . . at the end	3.62 (3.29; 3.95)	1.67	5.38 (5.10; 5.66)	1.44
"How much did you like coming to the sessions?" (0 = not at all, 7 = extremely)				
. . . at the beginning	5.17 (4.94; 5.40)	1.18	5.74 (5.48; 6.00)	1.34
. . . during the study	3.81 (3.55; 4.07)	1.33	5.77 (5.53; 6.00)	1.19
. . . at the end	3.63 (3.31; 3.96)	1.64	5.47 (5.18; 5.76)	1.49
"Would you recommend participating in the study to others?" (0 = not at all, 7 = very much)				
	5.54 (5.30; 5.79)	1.23	6.12 (5.89; 6.34)	1.16
"Would you do it again?" (0 = no way, 7 = any time)				
	5.94 (5.67; 6.21)	1.37	6.30 (6.08; 6.52)	1.14

Table 3. Self-ratings on improvements in several aspects of cognitive, psychological, and physical functioning at posttest

Item	*M* (95%-CI)		*SD*		Effect Size = *M*/*SD*	
	Younger	Older	Younger	Older	Younger	Older
Memory	1.09 (0.92; 1.26)	1.22 (1.08; 1.37)	0.86	0.75	1.26	1.62
Attention	0.82 (0.65; 1.00)	1.29 (1.12; 1.46)	0.89	0.86	0.93	1.50
Everyday thinking	0.68 (0.52; 0.85)	0.87 (0.71; 1.04)	0.84	0.84	0.82	1.04
Everyday memory	0.98 (0.80; 1.16)	0.92 (0.77; 1.07)	0.92	0.76	1.07	1.21
Speed of thought	0.60 (0.45; 0.76)	0.93 (0.77; 1.10)	0.78	0.84	0.78	1.11
Mental fitness	0.83 (0.66; 1.00)	1.29 (1.10; 1.48)	0.86	0.98	0.97	1.32
General well-being	0.30 (0.11; 0.48)	1.17 (0.95; 1.38)	0.93	1.08	0.32	1.08
Life satisfaction	0.26 (0.12; 0.40)	1.13 (0.93; 1.32)	0.70	1.02	0.37	1.11
Physical well-being	–0.12 (–0.24; 0.00)	0.62 (0.43; 0.81)	0.60	0.98	–0.20	0.63
Physical fitness	–0.20 (–0.37; –0.03)	0.51 (0.34; 0.69)	0.86	0.92	–0.23	0.56

Note. For each aspect, participants were asked *"How much would you say that your participation in the study influenced . . . ?"* The neutral point ("no change" of the scale (from –3 for maximum decrease to +3 for maximum improvement) was 0. Therefore confidence intervals that do not include 0 denote evaluations of change significantly different from zero at the $p < .05$ level. Effect sizes were calculated as standardized mean deviations from zero change.

points among the younger participants. Mixed-model analyses indicated that the interactions of age group and retrospective change in these evaluations were significant for both dependent variables, $F(1, 410) = 25.79$, $p < .05$, for *"How much fun . . .?,"* and $F(1, 406) = 24.39$, $p < .05$, for *"How much did you like coming . . .?"*. Together with the ratings on whether participants would recommend taking part in the study, and participate in the study again, overall results show that both younger and older adults judged the study very positively. It has to be noted, however, that because many factors might have contributed to these evaluations, such as the financial reimbursement and the social contact with other participants and the study personnel, we cannot simply attribute this positive feedback to the practice program alone.

Subjective Evaluation of Training Effects

The participants were also asked at the posttest session to rate whether they perceived any changes having occurred in several aspects of everyday cognitive functioning as well as psychological and physical well-being. Table 3 shows that most of these ratings showed average positive changes that were reliable and of a considerable size when normed to interindividual differences in the amount of perceived changes. While such ratings for the cognitive domain can only be considered as "soft criteria" that are not necessarily related to objective improvements in everyday cognitive performances, which are subject to other investigations with data from the COGITO study that are not presented here, it is still an important and by no means trivial finding that participants subjectively experienced considerable positive effects on their mental fitness, as the success of any training program may, in part, be mediated through enhancing self-concept and control beliefs (Dittmann-Kohli, Lachman, Kliegl, & Baltes, 1991).

Discussion and Outlook

In this article, we outlined some general and specific principles for developing software for computerized cognitive enrichment programs. Several of these principles were realized in the COGITO study. Rates of successful study completion and subjective ratings indicate that extensive amounts of practice could be completed with our newly developed program. Moreover, the experience of participating in the study was generally positive, even though (or perhaps because) most of the tasks were quite demanding across the 100 sessions. The positive ratings were somewhat lower for later study phases (as evaluated in retrospection) for younger adults but showed comparably high values for all study phases among older adults. Moreover, perceived changes in everyday cognitive functioning and psychological well-being were positive and generally of high magnitude. Although they may not necessarily be directly related to gains in objective performance, these improvements in self-concept may have important long-term effects on cognitive functioning, at least for older individuals experiencing cognitive decline (for a review of the available evidence, see Hertzog et al., 2009). For example, an older individual with a higher level of cognitive confidence may be more mobile and have more courage to continue carrying out or to seeking new stimulating and challenging activities. In turn, such an active lifestyle is associated with smaller cognitive declines (e.g., Ghisletta et al., 2006; Hertzog et al., 2009; Lövdén et al., 2005).

The objective effectiveness of the training, that is, the question of whether it can enhance cognitive abilities, needs to be addressed with analyses of improvements on broad selections of untrained transfer tasks in comparison to untrained control groups. Such analyses are currently under way for the COGITO study. Even if such effects can be demonstrated, however, the exact mechanisms will be difficult to detect because participation in the study did not just entail practicing the tasks in question for 100 sessions. For many participants, the increase in social contact, gains in self-efficacy, and the mere physical activity of coming to the lab several times a week might have contributed to training effects. Statistical control procedures (Lustig, Shah, Seidler, & Reuter-Lorenz, 2009), further studies with multiple control and treatment conditions, and the inclusion of functional and structural neuroimaging at several occasions before, during, and after the intervention are needed to gain more precise knowledge of the mechanisms that control cognitive plasticity (see McArdle & Prindle, 2008).

Regarding limitations of the present investigation, it is important to note that, even though in the COGITO study the feasibility of an internet-based cognitive enrichment program could be demonstrated, it was still a laboratory study with standardized technical equipment and a controlled testing situation. The application of this or similar programs in individuals' homes via the internet will, therefore, require further technical developments and empirical investigations. If the positive effects of cognitive enrichment programs can be demonstrated and confirmed in future intervention studies, however, we see particular advantages in creating such programs on internet-based platforms. In addition to the benefit that such web-based approaches have for researchers, such as the ability to create a research database to ascertain the effectiveness of such programs and the capacity to include nonpracticed transfer tasks at regular intervals, internet platforms also have the potential to include some of the potentially beneficial social aspects of other cognitive training programs. The motivating effect of exchanging experiences with other participants on improvements, successful strategies, and task preferences in particular may foster the pleasure and perseverance experienced by participants when engaging in mental exercise.

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