COGNITIVE AGING RESEARCH USING THE INTERNET: FOUR CASE STUDIES

Elizabeth A. Maylor and Stian Reimers
Department of Psychology, University of Warwick, Coventry, UK, CV4 7AL
e.a.maylor@warwick.ac.uk *s.reimers@ucl.ac.uk*

Abstract

Data collection via the Internet has recently become popular not least because of the time, energy and resources that can be saved by testing substantial numbers of participants over a short period. However, to date, there have been few Internet studies of cognitive development or aging. We briefly discuss some advantages and disadvantages of this new methodology before illustrating its potential by presenting four case studies of (1) task switching across the life span, (2) age and gender effects on intraindividual variability, (3) impulsivity and delay discounting across adulthood, and (4) gender and sexual orientation differences in rates of cognitive aging. We conclude that, where comparisons can be drawn, the data generally replicate laboratory findings. Moreover, they extend them in several interesting ways such as providing a much finer-grained analysis of changes with age than has previously been possible.

With the enormous recent increase in access to the Internet has come a rapidly expanding literature reporting psychological experiments conducted online (see Birnbaum, 2004; Skitka & Sargis, 2006, for reviews). There are many obvious advantages of such methodology. For example, it can save researchers both time and money – once an experiment is set up, it can be run concurrently on large numbers of unpaid volunteers. These generally represent a wider demographic than the usual undergraduate population employed in laboratory-based research and hence the results may be more generalizable. Experimenter bias can be avoided because Internet experiments run automatically. Most crucially for our purposes, reaction times (RTs) can now be measured to a reasonable level of accuracy over the Internet (Reimers & Stewart, in press; see also Ulrich & Giray, 1989, for evidence that a lack of millisecond accuracy makes little difference to results anyway).

Of course, there are also some obvious disadvantages associated with Internet experimentation. These include the possibility of a biased sample as although most people now have access to computers, not everyone will have the appropriate software installed for downloading and running experiments. People may not be honest, for example, in answering questions about demographics (age, education, gender, etc). They may not treat the experiment seriously (although it is not always certain that the traditional undergraduate population does so). More importantly, people may not always understand the instructions and, unlike in laboratory research, there is no opportunity to check and provide further instructions if necessary. Internet studies provide no control over the conditions under which the experiment is conducted – uncontrolled factors include monitor size, hand positions, distractions, noise, time of day, and so on. Also, there is no control over the participants' state – for example, they may be tired, intoxicated, or not wearing their glasses.

However, in view of the large numbers of people who can be tested in Internet studies, researchers can ensure the integrity of their data by taking a conservative approach to the datasets they allow to enter the analysis (see later). In general, this methodology tends to produce effects that account for only a small proportion of the variance but are highly significant. The effects may be more generalizable to real world situations if they emerge from experiments conducted on diverse samples under poorly controlled conditions. It is therefore argued that the considerable advantages more than outweigh the disadvantages, particularly as evidence suggests that web-based studies can reliably replicate laboratory findings (see Buchanan & Smith, 1999; Gosling, Vazire, Srivastava, & John, 2004; Krantz & Dalal, 2000; McGraw, Tew, & Williams, 2000).

Access to the Internet is now widespread in schools; older adults are also increasingly being encouraged to use the Internet although home access decreases with age (Cutler, Hendricks, & Guyer, 2003; Selwyn, Gorard, Furlong, & Madden, 2003). In 2004, 22% of American over-65s had Internet access, compared to 15% in 2000, and the number of 'silver surfers' is likely to increase dramatically over the next few years (Fox, 2004). Thus, there is currently enormous potential for conducting life span research online. One recent impressive example is a study by Robins, Trzesniewski, Gosling and Potter (2002) in which 326,641 individuals aged between 9 and 90 years were asked to rate their level of self-esteem on a 5-point scale. The results resolved discrepancies in the literature by revealing a cubic relationship such that self-esteem was "high in childhood, dropped during adolescence, rose gradually throughout adulthood, and declined sharply in old age" (p. 423). However, the authors noted that their sample was obviously restricted to those with access to the Internet and suggested that their results require replication with a representative sample.

In this paper, we present four further illustrations of Internet studies across a wide age range that both replicate and extend findings from more traditional laboratory experiments.

Case Study I: Task Switching

Executive control processes are high-level functions that organize, sequence and regulate behavior. As such, they are vital for most everyday activity, particularly that which requires planning, holding open multiple goals, or cognitive flexibility. In laboratory tests, it is apparent that executive control improves through childhood and adolescence but declines in old age (e.g., Fristoe, Salthouse, & Woodard, 1997; Zelazo & Müller, 2002). The result is an inverted-U-shaped function across the life span, although executive control is not unique in this – for example, processing speed also shows a similar shaped function across the life span (e.g., Cerella & Hale, 1994).

