

To appear in *Psychology and Aging*

Depression, anxiety, and within-person variability in adults aged 18 to 85 years

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## Abstract

Mild depression and anxiety were investigated in relation to measures of within-person (WP) variability and mean RT from psychomotor, executive function, visual search, and word recognition tasks in a continuous age range (18 to 85 years,  $M = 50.33$ ,  $SD = 20.37$ ) of 300 community-dwelling adults. Structural equation modeling identified a significant Age x Depression interaction in relation to visual search for measures of WP variability but not for mean RT. Older more depressed adults exhibited greater variability. WP variability in executive function and other cognitive constructs covaried, and the significant Age x Depression interaction with visual search was accounted for by WP variability in executive control. The findings suggest that age-, and depression-related reductions in attentional resources may contribute to increased variability in visual search, and that variability in executive control may be the mechanism underlying these effects.

Keywords: Age, depression, anxiety, intraindividual variability, cognition

It is not uncommon for otherwise healthy community-dwelling individuals to experience episodes of depression or anxiety in their day-to-day lives. Although such episodes may not obviously affect everyday functioning, it is possible that their effects manifest in relatively subtle, but nonetheless important, ways. It is this possibility that motivates the present study. Specifically, we focus on the extent to which depression or anxiety affects cognitive function, and in particular, how this association may vary according to age. Although work has investigated mental health and cognition while taking age into account, our interest is in an aspect of cognitive function that has been relatively neglected in this area, within-person (WP) variability (also referred to as intraindividual variability).

Typically operationalized as the intraindividual trial-to-trial RT, or session-to-session, variability in cognitive performance, it is suggested that increased WP variability may reflect neurobiological disturbance and compromise to central nervous system integrity (Hendrickson, 1982; Hultsch & MacDonald, 2004; Li & Lindenberger, 1999; MacDonald, Bäckman, & Nyberg, 2006). Indeed, several neurobiological factors may explain increased behavioral WP variability in old age. For instance, deficient neuromodulation, associated increases in neural noise, and consequent reductions in cortical representation is one possible underlying mechanism (Li, Lindenberger, & Sikström, 2001). Additionally, recent magnetic resonance imaging (MRI) work demonstrates that compromise to brain structures also contributes to increased variability. For example, Bunce, Anstey, Christensen, Dear, Wen, and Sachdev (2007), investigated community-dwelling adults aged 60-64 years, and found that frontal white matter lesioning was associated with measures of WP variability, but not with measures of processing speed, memory, or global cognition. Degree of frontal and centrum semiovale white matter water diffusion is also correlated with intraindividual variability in older persons (Deary, Bastin, Pattie et al., 2006), and an association with corpus callosum size in individuals with mild cognitive disorders, but not in persons belonging to a healthy normative sample, has also been found (Anstey, Mack, Christensen, et al., 2007). Finally, a functional MRI study in young individuals (Bellgrove, Hester, & Garavan, 2004) found a significant association between WP variability in a go/no-go response paradigm, and task-related activations in the frontal cortex. This latter finding is consistent with the view that frontally mediated attentional and executive control mechanisms contribute to WP variability.

This brain imaging work implicating neurobiological disturbance and/or the frontal cortex in WP variability, is consistent with behavioral work showing greater variability in patients with focal frontal lesions (Stuss, Murphy, Binns, & Alexander, 2003), and also work

suggesting greater variability in more demanding frontally supported executive control tasks (Bunce, MacDonald, & Hultsch, 2004; West, Murphy, Armilio, Craik, & Stuss, 2002). Additionally, research suggests greater WP variability to be associated with age-related neurobiological decline (e.g., Anstey, 1999; Bunce et al., 2004; Hultsch, MacDonald, & Dixon, 2002; MacDonald, Hultsch, & Bunce, 2006; Nesslerode & Salthouse, 2004; West et al., 2002; Wegesin & Stern, 2004), and also a range of conditions involving some form of neurobiological disturbance including mild cognitive impairment or mild dementia (Christensen, Dear, Anstey, Parslow, Sachdev, & Jorm, 2005; Hultsch, MacDonald, Hunter, Levy-Bencheton, & Strauss, 2000; Knotek, Bayles, & Kaszniak, 1990; Strauss, Bielak, Bunce, Hunter, & Hultsch, 2007), traumatic brain injury (e.g., Bleiberg, Garmoe, Halpern, Reeves, & Nadler, 1997; Stuss, Pogue, Buckle, & Bondar, 1994), Parkinson's disease (Burton, Strauss, Hultsch, Moll, & Hunter, 2006), and epilepsy (Bruhn & Parsons, 1977). Finally, WP variability also predicts longitudinal cognitive decline in aging populations (Lövdén, Li, Shing, & Lindenberger, 2007; MacDonald, Hultsch, & Dixon, 2003).

Given this evidence of associations between WP variability, neurobiological integrity, and disease pathology, what reason is there to expect an association with depression or anxiety? Theoretically, a possible mechanism by which depression or anxiety may influence WP variability is executive control. Increased WP variability is largely due to a greater proportion of unusually slow responses falling into the tail of the RT distribution (e.g., Spieler, Balota, & Faust, 1996; West et al., 2002). It has been proposed that such intermittent slow responding may represent fluctuations in executive control (Bunce et al., 2004; West et al., 2002), or relatedly, attentional lapses (Bunce, Warr, & Cochrane, 1993), although this latter view has been questioned (Salthouse, 1993). Theoretical accounts of how depression or anxiety may affect cognitive performance generally draw on resource theory (e.g., Kahneman, 1973), and emphasize attentional resource reductions and task-irrelevant thoughts. For example, Hartlage, Alloy, Vazquez, and Dykman (1993) propose that depression is associated with a reduced capacity to process information, and a tendency to direct remaining resources towards depression-related thoughts. This may result in cognitive deficits, particularly in more effortful processing. Additionally, the role of executive control is inherent to cognitive models of anxiety (e.g., Eysenck & Calvo, 1992), where anxiety is held to interfere with working memory resulting in a reduction of information processing capacity and efficiency. Neurobiological research implicates frontal areas and also white matter lesioning in mood disorders (e.g., Harrison, 2002), and work suggests that stress triggers the secretion of glucocorticoids (e.g., Sapolsky, 1999). As there is a high density of

corticosteroid receptors in the frontal lobes (Murros, Fogelholm, Kettunen, & Vuorela, 1993), there is a possibility that elevated stress leads to increased glucocorticoid-related effects in the frontal cortex, and this may detrimentally affect executive control processes.

