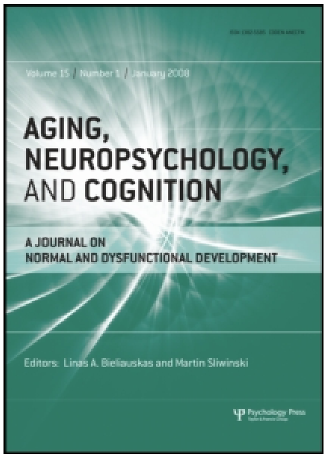

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Age and Flexible Thinking: An Experimental Demonstration of the Beneficial Effects of Increased Cognitively Stimulating Activity on Fluid Intelligence in Healthy Older Adults

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Age and Flexible Thinking: An Experimental Demonstration of the Beneficial Effects of Increased Cognitively Stimulating Activity on Fluid Intelligence in Healthy Older Adults

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ABSTRACT

The disuse hypothesis of cognitive aging attributes decrements in fluid intelligence in older adults to reduced cognitively stimulating activity. This study experimentally tested the hypothesis that a period of *increased* mentally stimulating activities thus would *enhance* older adults' fluid intelligence performance. Participants ($N = 44$, mean age 67.82) were administered pre- and post-test measures, including the fluid intelligence measure, Cattell's Culture Fair (CCF) test. Experimental participants engaged in diverse, novel, mentally stimulating activities for 10–12 weeks and were compared to a control condition. Results supported the hypothesis; the experimental group showed greater pre- to post-CCF gain than did controls (effect size $d = 0.56$), with a similar gain on a spatial-perceptual task (WAIS-R Blocks). Even brief periods of increased cognitive stimulation can improve older adults' problem solving and flexible thinking.

Keywords: Disuse theory of cognitive aging; Environmental enrichment; Neuronal plasiticity; Fluid intelligence; Successful aging.

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INTRODUCTION

A fundamental issue for the study of cognition and aging is whether "fluid intelligence" – our ability to creatively and flexibly grapple with the world in ways that do not explicitly rely on prior learning or knowledge – can be maintained into late adulthood. It is well documented that our general knowledge, or semantic memory, tenaciously holds its own or even improves with increasing age, possibly even until the sixth, seventh, or later decades (e.g., Baltes, Staudinger, & Lindenberger, 1999). This preservation of "crystallized intelligence" contrasts markedly with documented age-associated declines in fluid intelligence (Baltes, 1987; Baltes & Lindenberger, 1997; Baltes et al., 1999; Horn & Cattell, 1967; Schaie, 1994; Schaie & Hertzog, 1983; Schaie & Willis, 1993). Fluid intelligence, or that part of intelligence that involves active problem solving in tasks for which solutions cannot simply be derived from formal training or prior knowledge (Horn & Cattell, 1967; Stuart-Hamilton, 1996), often shows monotonic and approximately linear declines with age. These decreases are particularly evident after age 60, with some decrements observed even earlier, and additional, more accelerated, declines in very old age (Baltes et al., 1999; Schaie & Hertzog, 1983). Yet it is not clear that such declines in fluid intelligence are, in fact, inevitable.

Several lines of evidence (reviewed below) converge in pointing to the possibility that older adults may, under appropriate conditions, show much more flexible and adaptive thinking than might be expected. These studies suggest that environmental conditions that invite the use of fluid intelligence may be surprisingly important in maintaining cognitive performance. However, these sources of evidence are either indirect (e.g., longitudinal correlational studies showing comparatively preserved intellectual functioning in older adults who continue to engage in cognitively complex work and leisure activities), or involve forms of test-specific training rather than manipulations of involvement in more diverse, and less closely test-related, everyday cognitive and creative activities. There are no direct experimental demonstrations in healthy older adults of improvements in fluid intelligence arising from increased environmental cognitive stimulation. The aim of the research reported here was to experimentally test whether introducing older adults to a period of novel, mentally stimulating activities would counteract decline arising from the relative "disuse" of fluid intelligence.

Specifically, our experiments tested the "disuse" theory of cognitive aging with regard to fluid intelligence. According to this theory (e.g., Christensen et al., 1996; Orrell & Sahakian, 1995; Paggi & Hayslip, 1999; Schooler, Mulatu, & Oates, 1999; also cf. Flynn, 2003), the lack of use (or disuse) of problem-solving skills causes a reciprocal reduction of ability in this area, and older adults' reduced performance on measures of fluid intelligence may be attributed to the diminished use of their problem-solving capacities. Consistent with the disuse theory, a wide range of evidence from both animal and human studies demonstrates that there is considerable neuronal – and cognitive-behavioural – plasticity in response to prolonged changes in experiential input or perceptual-sensory stimuli.