Researchers have attempted to explain the inverted-U-shaped function of executive control across the life span in terms of frontal lobe functioning (see Reimers & Maylor, 2005, for a summary). Thus, evidence from functional imaging and neuropsychological studies suggests that tasks requiring some form of executive control depend on the use of at least a part of the frontal lobes. In children, frontal lobe development continues through adolescence over the same developmental time period as performance on executive control tasks improve. Also frontal lobe deterioration is well documented in old age.

Task switching is regarded as an example of an executive control process (Miyake et al., 2000). In a typical procedure, participants would have to switch between two orthogonal classifications of stimuli. For example, the stimuli could be the numbers 1-8 and the two classifications would be on the basis of oddness (odd/even) and size (small/large). In a switch block, participants would have to alternate between two odd/even classifications followed by two small/large classifications. In single task blocks, they would either always make odd/even classifications or small/large classifications.

Two different measures of executive control can be defined in task switching experiments: (1) General switch costs, also known as mixing or set selection costs, reflect the difficulty in maintaining and selecting among two or more potential response sets and are measured by the difference in performance between switch blocks and single task blocks. (2) Specific switch costs represent the difficulty in switching from one response set to another and are measured by the difference in performance between switch trials and nonswitch trials within switch blocks.

Evidence on these two aspects of task switching with respect to development and aging is somewhat mixed in the literature (though it has a long history, going back at least to Brinley, 1965). However, the overall picture is that for general switch costs, even after taking into account age differences in processing speed, these are greater for older adults than for young adults (Wecker, Kramer, Hallam, & Delis, 2005). They are also greater in young children than in adults (Kray, Eber, & Lindenberger, 2004). For specific switch costs, again after taking overall speed into account, these are largely unaffected by both development and old age (Kray et al., 2004), though there are exceptions.

At present, however, there is very limited evidence on the way in which task switching changes across the life span – most studies focus either on development or aging, or they test just three groups (children, young adults and older adults). But the physiological evidence suggests that the frontal lobes actually decline quite early, from at least middle age and possibly from young adulthood. We would therefore predict that task switching should decline similarly, that is, prior to old age.

One task switching study that used a wide and continuous range of ages is by Cepeda, Kramer and Gonzalez de Sather (2001) who tested 152 people between the ages of 7 and 82 years. The data were analysed in nine age bands, with 12-21 people in each band. Although there was evidence of general inverted-U-shaped performance, the relatively small numbers of people in each age band made it difficult to trace age effects outside of the extremes of childhood and old age. However, the authors concluded that "switch costs decreased from childhood to young adulthood, remained fairly constant across the adult years, and then began to increase after the age of 60" (p. 726).

The main aim of our study was therefore to collect sufficient data to examine task switching ability particularly through young adulthood and middle age. In order to obtain sufficient numbers to allow a fine-grained analysis across the life span, we conducted the experiment on the Internet using one of the author's (SR's) involvement with a British Broadcasting Corporation (BBC) television series (*The Human Mind*) to recruit participants. At the end of each episode, four million viewers were encouraged to visit the BBC website, which included the present study (see Reimers & Maylor, 2005, for details).

The experiment could be accessed by anyone with Adobe Flash installed on their computer. The programme is downloaded onto the user's machine and then runs locally. At the end of the experiment, the data and the user's IP address are sent to a remote server. This can then pass back information on performance to the participant (i.e., the participant's own means and also the means of those who have already taken part).

The stimuli were pictures of four faces: a happy female, a happy male, a sad female and a sad male. There were two single task blocks of 12 trials each, in which participants were asked to respond as quickly and as accurately as possible on the basis of gender (female/male) or emotion (happy/sad). Half of the participants began with the gender task and half began with the emotion task. Following the single task blocks, there was a switch block of 32 trials in which participants were required to alternate between two gender classifications and two emotion classifications (half starting the block with gender, half starting with emotion). Prior to the appearance of each face in the switch block, a cue (EMOTION or GENDER) appeared for 1 s below the stimulus to remind participants of the current classification.

In four months, 12,103 people had completed the experiment. We first excluded submissions from IP addresses from which data had already been received in case the same person was doing the task multiple times, thereby excluding 3,964 participants. The data were corrupt or incomplete for 40 people and 1,690 people did not submit their ages so could not be included. The submitted ages ranged from 5-109 years. If there were fewer than five exemplars for a particular age, that age was excluded (n = 28), leaving a range of ages from 10-66 years.

After considering performance over the course of a block of trials, we excluded trials 1-4 for the single tasks and trials 1-12 for the switching block in order to focus on stable asymptotic performance. Trials with RTs greater than 3 s were excluded and also errors and trials immediately following errors were excluded from the calculation of mean correct RTs. We also excluded participants whose error rate in any block exceeded 25% and those who did not submit gender or education level information, leaving a final total of 5,271 participants.