Theoretically then, both cognitive and neurobiological perspectives implicate the frontal cortex and executive processes in relations between depression or anxiety and cognitive function. As it is well established that there are age-related changes in the frontal cortex (West, 1996; Raz & Rodrigue, 2006), it is plausible that these effects may be exacerbated in older adults. Indeed, findings consistent with this possibility have been produced by recent research (Stawski, Sliwinski, & Smyth, 2006) showing stress-related working memory and episodic memory deficits in older adults. Also, there is work that suggests executive function to account for depression-related cognitive deficits in older persons (Elderkin-Thompson, Mintz, Haroon, Lavretsky, & Kumar, 2006; Sheline, Barch, Garcia, Gersing, Pieper, Welsh-Bohmer et al., 2006). Because of the theoretical association between WP variability and executive control, and also because both older age and depression or anxiety may impact detrimentally on executive mechanisms, it is possible that measures of WP variability will be particularly sensitive to age-mental health associations where they exist. What evidence is there though, to support this?

As noted earlier, investigations of mental health and WP variability are scarce. However, those that exist suggest an association between subjective distress and elevated RT variability. For example, Sliwinski, Smyth, Hofer, and Stawski (2006) examined day-to-day variability in stress and WP variability among young adults aged 18 to 24 years, and older adults aged 66 to 96 years. A significant Stress x RT interaction suggested that higher WP stress was associated with slower, but not faster, RTs in a 2-back working memory task. Although the trend suggested this effect was greater in older adults, it was not significant. Additionally, a study conducted in our own laboratories (Bunce, Tzur, Ramchurn, Gains, & Bond, 2008) investigated the General Health Questionnaire-12 (GHQ: Goldberg, 1978), an indicator of depression and anxiety, social dysfunction, and loss of confidence, in relation to cognitive performance in adults aged 18 to 92 years. The findings suggested that poor mental health was associated with greater WP variability in psychomotor responding and a Stroop color-word task, and that this effect was stronger among older adults. Importantly, a dissociation was evident in that measures of central tendency (mean RT) from the same tasks did not produce significant Age x GHQ interactions. This dissociation suggests that measures of variability may be particularly sensitive to the cognitive effects of mild psychopathology in older adults. However, although the GHQ is a well-validated indicator of mental health

status, the scale does not distinguish between anxiety and depression. Therefore, it is not entirely clear from this study the extent to which mental health effects were due to either depression or anxiety.

Several aspects of these investigations are of note. First, the findings suggest that poor mental health is associated with increased WP variability. Second, there are indications that this effect grows stronger with increasing age. Finally, none of the above studies specifically investigated depression in relation to age and WP variability, and we were unable to locate any other published work addressing this issue. Therefore, although depression and anxiety often co-occur, it is not known if their effects on WP variability are independent, or whether their respective influences vary as a function of age. Moreover, there is no information concerning whether effects, where they occur, impact all domains of cognitive function, or whether they are selective.

It is this shortfall in the literature that guides the present study. Specifically, in a continuous age range of 300 community-dwelling adults aged 18 to 85 years, we used structural equation modeling to investigate whether Age x Mental health associations with intraindividual variability in psychomotor, visual search, and recognition domains were mediated by intraindividual variability in executive control. In our first model, we established whether WP variability in those cognitive domains varied according to age and mental health. Due to theoretical accounts suggesting age-related reductions in attentional resources, we expected that mental health-WP variability effects, where they existed, would be stronger in older persons. We reasoned, also, that depression or anxiety would impact upon measures of WP variability due to the putative association with executive control. Therefore, in two further models, following recommendations of Baron and Kenny (1986), we assessed whether significant Age x Mental health interactions were mediated by executive function. Our choice of executive control measures was guided by research suggesting this construct to be characterized by separable but related processes of shifting between mental sets, monitoring and updating working memory, and inhibition of prepotent responses (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000). Finally, an important element of the study was to contrast analyses using WP variability to measure the cognitive constructs, with a measure of central tendency (mean RT). A major concern here was whether the two measures dissociated in respect to Age x Mental health associations with cognitive function. The possibility of a dissociation was of considerable theoretical interest as it would not only provide important insights into mechanisms associated with intraindividual variability, but also give indication of the relative sensitivity of the two measures to subtle cognitive effects.

## Method

### *Participants*

Three hundred (172 women) community-dwelling persons aged 18-85 years ( $M = 50.33$ ,  $SD = 20.37$ ) participated in the study. Participants of working age were recruited from the university environment, or from local further education colleges. Persons above retirement age were recruited from local education or community groups, churches, and clubs. The ethnic profile of the participants reflected that of the university and surrounding college working population; approximately 85% were Caucasian, with the remainder made up of Afro-Caribbean and Asian (Indian, Pakistani, Bengali) participants. The sample was selected such that each of the following age bands was well represented; 18-25 years ( $n = 51$ ), 26-35 years ( $n = 42$ ), 36-45 years ( $n = 36$ ), 46-55 years ( $n = 35$ ), 56-65 years ( $n = 46$ ), 66-75 years ( $n = 49$ ), and 76+ years ( $n = 41$ ). A  $X^2$  test did not suggest the proportion of women to vary across these age ranges ( $p > .61$ ). As is common in samples with a wide age range, older adults reported significantly fewer years of education than younger adults ( $p < .001$ ). Interestingly, age groups who were 66 years and over rated their subjective general health relative to others their age as significantly higher than adults 26 to 35 years, and 36 to 45 years ( $ps < .05$ ).  $X^2$  tests suggested greater regular use of medications in older adults ( $p < .001$ ). Careful questioning during recruitment ensured that persons using anti-depressants, or who had experienced major health disorders that may affect cognitive function (e.g., stroke, traumatic brain injury), were excluded from the sample. The Mini-Mental State Examination (Folstein, Folstein & McHugh, 1975) was administered to all participants over 65 years, and only persons scoring 25 or more were included in the study. Verbal intelligence was assessed using the National Adult Reading Test (NART: Nelson, 1982). Estimates of full-scale IQ were obtained using standard procedures, and are reported here.