Environmental Enrichment Paradigms and Evidence of Neural Plasticity

Direct evidence for experiential-dependent changes in higher cognitive functioning comes from environmental enrichment paradigms used in animal studies (for a comprehensive review, see Van Praag, Kempermann, & Gage, 2000). Studies have shown that in several mammals, although primarily in rats, an increase of hippocampal depth of around 15% magnitude (which was attributed to an increase in granule cell numbers) was observed in animals exposed to environments that contained stimulating objects such as toys and ropes (Kempermann, Kuhn, & Gage, 1997). Rats exposed to such "enriched environments" also have been shown to have superior problem-solving skills in complex tasks (maze solving), and show an advantage in various tasks requiring response flexibility, such as learning a reversal of a previously learned visual discrimination (e.g., Krech, Rosenzweig, & Bennett, 1962). It is of particular interest to the current research paradigm to note that the beneficial effects of enrichment on problem-solving or response-flexibility are not restricted to animals at an early stage of life-span development, but also have been demonstrated in older animals (e.g., Doty, 1972; Diamond, Johnson, Protti, Ott, & Kajisa, 1985; Warren et al., 1982; also see Rosenzweig, 2003). Sirevaag and Greenough (1987; Turner & Greenough, 1985) conducted a comprehensive series of studies to analyze a wide range of possible cortical synaptic, cellular, and vascular changes in rats raised in enriched compared with control environments. Using light- and electron-microscope techniques, these researchers demonstrated that preferential enrichment experiences were associated with several significant and interrelated brain changes. Animals from enriched environments showed a greater number of synapses per neuron (more than 20% increase), enhanced dendrite length (approximately 10% increase), greater vascular volume (approximately 50% increase), and more astrocyte processes and higher mitrochondrial volume – indicating enhanced neuronal support and greater metabolic activity.

Other researchers studying human sensory-motor representations using neuroimaging techniques such as functional magnetic resonance imaging have demonstrated that there is increased cortical representation associated with special motor skills, for instance, an increased cortical representation of the reading finger in blind subjects who read Braille, together with the recruitment of formerly "visual" areas of the occipital cortex (V1 and V2) for tactile information processing (Hamilton & Pascual-Leone, 1998). Increased areas of activation in the primary motor cortex of sighted subjects following several weeks of practice engaging in particular finger sequence movements (Karni et al., 1995) also have been demonstrated. Other neuroimaging findings have pointed to additional plastic changes in the brain in relation to experience. For example, a correlation between the size of the posterior hippocampus and years of driving experience has been reported in London taxi drivers (Maguire et al., 2000).

Perhaps more closely related to the current research are attempts by Scheibel and colleagues (Jacobs & Scheibel, 1993; Jacobs, Scholl, & Scheibel, 1993; see also Orrell & Sahakian, 1995; Shimamura, Berry, Mangels, Rusting, & Jurica, 1995) to examine the relationship between neuronal structure and education (also including ongoing involvement in learning opportunities). For instance, these researchers found a positive relation between dendrite size and education in a cortical language area (Wernicke's area). Post-mortem analyses also showed that deceased persons with a college education had more dendritic branches than did those with only a high school education. Intriguing and suggestive as these latter findings are, however, they (unlike the enrichment studies with animals) are susceptible to differing causal interpretations: Were individuals who had more dendritic branching more likely to complete further years of formal education, or did more years of education lead to greater dendritic branching?

Test-relevant Training, Longitudinal Observational Studies, and Fluid Intelligence

An additional source of evidence pointing to the modifiability of fluid intelligence performance in older adults involves test-relevant training. One major study of this type is the Penn State Adult Development and Enrichment Program (ADEPT; Baltes & Willis, 1982). This involved a series of inter-related intervention studies varying in length from 1 month to 2 years, with a focus on the range of individual modifiability (plasticity) in fluid intelligence that can be affected by practice and training. Fluid intelligence was chosen since it was the domain of intelligence most affected by aging. Two types of training strategy were studied: the first involved self-guided practice and the second trainer-guided instruction (geared to teaching problem-solving skills applicable to particular task demands). The assessment of these interventions examined transfer of training effects to the broad spectrum of intelligence and the maintenance of any such gains.

One such study, that of Hofland, Willis, and Baltes (1981), provided participants ($N=30$, mean age 69 years) with the opportunity to have eight self-guided practice sessions on intelligence tests. Continuous improvement was seen across all eight sessions. These results were interpreted as showing that older people are quite able to use cognitive skills already within their repertoire to improve performance significantly on tests of intelligence, providing "clear evidence for plasticity or reserve capacity in old age" (Baltes & Lindenberger, 1988, p. 287).

Many other studies of guided training have been reported (e.g., Baltes, Dittman-Kohli, & Kliegl, 1986; Schaie & Willis, 1986; Willis, Blieszner, & Baltes, 1981). The pattern of results from these studies is consistent with that found in a study by Baltes et al. (1986). In the latter study ($N = 204$, mean age 72 years) using experimental and control groups, participants were tested prior to cognitive training and post training at 1 week, 1 and 6 months. Results showed significant improvement following cognitive training, with near-transfer measures showing a gain of between one-half and two-thirds of a standard deviation; however, the spectrum of transfer to non-practiced tasks was limited. (Near transfer measures were defined as those that, for example, shared the greatest similarity to the trained-on measures.) These gains were maintained for 6 months. Notably, these outcomes were interpreted as demonstrating that older adults have the reserve capacity to benefit from training even in the intellectual domain of fluid intelligence, which is normally subject to age-related decline (Baltes & Lindenberger, 1988; see Baltes et al., 1999 for a summary of cognitive intervention research). Other recent research has shown beneficial effects of training aimed to increase working memory capacity in *younger* adults (Olesen, Westerberg, & Klingberg, 2004). These outcomes provide convergent support for the notion that even relatively brief periods of training (5 weeks) may enhance on-line cognitive processing capability that, in turn, is known to be positively correlated with performance on reasoning and problem-solving tasks (e.g., Carpenter, Just, & Shell, 1990; Conway, Kane, & Engle, 2003).