Both RTs and error rates as a function of age from 10-66 years followed the expected U-shaped functions, replicating previous studies of speeded tasks across the life span (e.g., Cerella & Hale, 1994). Optimal performance was around 17-18 years of age and 60-year-olds were matched in level with 10-year-olds. General switch costs were greater than specific switch costs and both decreased during development and increased with aging. Overall differences in RT were then taken into account by dividing switch costs by baseline RTs to produce proportionate switch costs. Proportionate specific switch costs were completely unaffected by age from 10-66 years. In contrast, proportionate general switch costs showed a striking linear decrease from 10-17 years followed by an almost linear increase across adulthood. In this case, 40-year-olds were matched in level with 10-year-olds. These findings contrast with those of Cepeda et al. (2001) who found that switch costs were stable until 60 years of age but they are consistent with some other measures of executive control. For example, Garden, Phillips and McPherson (2001) noted that middle-aged participants performed more poorly than younger adults on some measures of executive functioning, consistent with evidence of relatively early decline in frontal lobe functioning.

Importantly, the results of this study demonstrate that switch costs between puberty and middle age are worthy of further investigation. They also suggest that we can have some confidence in web-based methodology for the study of task switching – it is reassuring that the results replicate several aspects of previous findings (e.g., greater general than specific switch costs) but also extend them to a more diverse population.

Case Study II: Intraindividual Variability

Trial-to-trial variation in speeded performance within an individual, or intraindividual variability (*SD* of the *M* RT, or RTSD), has attracted much interest recently, particularly in the aging literature (Hultsch & MacDonald, 2004). This is because, as a number of researchers have demonstrated, intraindividual variability in RT increases in old age, often over and above overall increases in *M* RT. A recent study by Deary and Der (2005) reported that RTSD is also affected by gender such that variability is greater for females than for males, which they suggested might reflect the long-term effect of sex hormones after puberty, causing greater variability in women. They tested almost 2,000 people aged between 15 and 66 using a specially designed piece of hardware that recorded choice RTs from 40 trials and gave as output *M* RT and RTSD for each participant. RT and RTSD both increased with age, as expected. Males and females did not differ in RT but RTSD and RTSD/RT (i.e., coefficient of variability, CV) were significantly greater for females than for males.

Deary and Der (2005) were unable to consider trial-to-trial effects, that is, the way in which performance changed from the first to the last trial of the block. However, trial-to-trial or learning effects could account for the gender difference they observed. For example, females could show a stronger learning effect, with RT at the start of a block more different to RT at the end of a block than for males. Or males and females may not differ at the start of a block, but females could take longer to reach asymptote than males. Males and females could differ in the way in which they trade off speed for accuracy across a block, with females initially more cautious than males. Thus, before we can conclude that gender effects on variability are due to random fluctuations in RT across trials, we need to rule out these more systematic changes over time.

To do this, we used the gender classification data from the single task block of 12 trials from the Reimers and Maylor (2005) study (see Reimers & Maylor, 2006). We first established that the data replicated the basic pattern found by Deary and Der (2005), namely, age effects on RT and RTSD and gender effects (females more variable than males) for both RTSD and CV. We next examined how performance varied across trials by gender and age to investigate whether the effects could be explained by systematic differences across a block. For both RTs and error rates, there were highly significant interactions between gender and trial: Males were 90 ms faster on trial 1, and 17 ms slower on trials 3-12, than females. Females were more accurate than males on trials 1 and 2, but equally accurate on trials 3-12. In contrast, RTs and error rates across trials for different age groups were approximately parallel.

Thus, it appears that the effect of gender on variability is due to systematic differences in performance across trials such that females are initially more cautious in their approach to a new task than males (i.e., slower but more accurate on the first two trials). After removing the first two trials, there was no longer any effect of gender on either RTSD or CV. In contrast, older adults are intrinsically more variable than young adults – thus, age and gender effects on RT variability have different origins. Importantly, this analysis of Internet data both replicated and extended previous findings on an aspect of performance (intraindividual variability) that is currently the focus of much recent aging research.

Case Study III: Impulsivity and Delay Discounting

In the same Internet study, we also collected data on impulsivity in order to investigate its relationship with switch costs on the basis that both would be expected to be associated with frontal/executive functioning. Although no significant correlations were found, the impulsivity data with respect to aging were interesting nonetheless (see Reimers, Maylor, Stewart, & Chater, 2006). We administered the Barratt Impulsiveness Scale (BIS; Patton, Stanford, & Barratt, 1995), which requires participants to respond on a 4-point scale from *never* to *always* to statements such as “I do things without thinking” and “I change jobs”.

Data analysis was restricted to participants aged 21-65 years in order to avoid those still in full-time education or retired. This sample (n = 6,219; 56% females) showed a strikingly linear decrease in impulsivity as measured by the BIS from early adulthood to retirement age. There was also a significant influence of education, with impulsivity lower at higher levels of education, but there was no difference between men and women.