### *Mental health measures*

The Hospital Anxiety and Depression Scale (*HADS*, Zigmond & Snaith, 1983) was used to measure subjective reports of anxiety and depression. This 14-item scale consists of two subscales relating to anxiety (items relate to tension and worry) and depression (items assess negative affect). Each item was scored on a 4-point Likert scale scored 0 (normal) to 3 (poor). A recent review (Bjelland, Dahl, Haug, & Neckelmann, 2002), suggests the scales possess good psychometric properties. Specifically, the majority of studies reviewed that conducted factorial work (totaling 14,588 persons) on the scale items, produced the two-

factor structure used in the present study, with Cronbach alphas predominantly  $>.80$ . Importantly, the two factor structure is stable across different age groups in the general population (Spinhoven, Ormel, Sloekers, Kempen, Speckens, & Van Hemert, 1997). Work assessing concurrent validity has produced correlations of .62 to .73 between the HADS-depression scale and the Beck's Depression Inventory, while correlations between the HADS-anxiety dimension and Spielberger's State-Trait Anxiety Inventory ranged .64 to .81. In the present study, Cronbach alphas of 0.82 and 0.77, respectively, for anxiety and depression subscales, suggested that internal consistency was good.

### *Executive control tasks*

As noted earlier, our selection of executive control tasks was guided by work suggesting the construct is characterized by shifting between mental sets, monitoring and updating working memory, and inhibition of prepotent responses (Miyake et al., 2000).

*Monitoring and updating information.* Referred to as *updating*, this task required continued updating of digits held in working memory. The task involved the rapid presentation of 300 single digits, successively (presentation time = 500 ms, inter-trial interval = 500 ms). Within each block of 100 trials, ten target sequences of three consecutive odd numbers were presented. Participants were instructed to press the spacebar on detection of these odd numbers sequences. Hit RTs were recorded from stimulus onset (i.e., presentation of the third consecutive odd number) to the participant's response. Twenty-four practice trials were completed prior to the task proper. The mean hit rate for this task was 21.27 ( $SD = 7.07$ ), and mean false alarm rate 1.67 ( $SD = 7.07$ ). RT data for correct responses are presented here.

*Set switching.* This task referred to as *switching*, was based on a shape-color switching task (Mayr, 2001), and involved a condition in which task set was switched across successive trials, and a condition in which trials were invariant. Sixteen practice trials were administered, and then 48 experimental trials (24 no-switch, 24 switch trials pseudorandomly presented, intertrial interval = 500 ms). For each trial, the instruction word "Shape" or "Colour" was presented, together with a picture stimulus that was either a square or a circle, colored either red or green. The instruction word indicated whether to respond to the shape or the color of the picture stimulus. For example, if "Shape" appeared as the instruction word, the color of the picture stimulus was to be ignored. Where the picture was a circle participants pressed the N-key, and where the picture was a square, they pressed the C-key. Conversely, if "Colour" appeared as the instruction word, shape was to be ignored, and if the



picture was green participants pressed the N-key, and if it was red they pressed the C-key. Thus, participants had to switch the stimulus-response mapping depending on the instruction word. Here, we present RT data for correct set switching trials (for color-to-shape, and shape-to-color trials).

*Inhibition.* A version of the Stroop color-word task was used to measure inhibition. Participants were required to respond to the *ink color* (either red, blue, yellow, or green) of the printed words “Red”, “Blue”, “Yellow”, and “Green”. Sixteen practice trials were administered, followed by 96 pseudorandomized test trials, half of which were congruent (word-color matched), and half incongruent (word-color not matched). Thus, for the incongruent trials, participants were required to inhibit the prepotent response to the written word in order to correctly respond to the ink color. Here, we present RT data for correct responses in the incongruent condition.

#### *Psychomotor tasks*

Three tasks were administered in this category of cognitive task.

*Simple RT.* In this task (referred to as *SRT*), where 8 practice trials and 48 test trials were administered, the stimulus letter ‘X’, was presented after a randomly determined inter-trial interval of between 300 and 1000 ms. Participants were instructed to press the ‘spacebar’ as soon as the ‘X’ appeared, RT data for which are presented here.

*2-choice RT (2CRT).* A black circle (25 mm diameter) was randomly presented to either the left or right of the computer screen (inter-trial interval of 500 ms). For 12 practice trials, and 48 test trials, participants pressed the X-key or M-key of the keyboard if the stimulus appeared to the left or right respectively. RT data for correct responses are presented here.

*4-choice RT (4CRT).* This task was the same as the 2-choice RT task but included two additional choices. Black circles appeared either top or bottom, or left or right, of the computer screen, and mapped spatially onto the S-, X-, M-, and K-keyboard keys with which participants were required to respond. RT data for correct responses are presented here.

#### *Visual Search*

Two visual search tasks, simple and conjunctive, were administered in this category.

*Simple visual search.* In this task (referred to as *VS-S*), 16 practice trials were administered followed by a total of 64 test trials. Half of the trials involved presentation of a 6 x 6 array of the letter “O”, and half involved a similar array of “O” letters, but with one

target “Q” letter embedded within. All arrays were presented pseudorandomly in green ink. Participants were required to respond “Yes” via the keyboard if the target letter was present, and “No” if not. The mean hit rate for this task was 31.22 ( $SD = 1.01$ ), and mean false alarm rate 0.36 ( $SD = 0.68$ ). RT data for correct target trials are presented here.

*Conjunctive visual search.* This version of the task (referred to as VS-C) was identical to the simple version, except that target responses had to be made on the basis of both color and shape. In a target trial, for example, 18 green “O” letters were intermixed with 17 red “Q” letters, and one green letter ‘Q’ (the target). Therefore, correct detection was contingent upon the conjunction of the color green and the letter “Q”. Non-target trials were identical except that, for example, 18 green “O” letters and 18 red “Q” letters were presented. The mean hit rate for this task was 26.10 ( $SD = 5.03$ ), and mean false alarm rate 0.67 ( $SD = 2.80$ ). RT data for correct target trials are presented here.