Nonetheless, despite the reported success of guided training interventions, a notable limitation of many test-specific training studies is the lack of successful transfer of performance gains to less closely related probes of cognitive function (e.g., Ball et al., 2002; Edwards et al., 2002; Baltes et al., 1999). One recent noteworthy exception involved an intervention focused on "recollection memory training" (Jennings, Webster, Kleykamp, & Hale, 2005). As demonstrated by Jacoby and others (e.g., Jennings & Jacoby, 1993, 1997, 2003; Koutstaal, 2003, 2006), conscious controlled memory processing shows age-related decline; this problem can be seen in everyday behaviour as older adults become increasingly likely to retell a story to the same audience. Jennings and Jacoby (2003) theorized that this was due to an automatic strengthening of the story memory trace, which would occur at the first telling and the story would be repeated as a consequence of this along with a failure of recollection for having already told the tale. Whereas the strengthening effect would occur for everyone, those with intact memory function would successfully avoid repetition through the recollection of information that would alert them to the fact that the story had already been related to the person concerned.

A task that similarly demands recollective processing is the so-called "repetition-lag procedure." In this procedure, a participant is asked to perform a word recognition task where a list of words that were read aloud during an initial study-phase is mixed with new (non-studied) words in a yes–no recognition task. There is, however, one important catch: Some of the new, non-studied words are shown on two occasions during the test, and so will take on some level of familiarity. Thus the second presentation could lead the participant to wrongly conclude that a repeated new word was presented in the original study list. To continue to make the correct response to "new" items requires conscious recollection of specific event details from memory.

In an earlier study, Jennings and Jacoby (1997) compared a group of younger and older adults on their ability to correctly differentiate original study words from the new words; repeated new words were shown after a lag (or delay) of either 0, 3, or 12 intervening items. It was found that the older adults made significantly more errors at a three-item lag and that this error-rate increased for a 12-item lag. In the training manipulation (in the 2005 paper) older adults were given six training sessions over a 3-week period. The lag period (between the first and second presentation of a new word) was gradually increased across the training sessions as the participant's performance improved; positive feedback was given for correct responses. Two control groups were used; one to control for any practice effects on the recognition test and the other (a no contact group) to control for any pre- to post-manipulation re-test effects on the cognitive measures. Following the six training sessions participants were able to perform at the same level as young adults in response to an 18- or 19-item lag. Equally important, the recollection-training group also showed a significant pre- to post-training gain on four different transfer tasks, involving different types of cognitive operations and different stimuli: a working memory (*n*-back) task, self-ordered pointing, source monitoring, and the Digit Symbol Substitution Test. Each of these tasks places clear demands on frontal function, thereby raising the possibility that recollection training induced a more general increase in frontal lobe dependent functioning.

Several longitudinal observational studies also offer support for the idea that greater participation in mentally stimulating activities produces reciprocal benefits in levels of cognitive function. One such longitudinal study (Schooler et al., 1999) showed that continued engagement in substantively complex work significantly increased workers' level of intellectual functioning – including performance on a measure of intellectual flexibility; this was particularly so for older workers. Structural equation modelling from this and earlier research led to the conclusion that work environments "offering challenge and opportunity for doing self-directed substantively complex work increase intellectual flexibility" (Schooler et al., 1999, p. 466). A subsequent study (Schooler & Mulatu, 2001) extended these findings to show that complex leisure time activities also increased intellectual functioning for workers and non-workers. Yet, these latter studies (see also Gribbin, Schaie, & Parham, 1980; Hultsch, Hertzog, Small, & Dixon, 1999) are again susceptible to a direction of causality critique: do older adults with higher cognitive ability actively seek out cognitive challenge and mental stimulation, or do they show higher or maintained levels of cognitive functioning because they more often engage in mentally stimulating activity?

Rationale and Hypothesis

The aim of the research we report here was to test, experimentally, the hypothesis that novel, mentally stimulating activities produce a corresponding benefit in cognitive function in older adults. In a two-phase experiment, healthy older participants were randomly assigned to either experimental or control conditions. (By randomly assigning participants to either increased or no increase in mentally stimulating activity, we avoid the direction of causality critique.) Participants in both the experimental and control conditions were administered cognitive tests, including a measure of fluid intelligence and a spatial-perceptual task, at both the beginning (pre) and end (post) of a 10–12-week period. After the pre-test measures, the experimental participants were provided numerous individual and group opportunities and materials to engage in a wide range of novel problem-solving and creative activities. Participants in the control condition also came into the laboratory for the initial cognitive tests, and for a few subsequent social group meetings, but did not receive novel cognitively stimulating opportunities.

If the disuse hypothesis of cognitive aging is correct, participants in the experimental group should show increased performance on the standardized measure of fluid intelligence from pre- to post-test, and this increase should be greater than that observed in the control group (that is, there should be a group × time interaction). The activities were especially developed and chosen to broadly encompass several areas of fluid intelligence, e.g., problem-solving, spatial awareness and manipulation, creativity, etc. It, therefore, was predicted that improvements would be observed *on tasks that were not themselves specifically practiced during the stimulation period.* As we report below, consistent with our hypothesis, in an exploratory, small scale, initial phase of our research, we found supportive evidence that engaging in novel, mentally stimulating tasks leads to an improvement in cognitive function – in particular, on a measure of fluid intelligence. This phase also provided suggestive evidence of greater gains in the experimental group on a test of visual-spatial ability. These initial findings are reported here (as Phase 1) together with an extension of the study (Phase 2) that was conducted to further establish the reliability of the findings from the preliminary study phase.

METHOD

Participants

Participants were randomly selected from a database of older adults who had volunteered to be tested in various experiments in a university setting. Participants in this database were recruited via several advertising campaigns, including advertisements in local newspapers, radio interviews, and posters placed in various public places (e.g., doctors' offices, pharmacies, health clubs, libraries, adult education centers, public swimming pools, and fitness centers). All participants were in the age range of 60–75 years and were living independently in the community. A total sample of 44 volunteers was recruited across the two experimental phases: Phase 1 (P1), $N = 20$; Phase 2 (P2), $N = 24$. The gender distribution across both phases was a three-to-one female-to-male ratio.