Closely linked to impulsivity, but more objectively quantifiable, is the notion of delay discounting. This suggests that as the delay to receipt of a reward increases, so the subjective value of the reward decreases. For example, if faced with the choice of £45 in 3 days or £70 in 3 months, around half the population chooses the smaller-sooner option while half chooses the larger-later option. Thus, to the extent that delay discounting of financial rewards reflects impulsivity, we expected a similar pattern of results with respect to increasing adult age, namely, a linear reduction in delay discounting. However, previous studies have not found this – Green and his colleagues noted that children discounted future rewards more than 20-year-olds who discounted more than 30-year-olds, with no difference between 30- and 70-year-olds (Green, Fry, & Myerson, 1994; Green, Myerson, Lichtman, Rosen, & Fry, 1996).

In a new Internet study, promoted via the front page of the BBC's Science and Nature website, we investigated delay discounting by asking participants the following question: "Which would you rather have - £45 in three days from now / £70 in three months time". Demographic data were also collected, together with information on other behaviors that might reflect impulsive decision making, such as smoking. Results were based on around 48,000 people aged 21-65 years.

The proportion of people choosing the smaller-sooner option fell approximately linearly with increasing age. A multiple regression analysis was performed to identify factors making significant independent contributions to participants' choices. As expected, the model accounted for only a small proportion of the overall variance (4.5%) but was a highly significant fit. There were significant independent effects (all p's < .001) of several factors, with the smaller-sooner (impulsive) choice associated with: younger age; female gender; lower education; lower income; smoking; higher body-mass index; sexual promiscuity; sexual infidelity; and younger age at first sexual intercourse.

To conclude, both impulsivity and delay discounting were found to decrease almost linearly across adulthood, contrary to earlier studies. The data therefore favor explanations that assume a mechanism changing throughout adult life, such as the gradual speeding up of subjective time (see Draaisma, 2004). A preference for immediate gratification appeared to be consistent across many domains of behavior (sex, smoking, food, finance). Clearly, data from a single question put to tens of thousands of people across a wide age range can generate meaningful results. (For other examples of the value of just one data point when collected from hundreds of participants over the Internet, see Maylor, in press; Maylor & Roberts, in press.)

Case Study IV: Gender and Sexual Orientation

Our final illustration is a study of the association between gender and age-cognition relations from young adulthood to retirement age with around 200,000 participants (Maylor et al., 2007), which was again conducted in collaboration with the BBC. Because of its scale, the study also provided the opportunity to further subdivide the groups to examine for the first time the influence of sexual orientation on age-related changes in cognition.

Gender differences in cognition are well known, with females generally outperforming males on tests of perceptual speed, verbal fluency, and memory for object locations, and males generally outperforming females on tests of visuospatial skills and mathematical reasoning (e.g., Kimura, 1999). In addition, there are systematic differences in cognition within each gender (especially in males) according to sexual orientation (LeVay, 1993) such that, for example, on some male-superior visuospatial tasks, homosexual men tend to perform less well than heterosexual men (Collaer, Reimers, & Manning, 2007). Thus, homosexuals tend to follow gender-atypical patterns of behavior (Rahman & Wilson, 2003), due in part to the relative feminization (in men) and masculinization (in women) of the brain by prenatal hormones (Ellis & Ames, 1987).

Gender differences have also been observed in age-related deterioration of the brain (see Meinz & Salthouse, 1998, for a review). For example, from MRI scans, brain atrophy as indicated by increased cerebrospinal fluid volume with age is greater in males than in females; reductions in brain volume with age for both frontal and temporal lobes are greater in males than in females; and reduction in hippocampal volume has been found across early adulthood for males but not for females. Such findings would lead to expectations of greater age-related cognitive decline in males than in females, which has indeed been observed in at least some cross-sectional and longitudinal studies (see Maylor et al., 2007, for a summary).

However, a number of other studies have failed to find significant gender differences in rates of cognitive aging and there have also been occasional reports that cognitive decline is actually greater in females than in males. Why is there such a mixed pattern of results? There could be a number of reasons, including the use of different tasks and dependent measures across the various studies, and particularly the use of different ages. Given that women live around seven years longer than men (Hayflick, 1996), studies of very old adults are likely to include more positively selected men than women. Moreover, if gender differences in rates of cognitive aging are small in magnitude, the studies showing null effects may have lacked power to detect interactions between age and gender.

Our Internet study therefore addressed these issues by (1) employing several tasks, some female-superior tasks and some male-superior tasks, with both accuracy and speed as dependent measures, (2) focusing on young and middle-aged adults (20-65 years), thereby avoiding very old age, and (3) recruiting large numbers of participants to maximize power. The main predictions were that performance would be affected by age, gender and their interaction such that men would show greater age-related decline than women, regardless of task or measure. We also predicted effects of age, sexual orientation and their interaction within each gender such that female non-heterosexuals would show greater age-related decline than female heterosexuals but that male non-heterosexuals would show less age-related decline than male heterosexuals (i.e., non-heterosexuals following gender atypical rates of aging).