#### *Word recognition*

In this episodic memory task, at study, 16 target concrete nouns (drawn from a pool used by Bunce, 2003) were randomly presented for 2 s, with an inter-word interval of 500 ms. Following a brief distracter task, at test, the 16 target words were intermixed with 16 foil words drawn from the same pool. Target and foil words were randomly presented, and participants required to respond “Yes” and “No” via keyboard keys to targets and foils, respectively. The mean number of hits for this task was 12.44 ( $SD = 2.46$ ), and mean number of false alarms was 3.51 ( $SD = 2.62$ ). RT data are presented for hits in this task.

#### *Procedure*

On arrival at the laboratory, participants completed informed consent, and then a brief biographical questionnaire. Participants aged over 65 years then completed the MMSE. The NART and a battery of PC-administered cognitive tasks (written in E-Prime, version 1.1) followed. Instructions throughout emphasized both speed and accuracy. Halfway through the battery of cognitive tasks, questionnaire scales, including those reported here, and measures for other parts of the study, were administered. Participants wore corrective reading glasses if appropriate throughout the session, which lasted for approximately one hour. At the end, participants were debriefed, and those traveling from off the university campus given an honorarium of £10 sterling.

#### *Data processing*

Other than the cognitive tasks for which hit rate data were presented earlier, mean error rates for the remaining tasks were all below 5%, with the exception of the switching task, where the mean error rate was 7.0%. RT data reported in the analyses that follow, as indicated earlier, were based on correct responses trials for the respective tasks. In computing measures of mean RT and WP variability, we used similar procedures to Hultsch et al. (2002). Data distributions for the respective tasks were inspected for any extremely fast or slow latencies that may reflect various sources of error (e.g., accidental key presses, task interruption). In order to eliminate such trials, we set a lower boundary of 150 ms, and an upper boundary of the individual mean RT + 3SD, beyond which trials were excluded. For the majority of tasks, the number of trials excluded following this procedure was below 5%. The exceptions were Switching (9.4%), and 4-CRT (6.4%). Eliminated RTs were replaced with the age group mean RT for that particular task. As removing outliers and replacing missing values in this way reduces variability, the procedure represents a conservative approach to the study of WP variability.

For each task, mean RT was computed from the raw correct response latencies, and for WP variability, the intraindividual standard deviation (*ISD*) was computed. Because the raw *ISD* increases in direct relation to age-related increases in RT, it is appropriate to statistically partial out such systematic age differences from *ISD* measures. Otherwise, greater *ISDs* are confounded by older adults' slower responding relative to younger adults. Similarly, trial-to-trial variance may reflect practice effects, or other systematic time-on-task influences. Therefore, we used a regression procedure (Hultsch et al., 2002) to partial out the effects of age-related, and trial-to-trial-related (and their higher-order interaction), variation in responding from *ISDs*. Specifically, RTs were regressed on chronological age (entered as a continuous variable) and trial number to produce residuals that are statistically independent of differences stemming from either of those sources. The residual scores were then converted to *t* scores ( $M = 50$ ,  $SD = 10$ ) to facilitate comparisons across tasks.

Finally, a small number datasets for specific cognitive tasks were lost for a minority of participants due to logging errors (total < 0.5%; Updating = 2; Switching = 1; Visual search-C = 2), and in these instances missing values were imputed with the EM algorithm in SPSS using all of the variables in the present study (see Shafer & Graham, 2002).

## Results

In order to explore associations between variables, bivariate correlations were computed and are presented in Table 1. The coefficients above the diagonal relate to mean RT, and those

below the diagonal to WP variability (i.e., ISDs). As is common in aging research, Table 1 reveals that older age was associated with higher NART scores. Although age was negatively associated with anxiety, depression did not vary according to age, and the vast majority of correlations involving gender were nonsignificant. Regarding associations between age and the cognitive variables, older age was associated with slower responding and greater WP variability for all tasks, the exception being updating, where older adults produced smaller ISDs. For some of the cognitive variables, higher NART scores were associated with slower responding and larger ISDs. As the direction of these correlations was unexpected, we consider this further below. Although depression and anxiety were strongly intercorrelated, their respective associations with cognitive variables were predominantly weak.

We investigated relations between age, mental health, and the cognitive variables through a series of structural equation models (using LISREL 8.72: Joreskog & Sorbom, 2005). This procedure possesses the advantages of allowing us to (a) investigate paths between the respective variables simultaneously, and (b) explore relations involving latent constructs. In order to assess how far mean RT and WP variability varied according to age and mental health, Age x Depression, and Age x Anxiety, cross-product interaction terms were computed. These were entered into the structural equation models reported below, together with the first-order effects for age, depression, and anxiety ( $z$ -scores were computed for all variables). Several statistics were used to evaluate these models. Following well established procedures (Kline, 1998), chi-squared tests were employed to assess goodness-of-fit. Good model fit is indicated when the  $X^2$  test is nonsignificant. That is, the theoretically specified model does not differ from the structural associations in the data. However, because  $X^2$  is particularly sensitive to sample size (as sample size increases, the likelihood of obtaining a nonsignificant  $X^2$  decreases), several other goodness-of-fit indexes that adjust for sample size were used. First,  $X^2$  was adjusted by dividing by degrees of freedom ( $X^2/df$ ). Additionally, the comparative fit index ( $CFI$ ), the non-normative fit index ( $NNFI$ ), and the root-mean-square error of approximation ( $RMSEA$ ) were used. Good fit is indicated when  $X^2/df < 2.0$ , both  $CFI$  and  $NNFI > .90$ , and  $RMSEA < .08$ . For all analyses,  $N = 300$ .