All volunteers were tested on a standardized cognitive screening battery, including several cognitive and neuropsychological tests that are detailed below. The battery also included several health exclusion screening criteria; in particular, participants with a history of any major cardiac or vascular surgery or pathology, who had received chemotherapy, or who had experienced prolonged unconsciousness, were excluded. Administration of the cognitive screening battery required approximately 90 min.

Cognitive and Neuropsychological Measures

The measure of fluid intelligence that was administered, and which represents the main dependent variable of the experiment, was *Cattell's Culture Fair* (CCF; Cattell & Cattell, 1960) test. Cattell's Culture Fair test is described by its authors as "measur[ing] individual intelligence in a manner designed to reduce, as much as possible, the influence of verbal fluency, cultural climate and educational level" (1960, p. 5, manual). The tests used are non-verbal and require participants to attempt to perceive relationships between shapes and figures. The test is composed of four subtests: series, classification, matrices, and conditions. Scale 2 (Forms A and B) was used. The four subtests require 2, 4, 3, and 2.5 min for completion, respectively. In the first subtest, *series*, participants see 12 incomplete progressive series of abstract shapes along with five alternatives for each; they are asked to select the alternative that best completes the series. For the *classifications* subtest, participants are shown 14 problems of five abstract shapes and figures and are asked to select which, out of the five, does not match or belong with the others. The odd one out was different in size, shape, orientation, or content. In the third subtest, *matrices,* participants are presented with 12 incomplete matrices containing either four or nine boxes containing shapes and figures; one of the matrix boxes is empty and the participant is asked to select the correct box (from a choice of five alternatives) to place in the matrix and complete the pattern correctly. In the fourth subtest, *conditions*, participants are shown eight sets of abstract figures consisting of shapes, and lines with one or two dots. The task of the participant is to work out the relationship between the dots, in the example shown, and then find one (out of five) alternatives where the same dot-to-shape relationship could be recreated. Thus if the dot shown, in the example, was inside a circle and outside of a square then the participant would try to select an alternative where it was also possible to locate a dot that would be inside a circle and outside of a square. The score obtained is the sum of all correct answers across the four subtests; the total possible correct score is 40.

The CCF has been used in many studies of adult intelligence (e.g., Baltes, Sowarka, & Kliegl, 1989; Colom & Garcia-Lopez, 2003; Klauer, Willmes, & Phye, 2002; Rabbitt, 2000) and is invariably identified as a measure of fluid intelligence. The CCF has also been used as a measure to examine between-generational gains in intelligence, and has been characterized as "one of the best available measures of fluid intelligence" (Colom & Garcia-Lopez, 2003, p. 33).

A measure of mood, the *Hospital Anxiety and Depression Scale* (HADS; Zigmond & Snaith, 1983), was used as a screening tool to exclude depressed individuals in the current research. This measure is a short self-report scale designed to test for symptoms of anxiety and depression. The upper end of the borderline score range is used (10/11 for each subscale) as a screening criterion and this provides a low proportion of false positives of participants that could be considered to be suffering from a mood disorder. As described below, reference to this measure of mood, and possible changes across the pre- to post-test period, also figured in the rationale for the research that was provided to participants.

The *National Adult Reading Test* (NART, Nelson, 1982) provides a measure of crystallized intelligence and partially reflects the level of formal education completed by participants. This measure was used to enable matching of the groups within the experiment on this aspect of cognitive ability and as such was only administered at pre-test.

The *Mini Mental State Examination* (MMSE; Folstein, Folstein, & McHugh, 1975), a formalized mental status examination, was also administered at pre-test only and represents a brief measure to facilitate the exclusion of participants who likely are suffering from dementia. Folstein et al. (1975) report that a score of below 20 was found, essentially, only in patients with dementia. Woodruff-Pak (1997, p. 45) reports that a question of mental impairment arises for scores equal to or below 23. A score equal to or greater than 25 (out of a total of 30) was the specified cut-off criteria for the current study (for other comments on interpretation of scores see Lezak, 1995, pp. 741–744).

The *WAIS-R Blocks* (Wechsler, 1981) was used as an additional pre- and post-test measure. This test measures visual-spatial ability and is described as a visual-construction task. It is a particularly valuable task to include as the nature of fluid intelligence tasks is such that they depend heavily on visual-spatial manipulation of the stimuli to arrive at solutions to test questions. As Horn and Hofer (1992) propose, visualization components are inevitably involved in tests that are based on solving matrices and thus should be given concurrently with measures of fluid reasoning ability. There are several sources of evidence for the strong link between fluid intelligence performance and visualization. One of these comes from Salthouse, Atkinson and Berish (2003), where, in a study looking at the relationship between fluid intelligence and frontal lobe function, they found that spatial visualization tasks showed a very strong correlation ($r = .90$) with fluid intelligence measures. More generally, age-related decline on visual-spatial tasks is widely reported (e.g., Horn & Cattell, 1967; Jenkins, Myerson, Joerding, & Hale, 2000; Schaie & Hertzog, 1983; Schwartzman, Gold, Andres, Arbuckle, & Chaikelson, 1987).