Full details of the overall design and implementation of the study on the BBC's Science and Nature website are provided by Reimers (2007). In brief, the study was divided into six blocks, each lasting 3-6 minutes. (Participants did not have to complete all six in one session.) There were four cognitive tasks, in addition to questions about preferences, personality, and demographics. Of relevance here, participants were asked about their age, gender, sexual orientation (heterosexual, homosexual, or bisexual), education, and self-rated health. They were also asked to indicate their consumption of medicines, alcohol, nicotine, and drugs. Data were collected over the course of three months, during which time over a quarter of a million people successfully completed all elements of the study.

The four cognitive tasks were chosen to provide two on which men would outperform women (mental rotation and line angle judgment), and two on which women would outperform men (two versions of category fluency and object location memory). In the mental rotation task, participants were shown an object on the left of the screen and their task was to choose the two objects on the right (out of four) that matched the reference object when viewed from a different angle. The line angle judgment task required participants to select a line from an array of 15 lines that matched the angle of a test line displayed above the array. In the category fluency task, participants were given a minute to type as many words as possible belonging to a specified category. The first category was "objects usually colored GREY" and the second category was "words that mean the same as HAPPY". Finally, in the object location memory task, participants were given a minute to memorize the locations of 27 objects on the screen, after which the objects disappeared and then reappeared with around half having been swapped pair-wise in screen position. Participants were required to select the items that had moved.

For the analyses of the data by age and gender, participants were categorized into nine 5-year intervals from 20 to 65 years. There were more men than women at all ages (totals of 109,612 and 88,509, respectively). As is usually the case with Internet studies, the age distribution was positively skewed but there were still at least 1,000 participants of each gender in all age groups. In terms of background measures, we successfully replicated previous findings of a negligible influence of age on self-rated health, despite a large increase with age in medicine intake (cf. Salthouse, Kausler, & Saults, 1990). Medicine intake was greater for women than for men, and level of education was lower for women than for men, particularly at older ages. As expected (e.g., Davy, 2006), there was higher consumption by men than by women of alcohol, nicotine, and drugs. All these variables were therefore taken into account as covariates in the analyses of the cognitive data, although the results were qualitatively unaffected by their inclusion.

Scores in terms of numbers correct for the cognitive tasks all declined significantly with increasing age (see Herlitz & Yonker, 2004; Hommel, Li, & Li, 2004, for similar declines), and men duly outperformed women on the male-superior tasks (mental rotation and line angle judgment) whereas women outperformed men on the female-superior tasks (category fluency and object

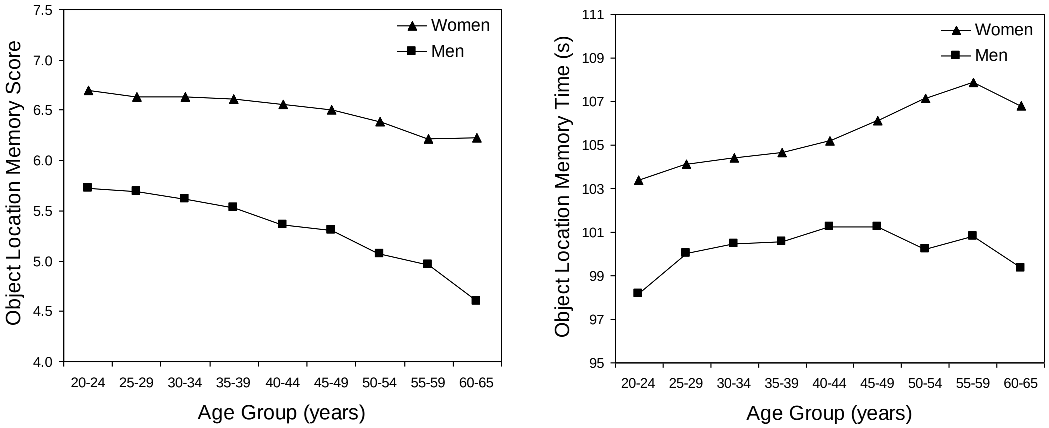

Figure 1. Mean correct scores (left panel) and completion times (right panel) for women and men as a function of age group for one of the cognitive tasks (object memory location) in Maylor et al.'s (2007) study.

location memory). Moreover, there were significant interactions between age and gender in all cases, indicating more marked cognitive decline with age for men than for women. Illustrative data from one of the tasks (object location memory) are shown in Figure 1 (left panel).

The time taken to complete the task was measured for two of the cognitive tasks, namely, line angle judgment and object location memory. Not surprisingly, older adults were slower than younger adults (Cerella, 1985; Salthouse, 1996) in both cases. Men were slower than women in the line angle judgment task, whereas women were slower than men in the object location task (Figure 1, right panel). In addition, there were significant interactions between age and gender, indicating more marked slowing with age for women than for men in both cases. However, the inclusion of time to complete the task as a covariate in the analyses of scores on each task did not alter the original pattern of results.