The structural equation models we evaluated were based on Figure 1, where age, depression, anxiety, and the Age x Depression, and Age x Anxiety interaction terms, formed exogenous variables, and psychomotor, executive function, visual search, and recognition served as endogenous variables. As one of our main interests was to assess the extent to which either WP variability or mean RT varied as a function of age and mental health, and also how far those associations, where they existed, were accounted for by executive

function, we evaluated the models in a series of steps (cf., Baron & Kenny, 1986). In Step 1, the model described in Figure 1 was evaluated. Of particular interest here, was whether any of the Age x Mental health paths attained significance having controlled for the primary effects of age and the respective mental health variables. In a second model evaluated at Step 2, all direct paths from the exogenous to endogenous variables were eliminated except for those leading to executive function. However, at this step, additional direct paths were introduced from executive function to psychomotor and visual search latent constructs, and also to recognition. Although the goodness-of-fit of the model at this step is indicative of how well executive function is explaining relations between the exogenous and cognitive variables, a major interest here was whether either of the Age x Mental health paths to executive function were significant. A significant interaction at this step is consistent with the possibility that executive function mediated relations between exogenous and endogenous variables. The final step combined Steps 1 and 2. That is, the model was as in Figure 1, but with additional direct paths from executive function to psychomotor, visual search, and to recognition. The critical element at this final step was whether any significant Age x Mental health paths identified at Step 1 became nonsignificant when executive function was taken in account in this third model.

#### *WP variability*

For WP variability, standardized path coefficients for the respective steps are presented in Table 2. At Step 1, although  $X^2$  was significant ( $X^2(50) = 95.80, p < .01$ ), the other statistics that are less sensitive to sample size, suggested goodness-of-fit was good;  $X^2/df = 1.92$ ,  $NNFI = .98$ ,  $CFI = .99$ ,  $RMSEA = .06$ . Consideration of Table 2 (Step 1) reveals some important and significant path coefficients. Older age is significantly associated with greater WP variability in psychomotor, executive function and visual search constructs ( $ps < .01$ ). Importantly, significant paths are evident between both Age x Depression, and Age x Anxiety, and visual search ( $ps < .01$  and  $.05$ , respectively). As these statistics suggest ISDs in visual search varied according to age and mental health, we reran this model without the latent construct for visual search, but with direct paths introduced from the exogenous variables to the simple and conjunctive visual search measures. For anxiety, paths for both interaction terms were nonsignificant, and for depression, the path for the interaction term to simple visual search was also nonsignificant. However, in respect to the relatively more effortful conjunctive visual search task, the Age x Depression interaction term attained significance ( $p < .01$ ). The form of this interaction is shown in Figure 2. It is evident that older

age and higher depression scores are associated with greater WP variability in this more demanding version of the task.

In Step 2, the model where paths were directed to and from executive function was assessed. If executive function was the mechanism by which the Age x Depression interaction influenced visual search, then we would expect paths between those variables and executive function to become significant.

Although  $X^2$  was significant ( $X^2(62) = 95.15, p < .01$ ), the other statistics indicated satisfactory model fit;  $X^2/df = 1.54$ ,  $NNFI = .99$ ,  $CFI = .99$ ,  $RMSEA = .04$ . However, consideration of the path coefficients for ISDs at Step 2 in Table 2 reveals important information. Age and executive function were positively associated, as were executive function and the other cognitive variables (all  $ps < .01$ ). These latter paths are indicative of covariation between WP variability in executive function and WP variability in other cognitive domains. Notably though, the Age x Depression (although not the Age x Anxiety) path to executive function was significant ( $p < .05$ ), as was the path between executive function and visual search ( $p < .01$ ). This finding is consistent with the view that WP variability in executive function was the mechanism by which the Age x Depression association influenced WP variability in visual search.

In order to further test this possibility, we evaluated a third model at Step 3 in which Step 1 and 2 models were combined (i.e., Figure 1 but with additional direct paths from executive function to psychomotor, visual search, and to recognition). If executive function was accounting for the Age x Depression interaction in respect to visual search, the direct Age x Depression  $\rightarrow$  visual search path should become nonsignificant at this step. In order to keep this model identified, the variances for  $e_{10}$ ,  $e_{11}$ , and  $e_{12}$  were equally constrained. This model provided satisfactory fit,  $X^2(49) = 86.04, p < .01$ ,  $X^2/df = 1.76$ ,  $NNFI = .98$ ,  $CFI = .99$ ,  $RMSEA = .05$ . Importantly though, Table 2 shows that the Age x Depression path to visual search became nonsignificant ( $p > .05$ ), suggesting that executive function accounted for the Age x Depression effects on that variable.

A concern with the foregoing analyses is that the mediating role of executive function on Age x Depression  $\rightarrow$  visual search relations may have been related to the nested design, and driven by other variables included in the model (i.e., psychomotor and recognition variables). Therefore, we tested a trimmed version of the model that focused on the three main variables (all 'significant' paths were  $p < .01$ ): At Step 1 of these analyses, Age x Depression was a significant predictor of both executive function ( $\beta = .40$ ) and visual search ( $\beta = .42$ ). At Step 2, Age x Depression significantly predicted executive function ( $\beta = .41$ )

which in turn, significantly predicted visual search ( $\beta = .97$ ). In Step 3, Age x Depression significantly predicted executive function ( $\beta = .38$ ) which again significantly predicted visual search ( $\beta = .92$ ). Critically though, and consistent with a mediator model, the path between Age x Depression and visual search became nonsignificant ( $\beta = .07$ ) at this step. These additional analyses demonstrate that the mediating role of executive function was unrelated to the influence of other variables (psychomotor performance and recognition). Importantly, this rules out the possibility that the findings were related to changes in the executive function measurement model at the various steps of the original analyses.

### *Mean RT*

We then repeated the structural models, but this time focusing on mean RT. Our interest was to see if this measure better accounted for Age x Mental health associations in relation to the cognitive variables. We repeated the structural model presented in Figure 1. Goodness-of-fit statistics suggested somewhat poorer fit for this version of the model,  $X^2(50) = 108.20, p < .01, X^2/df = 2.16, NNFI = .98, CFI = .99, RMSEA = .06$ . Importantly, consideration of the standardized regression weights in Table 2 (Step 1) shows that although age was significantly and positively associated with the cognitive constructs ( $ps < .01$ ), none of the mental health primary effects, or the Age x Mental health paths, were statistically reliable ( $ps > .10$ ). The implications of this finding are twofold. First, this suggests that the influence of depression or anxiety on cognitive function as measured by mean RT does not vary according to age. Second, the lack of significant Age x Mental health paths in relation to cognitive variables does not justify evaluation of the models for Steps 2 and 3, as was the case for WP variability.