In addition to these standardized measures, a questionnaire was designed, for use in the current study, to establish the amount of current involvement in mentally stimulating activities that the participants experienced on a day-to-day basis: the *Life Activities Questionnaire* (LAQ). The form and content of the questionnaire were based on a similar questionnaire used in prior research by Wilson and colleagues (Wilson et al., 1999, 2002). Wilson et al. (2002) used a baseline measure of seven common activities, each of which was proposed to involve information processing as a central component. These activities were: viewing television, listening to the radio, reading newspapers, reading magazines, reading books, playing games such as cards, checkers, doing crosswords or other puzzles, and going to museums. Of note, these were activities that did not make particular demands relating to social interaction or physical activity. Wilson et al. used a frequency of participation measure based on a five-point scale, where one point was allocated if an activity was carried out once a year or less and five points were allocated if the activity was carried out every day or about every day. Intermediate points were allocated for activity frequencies between these two end points. The final score was obtained by averaging responses to each item, rather than weighting items on estimates of cognitive demand, as this had been shown to be indistinguishable from a composite measure based on both frequency and cognitive intensity (Wilson et al., 2002, p. 743).

The validity of this activities questionnaire was established in an earlier study (Wilson et al., 1999). Activities included in the current questionnaire were: "active" television watching (where some form of interaction was involved or where the program contained some educational content); reading newspapers, books, and magazines; game playing including card games, draughts, chess, board games, crossword puzzles, jigsaw puzzles and solving logic problem puzzles; social activity stimulation, such as eating out with friends, having friends round for dinner, attending other group social activities; involvement in a hobby or club or any volunteer work (e.g., golf club, train enthusiasts, painting, photography, etc.); keeping in contact with friends and family (e.g., letter writing or e-mailing, telephoning, sending birthday cards and buying gifts); planning, shopping for, and preparing meals; educational activities – adult education classes of any sort where you are learning new information or skills; and visits to art galleries, the theatre and places of historical interest. The same five-point scale as that used by Wilson et al. (2002) was utilized. This questionnaire provided a measure to ensure that *pre-experimental* levels of cognitively stimulating activity did not differ between the experimental versus the control group.

Design

Participants were randomly allocated into one of two groups, an experimental or a control group, of equal size. Both the control and experimental groups were tested on the battery of pre- and post-test measures with an intervening period of approximately 10–12 weeks. The experimental group also undertook a period of mentally stimulating activities between pre- and post-test. The pre- and post-measures were analyzed in a 2 × 2 mixed design analyses of variance (ANOVA), with group (experimental vs. control) as a between subjects factor and time (pre vs. post) as a within subjects factor.

Experimental Procedure and Materials

The experimental manipulation encouraged and guided participants in engaging in a diverse set of novel perceptual-motor and cognitive activities that were thought to be mentally stimulating (i.e., inducing the use of problem solving and/or creative abilities). Some activities were undertaken individually, at home, whereas others were undertaken in a group context in the laboratory.

The explanation to the participants in the experimental group, regarding the purpose of the research, was that we were seeking to examine how engaging in novel and challenging activities affected feelings of well-being and how mood states influence performance on certain tests. The control group participants were told that the purpose of the research was to examine how performance on some tests changes on re-test and to see how mood states may relate to this performance. Thus, expectation as to outcome should not differ between the experimental and control groups.

Participants were instructed to carry out the home activities at a time of day that suited them best. Although it has been shown that the morning is generally a better time of day for older adults (see Lustig, Hasher, & Tonev, 2001), it was not practical to demand that participants allocate set times of the day to the activities. However, a group testing session and group social activities were all carried out in the morning, between

09:30 and 12:00 h. Individual testing sessions were arranged to suit the participant.

In each experimental phase, 12 "home activity" tasks were distributed to participants with the instruction to complete two activities a week with a gap of 2 days between tasks. These comprised mentally stimulating home activities including word manipulation, "making sense of figures" (a simple mathematics activity); creative drawing activities; identification of mystery photos and dot-to-dot puzzles; word-logic puzzles and creative modelling activities. Each of the six different activity types had two forms (Form A and B). For the creative activities all materials were supplied. Participants were asked to spend between 40 min to 1 h on each home activity; however, informal feedback from participants suggested that, in general, up to 1 h was devoted to the home activity tasks, as suggested, but that if the participant had found the task particularly enjoyable or engrossing they had sometimes spent considerably longer on it.

The three in-lab sessions involved the use of a tape of Tuvan throat music, "Sound of the Steppes" (for unfamiliar music exposure and musical critique), cardboard tubes, tape and marbles (for interactive group construction of a working marble run), newspapers, string and plastic pulleys (for group construction of a newspaper tower), an origami book with origami paper (*Origami for Beginners*), and a board game called "Ingenuity" (for description see www.ingenuitygames.com).

Cognitive and Neuropsychological Test Administration

All tests were administered following a standardized delivery format and were administered in the same order. A group administration (pre- and post-test) of several tests was held for both control and experimental groups. For the control group this was followed by a cup of tea and the opportunity for a general chat. In addition, the experimental group also carried out the first of the group activity sessions and was allocated home activity tasks and any necessary task-related materials and instructions to take home with them. The group sessions (five in total for the experimental group and two for the control group) varied in size, depending on participant commitments (four to eight participants per group).

Following the experimental period of mentally stimulating activities (over 10–12 weeks) for the experimental group, or following a period of the same length but without the activities for the control group, participants were re-tested on the same experimental measures as used in the first test session. As at pre-test, some testing was administered in a group test session and the rest were administered individually. The mood questionnaire was also re-presented, consistent with the participant's expectations, with the explanation that we were seeking to evaluate any change in the participant's mood between the two testing sessions. The post-test individual session took approximately 90 min per participant. Participants were debriefed following the final group testing session and travel expenses were reimbursed.