The data were also analyzed by age and sexual orientation (heterosexual, homosexual, and bisexual) for each gender. For background measures, heterosexuals reported better health and a lower intake of medicines in comparison with non-heterosexuals, regardless of age or gender, consistent with evidence that heterosexuals of both genders have better mental and physical health than non-heterosexuals (e.g., de Graaf, Sandfort, & ten Have, 2006; Julien & Chartrand, 2005; King et al., 2003). In both women and men, nicotine intake and drug use were lower for heterosexuals than for non-heterosexuals, again in line with previous research (e.g., Ryan, Wortley, Easton, Pederson, & Greenwood, 2001). As before, these measures were included as covariates in the main analyses below but with little alteration in the general pattern of results.

There were significant effects of sexual orientation on cognitive scores for both women and men. In most cases, heterosexuals of a particular gender outperformed non-heterosexuals on tasks for which that gender was superior, or underperformed non-heterosexuals where that gender was inferior (for similar findings, see Rahman, Abrahams, & Wilson, 2003; Rahman & Wilson, 2003; Rahman, Wilson, & Abrahams, 2003). Crucially, however, there was no clear evidence of differential age-related decline according to sexual orientation for either women or men, contrary to our predictions.

To summarize, this Internet study produced largely expected overall effects of age, gender, and sexual orientation on cognitive performance. Moreover, men's scores showed greater age-related decline than did women's, regardless of whether the task was one on which men were superior, whereas sexual orientation was not associated with rate of cognitive decline. These conclusions were unaffected by covarying measures of health, education, and consumption of alcohol, nicotine, and drugs (most of which displayed expected effects of gender and sexual orientation, and differential relations across adulthood).

Our findings with respect to gender are consistent with neuroimaging evidence of greater age-related deterioration of the brain in males than in females and with at least some previous cognitive data. Nevertheless, it has to be acknowledged that, although highly significant, our age-gender interactions were extremely small, accounting for only 0.1% of the variance in cognitive performance. Thus, even taking into account the fact that small effect sizes are inevitable in research conducted on the Internet (see earlier), the present observations support the view that some previous studies may have failed to find significantly different rates of cognitive decline with aging in women and men because of insufficient statistical power.

The present findings also offer a possible explanation for at least some of the previous cases of greater age-related decline in females than in males. With time taken to perform the task as the dependent measure, we found significantly greater age-related slowing for women than for men (though covarying time in the analysis of scores did not alter the main pattern). Similar results for reaction times were observed by Meinz and Salthouse (1998) and more recently by Der and Deary (2006), suggesting that the use of different dependent measures (speed vs. accuracy) may partly explain discrepancies in the literature.

How can we account for gender differences in cognitive aging? Although our study was not designed to test between possible explanations (including neurophysiological, hormonal, and social differences), the results do at least rule out the intuitively simple notion that men decline more quickly than women because they are, on average, closer to death and therefore more likely to be experiencing terminal decline (Berg, 1996). Thus, we found exactly the same pattern of results when we took account of the 7-year gender difference in longevity (Hayflick, 1996) by comparing women aged 27-65 years with men aged 20-58 years.

Finally, the scale of this Internet study was such that further division of each gender by sexual orientation was possible, which resulted in the novel finding of similar rates of cognitive aging in heterosexuals and non-heterosexuals. This was contrary to expectations of gender-atypical patterns of performance in non-heterosexuals (cf. Rahman & Wilson, 2003) and suggests that future investigations should focus on age-related changes in neurophysiological, hormonal, social and other factors that vary between women and men, but not between heterosexuals and non-heterosexuals of the same gender.

Conclusions

Our main aim in presenting these four case studies was to demonstrate the potential for conducting life span/aging research using the Internet. It is at least reassuring that, where comparisons can be drawn, the data generally replicate existing findings from the laboratory or from traditional survey methods. But Internet methodology can also extend the data by providing a much finer-grained analysis of changes with age than is usually possible. Some advantages of Internet studies were outlined earlier. To these can be added a number of additional advantages with respect to research on aging – for example, participants are not required to travel for testing, and older adults are probably less anxious when tested in their own familiar environments. It therefore seems likely that the Internet will be increasingly employed in the future to address life span and aging issues, though laboratory studies will still be necessary to confirm observations under controlled conditions.

References

Berg, S. (1996). Aging, behavior, and terminal decline. In J. E. Birren & K. W. Schaie (Eds.), *Handbook of the psychology of aging* (Fourth ed., pp. 323-337). San Diego, CA: Academic Press.Birnbaum, M. H. (2004). Human research and data collection via the Internet. *Annual Review of Psychology, 55,* 803-832.

Birnbaum, M. H. (2004). Human research and data collection via the Internet. *Annual Review of Psychology, 55,* 803-832.

Brinley, J. F. (1965). Cognitive sets, speed and accuracy of performance in the elderly. In A. T. Welford & J. E. Birren (Eds.), *Behavior, aging, and the nervous system* (pp. 114-149). Springfield: Charles C Thomas.

Buchanan, T., & Smith, J. L. (1999). Using the Internet for psychological research: Personality testing on the World Wide Web. *British Journal of Psychology, 90,* 125-144.