Finally, it was noted earlier that NART scores were correlated with some of the cognitive variables in the opposing direction to that expected; higher NART scores were associated with slower RTs and greater WP variability for some variables. We also noted a positive association between age and NART. Therefore, we re-computed the correlations between NART and cognitive variables, but having partialled out age. In all cases, the correlations became nonsignificant, or changed significantly to the expected direction (i.e., higher NART scores were associated with lower variability and faster responding). This clearly suggests that the association between NART and the cognitive variables varied according to age. As this represented a potential confound to our findings, we reran all of the structural equation models in respect to WP variability and mean RT, but controlling for NART scores. This made no difference to our original findings. Additionally, our analyses

have examined the first-order effects for anxiety and depression, but have not considered the possibility of a synergistic association between those variables. Therefore, we reran the models, but this time taking the Anxiety x Depression cross-product interaction term into account. With one exception (statistics indicated much poorer fit at Step 3 when the Anxiety x Depression interaction was added), this made little difference to our original findings, and suggests that our findings for depression were independent of anxiety.

### Discussion

This is the first study to systematically investigate depression and anxiety in relation to WP variability across a comprehensive battery of cognitive tasks in a continuous age range of community-dwelling adults aged 18 to 85 years. Structural equation modeling that simultaneously took into account multiple sources of variance produced several important findings. First, older persons with higher depression scores recorded significantly greater WP variability in the more effortful of the two visual search tasks, but not other cognitive tasks. Second, this association was not found in relation to mean RT measures for that variable, suggesting that the two measures dissociate in relation the age and depression. Further, executive function contributed to overall model fit in respect to WP variability (measures of WP variability in executive function covaried with WP variability in other cognitive domains), and there was evidence that intraindividual variability in executive function mediated the Age x Depression effects on variability in visual search. Finally, there was little evidence that anxiety influenced cognitive function in the present study, either independently or synergistically with other variables.

Given the empirical evidence supporting the suggestion that WP person variability reflects neurobiological disturbance and compromise to central nervous system integrity (Hendrickson, 1982; Hultsch & MacDonald, 2004; Li & Lindenberger, 1999; MacDonald et al., 2006), a major motivation for the present study was the possibility that this measure would provide insights into relations between psychopathology and cognition, and how this may vary according to age. Our findings build upon earlier work (Bunce et al., 2008; Sliwinski et al., 2006) and were informative in that WP variability, but not mean RT, was sensitive to Age x Depression, but not Age x Anxiety, associations. Moreover, analyses suggested this effect was selective to the more effortful visual search condition where the conjunction of two features was required in order to correctly perform the task. At a cognitive level, this finding is in line with the suggestion that attentional resources are reduced in depressed persons and this, together with the tendency to deploy those resources



towards depression-related thoughts, results in cognitive deficits, particularly in more effortful processing (Hartlage et al., 1993). This is of particular note within the context of top-down models of visual search that propose feature inhibition mechanisms that operate to reduce the activation of non-target features (Treisman & Sata, 1990). Our findings suggest that depression may interfere with those mechanisms, particularly in older persons, and that measures of WP variability, but not mean RT, are sensitive to that effect. More broadly, the findings suggest that the effect of mild depression on otherwise healthy persons is both subtle and selective. That this effect was stronger in older persons is consistent with the view that age differences in attentional resources, and relatedly, executive control processes, may combine synergistically with those attributable to depression to particularly impact on specific aspects of cognition in older persons. At the neurobiological level, given the proposed link between deficient neuromodulation, increased neural noise, and greater intraindividual variability in older persons (Li et al., 2001), the findings suggest that mild depression may exacerbate the deleterious effects of frontal neurotransmitter deficiencies, producing cognitive deficits in old age. Moreover, work implicating white matter lesioning in mood disorders (see Harrison, 2002), and research showing an association between WP variability and more extensive frontal white matter lesioning in older persons (Bunce et al., 2007), suggests a second possible mechanism that may explain our findings. Together, it is plausible that impaired neural connectivity arising from neurotransmitter deficiencies and compromised white matter tracts is elevated by mild depression and old age, and contributes behaviorally to increased intraindividual variability.

A second major concern was to examine the specific mechanism behind significant Age x Mental health effects where they existed. It has been suggested that fluctuations in executive control (Bunce et al., 2004; West et al., 2002), or relatedly, attentional lapses (Bunce et al., 1993), is the cognitive mechanism underlying intraindividual variability. Following the recommendations of Baron and Kenny (1986), therefore, we formally assessed how far WP variability in executive function accounted for the significant Age x Depression effects in relation to visual search. It is plausible that the mechanism by which age- and depression-related reductions in attentional resources affects wider cognition, is executive control. Therefore, having identified the significant Age x Depression interaction in respect to visual search in our first structural equation model (Step 1), we then ran two further models to establish how far executive function accounted for this association. The second model (Step 2), in which direct paths from the exogenous variables to psychomotor, visual search, and recognition constructs were omitted, and direct paths from executive function to

those constructs introduced, produced similar goodness-of-fit statistics to the first model. Importantly, the Age x Depression path coefficient to executive function became significant in this second model, as did paths from executive function to psychomotor, visual search, and recognition constructs. This not only suggests that WP variability in executive control is associated with WP variability in the other constructs, but also that executive function is accounting for the significant Age x Depression interaction in respect to visual search. Further support for this latter interpretation was sought in a third model (Step 3) where direct paths were reintroduced between all exogenous and endogenous variables (i.e., Figure 1), while retaining those from executive function to psychomotor, visual search, and recognition constructs. If executive function was the mechanism by which age-depression effects influenced visual search, then the direct Age x Depression to visual search coefficient would become nonsignificant. Importantly, that is exactly what happened, a finding that is consistent with the view that WP variability in executive control mediated relations between age, depression, and WP variability in visual search. More broadly, this finding adds to work elsewhere (Elderkin-Thompson et al., 2006; Sheline et al., 2006) suggesting that executive function plays a key role in mental health-related cognitive deficits in older persons.