Compliance and Attrition

Across the two groups the completion rate, once participants had committed to the experiment, was very high with only one participant being lost from the experimental group. This participant reported that she had underestimated her current level of alternative commitment and would not have time to complete the home activity assignments. Compliance with regard to the completion of the home activities was a little more varied; out of the twelve home activity packs given out the average completion rate was 11.3 of the tasks. This equated to most participants completing all the activities but one or two missing out a couple of activities that they did not find as appealing as others; for example, there were a couple of activities that were artistic in nature and these were the ones most often not attempted. All participants were administered the post-test measures at the end of the manipulation period, regardless of whether they had completed all the tasks.

RESULTS

Analyses showed that there were no significant *pre-test* between-group differences for the control versus experimental groups on age, years in formal education, crystallized intelligence (NART), or fluid intelligence (see Table 1). Thus, participants in the two groups started out at similar (matched) levels on these variables. The groups also were well equated on pre-experimental levels of cognitively stimulating activity, as determined by the Life Activities Questionnaire (control group $M=2.79$; $SD=0.41$; experimental group $M=2.79$; $SD=0.48$), $F < 1$ for the effect of group.

Experimental Phase 1 (P1)

The first experimental phase (P1) represented a small exploratory study (with 10 participants per group; mean age of 68.70, $SD=4.72$). Results from this study were encouraging. Comparison of the two groups, on pre- to post-test changes on the fluid intelligence measure of the CCF, showed that the experimental group made a gain in score of 3.10 points (from a mean of 32.40 at pre-test to a score of 35.50 at post-test). This was in comparison to the control group, which showed a slight decline in performance of –0.60 of a point (pre-test score of 32.70 and post-test score of 32.10). A 2 × 2 ANOVA on the pre- and post-manipulation CCF scores, treating group

TABLE 1. Pre-test demographic characteristics for all experimental and control conditions

Experimental Phase	*n*	Age	Yrs Ed	NART	CCF
Phase 1					
Control group	10				
M		69.70	14.10	42.80	32.70
SD		4.22	4.64	3.41	6.55
Experimental group	10				
M		66.70	15.30	43.00	32.40
SD		4.72	4.74	3.09	4.43
Combined Phases 1 and 2					
Control group	22				
M		67.00	12.84	40.68	29.91
SD		3.81	2.84	5.58	6.27
Experimental group	22				
M		68.36	12.80	38.27	29.32
SD		3.97	3.28	8.01	5.45

Note: Starting point data for participants in each group (control and experimental), including mean (*M*) and standard deviation (*SD*), for age, years of formal education (Yrs Ed), National Adult Reading test (NART), and Cattell's Culture Fair intelligence test (CCF). Independent sample *t*-test comparisons of the control vs. experimental groups for the four pre-test measures: age, $t(42)=1.61$, $p=.12$; years in formal education, $t(42)=1.29$, $p=.20$; crystallized intelligence (NART), $t(42)=-0.05$, $p=.96$; fluid intelligence, $t(42)=0.33$, $p=.74$. The NART IQ estimates for the combined Phases 1 and 2 control group and experimental group were 120 and 116, respectively.

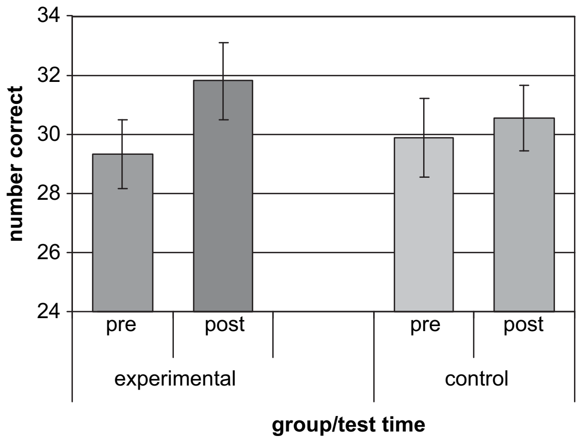
(experimental vs. control) as a between-subjects factor, showed this difference to be significant, $F(1, 18) = 6.37$, $p = .01$ for the group × time interaction,[1] effect size $d = 1.19$. Thus the experimental group demonstrated a significantly greater gain in fluid intelligence performance from pre- to post-test than did the control group.

Experimental Phase 2 (P2)

The second experimental phase (P2) was a replication of the first phase, conducted to provide a larger sample ($N = 24$, mean age of 67.92 years). Results from the combined P1/P2 phases ($N = 44$) continued to provide support for the hypothesis. Both the control group and the experimental group showed a performance increase on the CCF (pre- to post-test). Consistent

[1] The significance values for the tests of the primary hypotheses are given as one-tailed values. The rationale for this is two-fold: Firstly, if the group exposed to the mentally stimulating activity were to show *significantly poorer* pre- to post-test levels of performance than that shown by the control group who were not given these activities, this would not be considered to be of particular theoretical interest – since there is no published evidence to suggest this would occur; secondly, it seems reasonable to assume that the experimental effect size, given the relatively time-limited (10–12 week) experimental intervention, is likely to be small, so that this procedure reduces the probability, in this exploratory phase, of a Type II error. As noted in the Discussion, there is a clear need for a larger-scale investigation involving a longer-term manipulation than is used here.

Figure 1. Pre- and post-test mean group scores on the Cattell's Culture Fair intelligence test (CCF). *Note:* The maximum number correct for the CCF is 40. Standard error bars are shown, with 1 *SE* above, and below, the mean.