Cepeda, N. J., Kramer, A. F., & Gonzalez de Sather, J. C. M. (2001). Changes in executive control across the life span: Examination of task-switching performance. *Developmental Psychology, 37,* 715-730.

Cerella, J. (1985). Information processing rates in the elderly. *Psychological Bulletin, 98,* 67-83.

Cerella, J., & Hale, S. (1994). The rise and fall in information-processing rates over the life span. *Acta Psychologica, 86,* 109-197.

Collaer, M. L., Reimers, S., & Manning, J. T. (2007). Visuospatial performance on an Internet line judgment task and potential hormonal markers: Sex, sexual orientation, and 2D:4D. *Archives of Sexual Behavior, 36.* doi: 10.1007/s10508-006-9152-1

Cutler, S. J., Hendricks, J., & Guyer, A. (2003). Age differences in home computer availability and use. *Journal of Gerontology Series B: Psychological Sciences and Social Sciences, 58,* S271-S280.

Davy, M. (2006). Time and generational cohort trends in smoking among men and women in Great Britain, 1972-2004/05. *Health Statistics Quarterly, 32,* 35-43.

Deary, I. J., & Der, G. (2005). Reaction time, age, and cognitive ability: Longitudinal findings from age 16 to 63 years in representative population samples. *Aging, Neuropsychology, and Cognition, 12,* 187-215.

de Graaf, R., Sandfort, T. G. M., & ten Have, M.(2006). Suicidality and sexual orientation: Differences between men and women in a general population-based sample from the Netherlands. *Archives of Sexual Behavior, 35,* 253-262.

Der, G., & Deary, I. J. (2006). Age and sex differences in reaction time in adulthood: Results from the United Kingdom Health and Lifestyle Survey. *Psychology and Aging, 21,* 62-73.

Draaisma, D. (2004). *Why life speeds up as you get older: How memory shapes our past*. Cambridge, UK: Cambridge University Press.

Ellis, L., & Ames, M. A. (1987). Neurohormonal functioning and sexual orientation: A theory of homosexuality-heterosexuality. *Psychological Bulletin, 101,* 233-258.

Fox, S. (2004). *Older Americans and the Internet.* Retrieved April 3, 2007, from the Pew Internet & American Life Project Web site: http://www.pewinternet.org/pdfs/PIP_Seniors_Online_2004.pdf

Fristoe, N. M., Salthouse, T. A., & Woodard, J. L. (1997). Examination of age-related deficits on the Wisconsin Card Sorting Test. *Neuropsychology, 11*, 428-436.

Garden, S. E., Phillips, L. H., & MacPherson, S. E. (2001). Midlife aging, open-ended planning, and laboratory measures of executive function. *Neuropsychology, 15*, 472-482.

Gosling, S. D., Vazire, S., Srivastava, S., & John, O. P. (2004). Should we trust web-based studies? A comparative analysis of six preconceptions about Internet questionnaires. *American Psychologist, 59,* 93-104.

Green, L., Fry, A. F., & Myerson, J. (1994). Discounting of delayed rewards: A life-span comparison. *Psychological Science, 5*, 33-36.

Green, L., Myerson, J., Lichtman, D., Rosen, S., & Fry, A. (1996). Temporal discounting in choice between delayed rewards: The role of age and income. *Psychology and Aging, 11*, 79-84.

Hayflick, L. (1996). *How and why we age* (Second ed.). New York: Ballantine.

Herlitz, A., & Yonker, J. E. (2004). Hormonal effects on cognition in adults. In R. A. Dixon, L. Bäckman, & L.-G. Nilsson (Eds.), *New frontiers in cognitive aging* (pp. 253-277). Oxford: Oxford University Press.

Hommel, B., Li, K. Z. H., & Li, S.-C. (2004). Visual search across the life span. *Developmental Psychology, 40*, 545-558.

Hultsch, D. F., & MacDonald, S. W. S. (2004). Intraindividual variability in performance as a theoretical window onto cognitive aging. In R. A. Dixon, L. Bäckman & L.-G. Nilsson (Eds.), *New Frontiers in Cognitive Aging* (pp. 65-88). Oxford, England: OUP.

Julien, D., & Chartrand, E. (2005). Recension des études utilisant un échantillon probabiliste sur la santé des personnes gaies, lesbiennes et bisexuelles. *Canadian Psychology/Psychologie Canadienne, 46,* 235-250.

Kimura, D. (1999). *Sex and cognition.* Cambridge, MA: The MIT Press.

King, M., McKeown, E., Warner, J., Ramsay, A., Johnson, K., Cort, C., et al. (2003). Mental health and quality of life of gay men and lesbians in England and Wales: Controlled, cross-sectional study. *British Journal of Psychiatry, 183,* 552-558.

Krantz, J. H., & Dalal, R. (2000). Validity of web-based psychological research. In M. H. Birnbaum (Ed.), *Psychological experiments on the Internet* (pp. 35-60). San Diego: Academic Press.