Another finding of interest was that there was only weak evidence that anxiety impacted on the cognitive variables. Although a significant Age x Anxiety interaction was found in relation to visual search, the effect size was small. Moreover, subsequent exploration revealed this association to be statistically unreliable. This finding contrasts with those of Sliwinski et al. (2006), who found a weak association between day-to-day variation in stress and response variability in a working memory task among older adults. It should be noted though, that in the present study, we did not assess daily covariation in anxiety and cognitive measures, or specifically seek out individuals experiencing elevated anxiety (or depression). It is possible, therefore, that the levels of anxiety exhibited by our participants were not sufficiently high to impact on the cognitive variables. The present findings build upon our earlier study (Bunce et al., 2008) where significant Age x Mental health interactions were found in respect to WP variability in psychomotor and Stroop tasks. By contrast with the present results, the measure of mental health used in that earlier study (the GHQ-12) captured not only depression and anxiety, but also social dysfunction, and loss of confidence. The absence of Age x Depression or Anxiety interactions for psychomotor and Stroop tasks here, suggests that the effects of social dysfunction and loss of confidence may have been particularly influential in that earlier study<sup>1</sup>. It is important that further research investigates these complex associations further.

The dissociation between measures of WP variability and mean RT is of considerable theoretical interest as it indicates that the former measures may be particularly sensitive to mild psychopathology. Although not reported earlier, we also investigated Age x Mental health relations in respect to accuracy measures for all of the cognitive variables. That none were significant adds to the research suggesting that there are circumstances in which measures of WP variability are sensitive to subtle cognitive effects when measures of central tendency and accuracy are not.

The present study does possess some limitations that should be acknowledged. The first is that the data were cross-sectional, and although structural equation modeling implies causality in the conceptual sense, our data do not give indication as to cause and effect in temporal terms. Relatedly, concerns have been expressed about variance partitioning procedures, and population mean confounds, in cross-sectional samples (e.g., Hofer & Sliwinski, 2001; Lindenberger & Pötter, 1998; Sliwinski & Hofer, 1999). Additionally, there was a suggestion that verbal intelligence varied according to age, and therefore, may serve to confound our findings. To eliminate this possibility, we repeated our analyses while controlling for NART scores. As this did not make any difference to our original findings, we are confident that the influence of this source of variance was minimal. Finally, although not a limitation, our findings in the present study related to relatively mild anxiety and depression. It is possible that had the psychopathology been more severe, then mental health-related effects would have been stronger and wider ranging.

To conclude, in a sample of 300 community-dwelling adults aged 18 to 85 years we found evidence of covariation between WP variability in executive function and other cognitive domains, and also of a synergistic association between age and depression in relation to visual search. That association was evident in the more effortful visual search condition for WP variability, but not for mean RT. This dissociation suggests that the effects of depression in otherwise healthy functioning individuals are, indeed, subtle and selective. Importantly, this effect became more pronounced with increasing age, and was statistically accounted for by measures of executive function. It is important that future research explore such associations further, and in particular investigates the sensitivity of measures of WP variability to the cognitive effects of both mild and clinical levels of anxiety and depression. The present findings suggest that such work may not only provide important theoretical insights into age-psychopathology-cognitive relations, but may also contribute to the development of valuable assessment and diagnostic tools in healthy and clinical populations.

*Note 1*

Although not the focus of the present paper, we also administered the GHQ-12 and were, therefore, able to assess age associations with the constructs embedded within that scale. Although not significant at conventional levels of statistical significance, an Age x Social dysfunction interaction suggested that variability in the Stroop task was greater with increased age and social dysfunction.

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#### Acknowledgements

This research was funded by an Economic and Social Research Council, UK, grant (Ref. RES-000-22-1399) awarded to David Bunce. The authors would like to thank Kathryn Hubbard for her assistance with data collection.

Table 1. Bivariate correlations between biographical, mental health, and cognitive variables (Mean RT above the diagonal, within-person variability below the diagonal)

	M	SD	1	2	3	4	5	6	7	8	9	10	11	12	13	14
<i>M</i>	-	-						300.46	317.90	549.05	399.95	1976.93	1090.49	672.82	1320.98	903.53
<i>SD</i>	-	-						75.59	76.01	355.27	36.73	868.41	398.06	184.42	547.71	253.65
1.Age (years)	50.33	20.37	-					.51*	.54*	.42*	.36*	.49*	.67*	.58*	.51*	.50*
2.Gender	-	-	-.06	-				.04	-.08	-.03	.05	-.07	-.13	-.09	-.07	-.15*
3.NART	118.07	7.22	.45*	.04	-			.23*	.16*	.13	.14	.14	.24*	.16*	.14	.16*
4.Anxiety	6.42	3.85	-.27*	.12	-.13	-		-.06	-.02	.00	-.04	-.06	-.17*	-.12	-.07	-.12
5.Depression	3.45	2.97	-.03	-.01	-.04	.54*	-	.09	.08	.11	.04	.05	.03	.05	.09	.02
6.SRT	7.76	3.68	.53*	.00	.19*	-.11	.08	-	.61*	.39*	.33*	.49*	.52*	.52*	.44*	.38*
7.2CRT	7.80	3.43	.59*	-.07	.15	-.07	.05	.55*	-	.48*	.38*	.55*	.58*	.65*	.58*	.50*
8.4CRT	6.45	4.51	.58*	.02	.19*	-.07	.07	.51*	.59*	-	.20*	.36*	.40*	.42*	.38*	.36*
9.Updating	8.32	2.48	-.35*	.05	-.19*	.08	.02	-.11	-.14	-.12	-	.34*	.36*	.32*	.31*	.32*
10.Switching	7.59	3.52	.51*	-.03	.16*	-.05	.05	.46*	.47*	.43*	-.13	-	.64*	.52*	.46*	.42*
11.Inhibition	8.04	3.73	.62*	-.10	.18*	-.18*	.04	.49*	.54*	.51*	-.16*	.55*	-	.67*	.65*	.51*
12.Vis-S	7.70	3.61	.54*	-.11	.16*	-.13	.05	.49*	.62*	.48*	-.16*	.50*	.64*	-	.76*	.52*
13.Vis-C	8.11	3.61	.64*	.00	.24*	-.13	.09	.48*	.56*	.52*	-.24*	.43*	.62*	.61*	-	.47*
14.Recognition	8.41	4.60	.35*	-.09	.09	-.09	-.05	.21*	.28*	.24*	-.14	.26*	.34*	.27*	.29*	-

Notes

For cognitive variables, *M*s and *SD*s on the vertical refer to *ISDs*, and on the horizontal to mean RT.