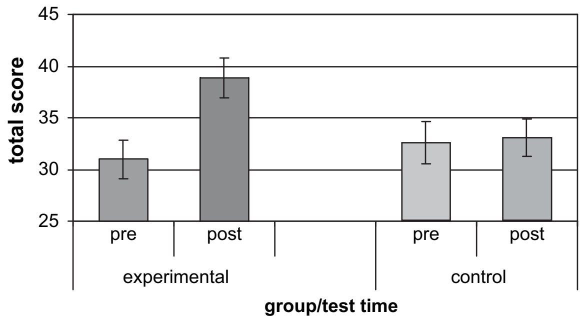


with the earlier PI findings, the increase was greater for the experimental group (mean pre-score of 29.32 to post-test score of 31.82; an increase of 2.5 points) than for the control group (mean pre-score of 29.91 to post-test score of 30.55; an increase of 0.64 points). Figure 1 presents the combined sample results. An ANOVA showed this difference between groups to be significant, $F(1, 42) = 3.35$, $p = .04$, for the group time interaction, effect size $d = 0.56$. Thus the experimental group showed a significantly greater increase in performance on the fluid intelligence measure, pre- to post-test, than did the control group. The effect size estimate points to a small-to-medium experimental effect.

Although it is customary to consider only the total score from the CCF, exploratory analyses of the subtests were carried out. These analyses revealed that the experimental group showed numerically greater pre- to post-test gains than did the control group on *each* of the four CCF subtests. Although no group × time interactions were observed for any of the four subtests considered separately, focused comparisons, conducted within the experimental group alone, showed a significant pre- to post-test gain on subtest two (classifications) and subtest four (conditions). It is not clear how these subtests differ from each other in terms of cognitive processing demands, or whether the effects observed would be replicated, but these potential differences in subtest gains could be further investigated in future research.

A separate analysis of the gains achieved by males and females was carried out. Although males showed gains that were very slightly numerically

FIGURE 2. Pre- and post-test mean group scores on the WAIS-R blocks. *Note:* The maximum total score for the WAIS-R Blocks is 45. Standard error bars are shown, with 1 *SE* above, and below, the mean.



greater (M = 2.86, SD = 1.95) than were the gains shown by females (M = 2.34, SD = 3.5), this difference was not significant, $F < 1$.

On the second measure of interest, where a directional trend had been observed in the Phase 1 experiment, for the P1/P2 combined sample the experimental group showed an increase in performance on the WAIS-R Blocks from pre- to post-test (mean pre-score of 31.00 to post-test score of 34.82; an increase of 3.82 points) whereas the control group showed a smaller increase pre- to post-test (mean pre-score of 32.62 to post-test score of 33.09; an increase of .47 of a point). These outcomes are shown in Figure 2. An ANOVA showed this difference between groups to be significant, $F(1, 41)=4.99$, $p=.02$, for the group×time interaction. Thus the experimental group showed a significantly greater increase in performance on this visual-spatial measure, pre- to post-test, than did the control group.

The measures of depression and anxiety, from the HADS, were analyzed for both groups from the pre- and post-manipulation testing points. The levels of these were very similar for both groups and remained very stable over the experimental period.

DISCUSSION

Primary Experimental Hypothesis

The disuse hypothesis of cognitive aging suggests that declines in cognitive performance by older adults, particularly on tasks that require active online manipulation of information rather than reliance on existing knowledge, arise as a result of decreased involvement in activities that call on such "fluid intelligence" capabilities. This hypothesis was tested in a two-phase experimental paradigm, the first of which was a pilot study and the second of which was intended to replicate the first and increase the sample size. In each phase, older adults were randomly assigned to either a control condition, or to an experimental condition in which they were encouraged to engage in a wide range of stimulating novel activities, both at home and in group-sessions in the laboratory, over a 10–12-week period. The results supported the hypothesis that increased participation in novel stimulating activities would be associated with increased cognitive performance on a test of fluid intelligence. The experimental group showed an increase in performance on Cattell's Culture Fair test of .56 of a standard deviation compared to that shown by controls (combined across-experiment effect size d for P1 and P2: $d=0.56$, $N=44$). This benefit is of a similar magnitude to that reported previously for studies of *test-specific guided training* (e.g., Baltes et al., 1986) and points to a small-to-medium experimental effect. However, unlike the guided training studies where benefits were restricted to the same or very similar tests, the benefits shown here were obtained through engagement in novel activities, such as word logic puzzles, critique of unfamiliar music, construction activities, and creative modelling, that were unrelated to the measure used to evaluate performance. The finding that levels of anxiety and depression were equal between the experimental and control groups and remained stable across the experimental period suggests that the performance improvements observed in the manipulation group cannot be attributed to any improvements in mood or reduction in anxiety levels.

These outcomes strongly suggest that increasing the opportunities of older adults for engagement in new and challenging pursuits can lead to much more flexible and adaptive thinking than might be expected based on the standard view of cognitive aging. Equally important, the observation that these gains in fluid intelligence performance were obtained using an experimental design, with healthy adults randomly allocated to either the experimental or control group, addresses the persistent question of the direction of causality in research on the effects of participation in cognitively stimulating activities on the cognitive function of older adults. The findings reported here provide new evidence to suggest that it is not only that individuals who lead more intellectually active lives are buffered against cognitive decline (causal direction from pre-existing higher levels of activity to enhanced or better preserved cognitive performance) but that engaging in more intellectually active pursuits may itself enhance cognitive performance (causal direction from engagement in cognitive activities to enhanced or better preserved cognitive performance).

The current research has provided evidence that is consistent with the experimental hypothesis, suggesting that a period of increased mental stimulation – using novel materials and novel cognitive processes that most likely demand the involvement of higher brain function – results in a corresponding increase in performance on measures of fluid intelligence. Evidence from a number of sources has been reported to suggest that fluid intelligence is dependent upon higher functioning, particularly frontal function, and also the integrity of the brain as a global unit (e.g., Isingrini et al., 1997; Stuart-Hamilton, 1996; Duncan, Emslie, & Williams, 1996).