Kray, J., Eber, J., & Lindenberger, U. (2004). Age differences in executive functioning across the lifespan: The role of verbalization in task preparation. *Acta Psychologica, 115,* 143-165.
LeVay, S. (1993). *The sexual brain*. Cambridge, Massachusetts: The MIT Press.
Maylor, E. A. (in press). Prospective memory through the ages. To appear in M. Kliegel, M. A. McDaniel, & G. O. Einstein (Eds.), *Prospective memory: Cognitive, neuroscience, developmental, and applied perspectives.* Mahwah: Erlbaum.
Maylor, E. A., Reimers, S., Choi, J., Collaer, M. L., Peters, M., & Silverman, I. (2007). Gender and sexual orientation differences in cognition across adulthood: Age is kinder to women than to men regardless of sexual orientation. *Archives of Sexual Behavior, 36*. doi: 10.1007/s10508-006-9155-y
Maylor, E. A., & Roberts, M. A. J. (in press). Similarity and attraction effects in episodic memory judgments. *Cognition*.
McGraw, K. O., Tew, M. D., & Williams, J. E. (2000). The integrity of Web-delivered experiments: Can you trust the data? *Psychological Science, 11,* 502-506.
Meinz, E. J., & Salthouse, T. A. (1998). Is age kinder to females than to males? *Psychonomic Bulletin & Review, 5,* 56-70.
Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41,* 49-100.
Patton, J. H., Stanford, M. S., & Barratt, E. S. (1995). Factor structure of the Barratt Impulsiveness Scale. *Journal of Clinical Psychology, 51,* 768-774.
Rahman, Q., Abrahams, S., & Wilson, G. D. (2003). Sexual-orientation-related differences in verbal fluency. *Neuropsychology, 17,* 240-246.
Rahman, Q., & Wilson, G. D. (2003). Large sexual-orientation-related differences in performance on mental rotation and judgment of line orientation tasks. *Neuropsychology, 17,* 25-31.
Rahman, Q., Wilson, G. D., & Abrahams, S. (2003). Sexual-orientation-related differences in spatial memory. *Journal of the International Neuropsychological Society, 9,* 376-383.
Reimers, S. (2007). The BBC Internet study: General methodology. *Archives of Sexual Behavior, 36*. doi:10.1007/s10508-006-9143-2
Reimers, S., & Maylor, E. A. (2005). Task switching across the life span: Effects of age on general and specific switch costs. *Developmental Psychology, 41,* 661-671.
Reimers, S., & Maylor, E. A. (2006). Gender effects on reaction time variability and trial-to-trial performance: Reply to Deary and Der (2005). *Aging, Neuropsychology, and Cognition, 13,* 479-489.
Reimers, S., Maylor, E. A., Stewart, N., & Chater, N. (2006, April). *Impulsivity and delay discounting through adulthood: A large-scale study.* Poster presented at the 11th Cognitive Aging Conference, Atlanta, Georgia.
Reimers, S., & Stewart, N. (in press). Adobe flash as a medium for online experimentation: A test of RT measurement capabilities. *Behavior Research Methods.*
Robins, R. W., Trzesniewski, K. H., Gosling, S. D., & Potter, J. (2002). Global self-esteem across the life span. *Psychology and Aging, 17,* 423-434.
Ryan, H., Wortley, P. M., Easton, A., Pederson, L., & Greenwood, G. (2001). Smoking among lesbians, gays, and bisexuals: A review of the literature. *American Journal of Preventive Medicine, 21,* 142-149.
Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review, 103,* 403-428.
Salthouse, T. A., Kausler, D. H., & Saults, J. S. (1990). Age, self-assessment health status, and cognition. *Journal of Gerontology, 45,* P156-P160.
Selwyn, N., Gorard, S., Furlong, J., & Madden, L. (2003). Older adults' use of information and communications technology in everyday life. *Ageing and Society, 23,* 561-582.
Skitka, L. J., & Sargis, E. G. (2006). The Internet as psychological laboratory. *Annual Review of Psychology, 57,* 529-555.
Ulrich, R., & Giray, M. (1989). Time resolution of clocks: Effects on reaction time measurement – Good news for bad clocks. *British Journal of Mathematical and Statistical Psychology, 42,* 1–12.

Wecker, N. S., Kramer, J. H., Hallam, B. J., & Delis, D. C. (2005). Mental flexibility: Age effects on switching. *Neuropsychology, 19,* 345-352.

Zelazo, P. D., & Müller, U. (2002). Executive function in typical and atypical development. In U. Goswami (Ed.), *Handbook of childhood cognitive development* (pp. 445-469). Oxford: Blackwell.

Maylor, E. A., & Reimers, S. (2007). Cognitive aging research using the Internet: Four case studies. In A. Garriga-Trillo (Ed.), *Converging research on predictors of cognitive impairment and neurodegenerative diseases* (pp. 29-41). Madrid: Publidisa.