\* =  $p < .01$ ; Gender, 1 = Men, 2 = Women; *ISD* = Intraindividual standard deviation; NART = National Adult Reading Test; SRT = Simple RT; 2CRT = 2-choice RT; 4CRT = 4-choice RT; Vis-S = Visual search simple; Vis-C = Visual search complex

Table 2. WP variability and mean RT: Structural equation model standardized regression weights

Path	Structural models			
	Step 1		Step 2	Step 3
	ISD	MRT	ISD	ISD
PsyMot ← Age	.74**	.57**		.47**
PsyMot ← Anxiety	.15	-.01		.09
PsyMot ← Dep	-.12	-.01		-.08
PsyMot ← Age x Anx	-.09	.14		-.02
PsyMot ← Age x Dep	.22	.11		.14
EF ← Age	.81**	.73**	.78**	.80**
EF ← Anx	.17	.12	.17	.17
EF ← Dep	-.12	-.13	-.14	-.11
EF ← Age x Anx	-.21	-.13	-.17	-.21
EF ← Age x Dep	.23	.23	.26*	.23
VS ← Age	.75**	.69**		.27
VS ← Anx	.21	.23		.11
VS ← Dep	-.21	-.10		-.14
VS ← Age x Anx	-.26*	-.24		-.14
VS ← Age x Dep	.38**	.21		.24
SRT ← PsyMot	.69**	.71**	.69**	.69**
2CRT ← PsyMot	.80**	.84**	.80**	.80**
4CRT ← PsyMot	.74**	.57**	.73**	.74**
Switch ← EF	.65**	.71**	.66**	.65**
Updat ← EF	-.26**	.44**	-.26**	-.26**
Inhibition ← EF	.82**	.88**	.82**	.82**
Recog ← Age	.33**	.49**		.07
Recog ← Anx	.01	-.03		-.04
Recog ← Dep	-.08	.05		-.04
Recog ← Age x Anx	.03	.03		.10
Recog ← Age x Dep	.02	-.02		-.05
VS-S ← VS	.78**	.92**	.78**	.78**
VS-C ← VS	.78**	.83**	.78**	.78**
PsyMot ← EF			.98**	.34
VS ← EF			.98**	.61*
Recog ← EF			.40**	.33**

Notes

\* =  $p < .05$ , \*\* =  $p < .01$ .

ISD = Intraindividual standard deviation

PsyMot = Psychomotor; Anx = Anxiety; Dep = Depression; VS = Visual search; EF = Executive function; SRT = Simple RT; 2CRT = 2-choice RT; 4CRT = 4-choice RT; Vis-S = Visual search simple; Vis-C = Visual search conjunctive; Recog = Recognition

## Figure captions

## Figure 1.

Structural equation model for age, Age x Mental health interaction terms, and cognitive variables

## Notes.

e1-e12 = error terms 1 to 12, A x Anx = Age x Anxiety, A x Dep = Age x Depression, PsyMot = Psychomotor, EF = Executive function, VS = Visual search, SRT = Simple RT, 2CRT = 2-choice RT, 4CRT = 4-choice RT, Sw = Switching, Up = Updating, Inh = Inhibition, VS-S = Visual search-simple, VS-C = Visual search-conjunctive, Rec = Recognition.

## Figure 2.

The significant Age x Depression interaction in respect to within-person variability in conjunctive visual search

## Notes.

ISD = Intraindividual standard deviation, Dep = Depression

Figure 1.

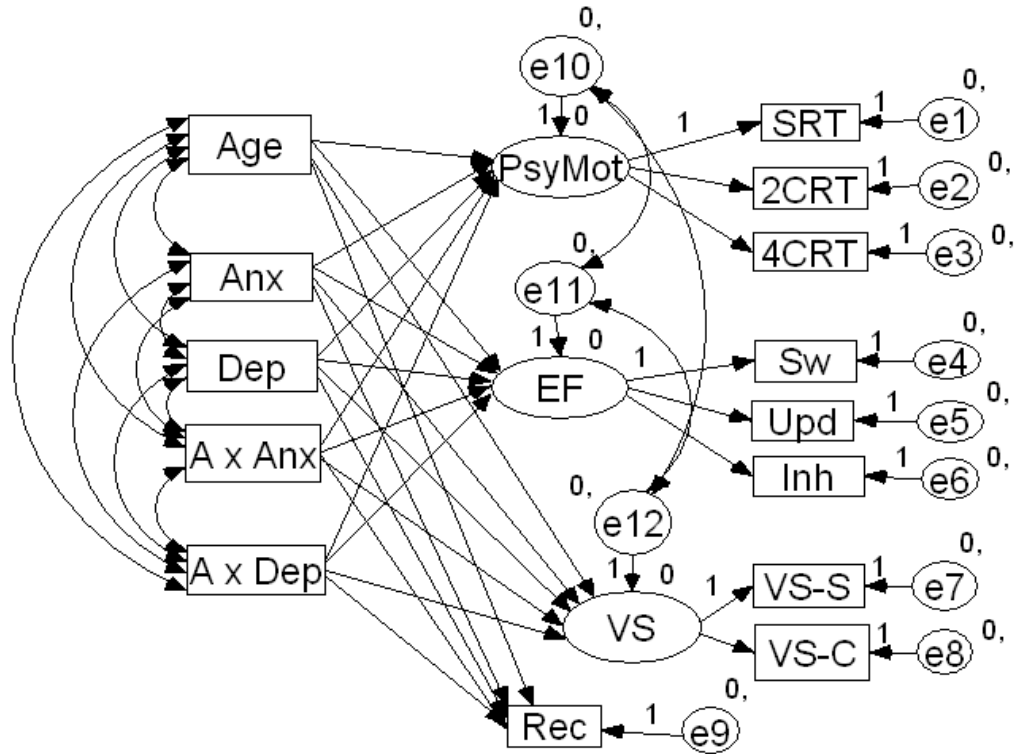


Figure 2.