It is possible that the experience of increased levels of engagement with mentally stimulating activities has a similar effect on the brain to that proposed by Jennings et al. (2005) wherein, considering the relatively broad transfer effects observed, they theorized that their experimental training method “does not improve a memory system per se but may enhance processes that are applicable across multiple systems” (p. 295). As our own manipulation is not specific to any particular ability, but is rather very broad in scope, we speculate that this overall improvement across multiple systems may be an equally plausible contributor to the experimental outcomes that we report here. The currently reported manipulation and that by Jennings et al. (2005) both demonstrated an improvement in areas of cognitive function specifically known to show age-related decline and, as such, may merit continued investigation in a wider population to assess their use as potential methods for rehabilitation training (e.g., in individuals with mild cognitive impairment, or Alzheimer’s disease).

Although the current research findings are consistent with the disuse hypothesis of age-related decline and also indirectly point to plasticity of brain processes as the underlying factor, causality is not proved. Behavioural changes inevitably depend on changes in brain function, but such changes cannot be claimed to directly or necessarily reflect neural plasticity. Although this is, indeed, a plausible explanation, stronger inferential grounds for this conclusion would require neuroanatomical, or functional neuroanatomical, evidence for *corresponding and correlated changes in brain activity* – along the lines such as that shown in recent investigations of the brain correlates, in young adults, of acquiring complex skills such as juggling (Draganski et al., 2004) or training to increase working memory capacity (Olesen et al., 2004). It also would need to be further bolstered by evidence of the attenuation or reversal of the brain changes when the increased novel stimulating activity is removed or reduced. The promising behavioural results reported here suggest that such a large-scale endeavour is both important, and potentially feasible.

Limitations

One threat to the validity of the reported research is the fact that the majority of the participants who volunteer to help with scientific research are unrepresentative of the normal population (Ganguli, Lytle, Reynolds, & Dodge, 1998; Helliwell, Aylesworth, McDowell, Baumgarten, & Sykes, 2001; for a summary see Rosenthal & Rosnow, 1991, pp. 225–226). This is a problem that is faced by many researchers and especially those carrying out laboratory-based investigations. Taking this paradigm out into the community, with the researcher going to the participants rather than the reverse, is one way to address this issue but this, of course, creates many new logistical problems. Such community-based research would allow the inclusion of, for example, much older participants, and those who already have lower existing levels of mental stimulation in their day-to-day existence (e.g., as a result of restrictions on mobility). It would be of value to assess how a change in these parameters affects the experimental outcome, thereby evaluating the generalizability of the experimental effect.

Two limitations of the reported research are the relatively small sample size, which limits statistical power, and the fact that the experimental intervention period was of relatively short duration, especially considering that any decline attributable to disuse may have occurred over a number of years. Several pragmatic constraints contributed to the number of participants that could be tested, and to the duration of the experimental intervention, particularly constraints on the time and resources available for the research. Both limitations might be addressed by performing a similar study but with an increased sample size and lasting over an extended period (6 months would seem a logical first extension). The pragmatic challenges that such an investigation poses are perhaps obvious, involving as it would a tremendous amount of organisation and very many person hours. Nonetheless, whereas it is accepted that the treatment period was short, an experimental effect was observed and this can be viewed as particularly noteworthy when taking the limitation of the brevity of the manipulation into account.

A further issue, deserving of mention, is the fact that the amount of social contact between the two groups was not equal. Although both the control and experimental groups experienced opportunities for social exchange (within the group sessions), the number of these sessions was greater for the experimental group. Whilst it seems unlikely that the social stimulation from the extra group sessions can provide an explanation for the differential increase in performance on the reported measures, it can be speculated that such social contact, in conjunction with the mentally stimulating activity, may have had a combined beneficial effect. Unfortunately it is not within the remit of this study to establish whether this is the case or not, though research suggests that marked withdrawal or disengagement from social activities is associated with increased risk of cognitive decline (Bassuk, Glass, & Beckman, 1999). Any extension study could use a control social contact group to assess the contributions made by the social component of the manipulation – this would be particularly pertinent if the study were to be of longer duration.

Two final observations might be made. First, this study does not allow the differential benefits derived from the home, versus the in-lab, activities to be separated. The relative contributions of these two components might be investigated in future research, particularly as this information would be valuable when trying to establish best practice for any potential rehabilitation programmes. Second, it is worth noting here that something of a dramatic change has been taking place in the population of older adults, such that it would seem that 60 or 65 is not as "old an age" as it once was. This is attributable, in part at least, to advances in health care so that older individuals in today's world are healthier. Also, given the constant exposure to technological change, they are perhaps likely to be somewhat more flexibly adaptive than earlier generations. Thus, future research might be extended to individuals who are of older ages than those who participated in the current study.

CONCLUSION

In summary, we have demonstrated that even a relatively brief period of increased cognitively stimulating activity had clear beneficial effects on the cognitive test performance of healthy older adults as measured by a widely accepted measure of fluid intelligence. These experimental outcomes add to a large and still growing body of evidence pointing to considerable plasticity in human intelligence functioning, including forms of thought and reasoning deemed most susceptible to age-related decline. With increased opportunities for novel and continuing exploration, and the full (and playful) use rather than disuse of our cognitive abilities, decrements in our capacity to creatively and flexibly grapple with the world, in ways that do not rely on prior learning or knowledge, may not be as severe, as sharp, or as early as – without such stretching towards mental flexibility – they otherwise would be.

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