

Appears in *Brain and Cognition* (2004)

## **Inconsistency in serial choice decision and motor reaction times dissociate in younger and older adults**

David Bunce<sup>1</sup>, Stuart W. S. MacDonald<sup>2</sup>, and David F. Hultsch<sup>3</sup>

1. Department of Psychology, Goldsmiths College, University of London, London, UK
2. Aging Research Center, Division of Geriatric Epidemiology, Department of Neurotec, Karolinska Institutet, Stockholm, Sweden, and Stockholm Gerontology Research Center, Sweden
3. Centre on Aging, University of Victoria, Canada

Address for correspondence: David Bunce, Department of Psychology, Goldsmiths College, University of London, London, SE14 6NW, UK

Email: d.bunce@gold.ac.uk

## Abstract

Intraindividual variability (inconsistency) in reaction time (RT) latencies was investigated in a group of younger ( $M = 25.46$  years) and older ( $M = 69.29$  years) men. Both groups performed 300 trials in 2-, 4-, and 8-choice RT conditions where RTs for decision and motor components of the task were recorded separately. A dissociation was evident in that inconsistency was greater in older adults for decision RTs when task demands relating to the number of choices and fatigue arising from time-on-task, were high. For younger persons, a weak trend toward greater inconsistency in motor RTs was evident. The results are consistent with accounts suggesting that inconsistency in neurobiological mechanisms increases with age, and that attentional lapses or fluctuations in executive control contribute to RT inconsistency.

Although valuable information is obtained through the investigation of mean performance level in reaction time (RT) data, there are also good reasons to consider the intraindividual variability of RTs across multiple trials or occasions. This phenomenon has been referred to as RT inconsistency (e.g., Hultsch, MacDonald, & Dixon, 2002) and may be indicative of neurobiological disturbance (Hendrikson, 1982; Hultsch & MacDonald, 2004; Jenson, 1982; Li & Lindenberger, 1999). Consistent with this proposition, research has shown that elevated inconsistency is associated with traumatic brain injury (Hetherington, Stuss, & Finlayson, 1996; Stuss, Pogue, Buckle, & Bondar, 1994; Stuss, Stethem, Hugenholtz, Picton, & Richard, 1989), and dementia (Gordon & Carson, 1990; Hultsch, MacDonald, Hunter, Levy-Bencheton, & Strauss, 2000; Knoteck, Bayles, & Kaszniak, 1990). It is possible that increasing age is associated with greater intraindividual variability in neurobiological mechanisms (Myerson, Hale, Wagstaff, Poon, & Smith, 1999; Welford, 1980), with a number of behavioral studies demonstrating that RT inconsistency increases with age for various cognitive tasks (Anstey, 1999; Fozard, Vercruyssen, Reynolds, Hancock, & Quilter, 1994; Hultsch et al., 2002; Salthouse, 1993; West, Murphy, Armilio, Craik, & Stuss, 2002). In light of the links among inconsistency, neurological disturbance, and increasing age, the study of RT variability may provide valuable insights into aging processes.

The present investigation focuses on age differences in RT inconsistency and addresses three issues that have received little research attention. The first relates to the pervasiveness of inconsistency throughout the nervous system. Is it the case that one element of the cognitive system becomes increasingly inconsistent relative to another with age? One approach to this question is to investigate inconsistency for different elements of the same task, such as the decision relative to the motor component of a choice RT task. Research has investigated aggregate measures of inconsistency across trials that provide a single summary measure for the task as a whole (e.g., Anstey, 1999; Fozard et al., 1994; Hultsch et al., 2002; Salthouse, 1993; West et al., 2002), but to date no work has evaluated inconsistency relating to the constituent components of a cognitive task. This is a notable omission, as fractionating RTs in this manner will provide important information as to whether inconsistency is a general characteristic of the information processing system, or is specific to particular elements of that system. Here we explore this issue through a choice RT task in which the RTs for the decision component have been recorded separately from those relating to the motor component.

The second issue we address relates to age differences in inconsistency as a function of time-on-task. Specifically, does inconsistency become greater across the course of a task

as the influence of fatigue increases, and does this vary according to age? Early work (Bills, 1931) demonstrated that extended cognitive work gives rise to occasional “blocks” where information processing is momentarily interrupted, and reflected in markedly slower responses. Further investigation (Bertelson & Joffe, 1963) supported the view that such occasional slower responses in extended tasks reflect mental fatigue, and Broadbent (1958) interpreted them as representing involuntary shifts of attention to irrelevant sources. However, in work reporting RT inconsistency, investigators have either recorded too few trials to assess inconsistency over extended periods, or have investigated within-session variability over blocks of trials that have been separated by short breaks. Consequently, it has not been possible to assess whether inconsistency is subject to fatigue effects as the RT task progresses. Given that neurobiological mechanisms have been hypothesized to underlie RT variability, it is plausible that acute fatigue affects the central nervous system by making it more inconsistent, with greater variability for older relative to younger persons. In the present study, inconsistency is separated into decision and motor task components, affording insights into the extent to which fatigue-related inconsistency is “consistent” for different elements of the information processing system. As decision and motor RTs were recorded continuously for 300 trials, we are also able to examine age-related inconsistency for those components during the early, middle, and late phases of the task.

The final issue we investigate relates to the association between RT inconsistency and task demands. Some theorists have suggested that temporary lapses of attention (Bunce, Warr, & Cochrane, 1993), or fluctuations in executive control (West et al., 2002), may contribute to RT inconsistency. Conceptually, there is considerable overlap between these ideas, and both hold that age differences in variability become greater with increased task difficulty or executive demands, propositions that receive empirical support (Cerella, 1985; Salthouse, 1991; West et al., 2002). In the present study, although we do not formally investigate executive control, we manipulate task demands by varying the number of response choices available in the decision component of the RT task (i.e., three conditions comprising 2, 4, or 8 choices). We assume that as the number of choices increase, the demands on attentional resources will increase due to the greater need to inhibit inappropriate response options, and this will be associated with elevated response inconsistency, particularly among older adults. It is important to note that this manipulation involves a quantitative change in the demands on attentional resources, as opposed to a qualitative change in terms of the underlying cognitive operations required to perform the task (i.e., changing the nature of the task). This distinction is important, because previous studies (e.g.,

West et al., 2002) that have assessed task demands with respect to age differences in inconsistency have done so through qualitatively changing the cognitive operations required for various task conditions (e.g., comparing an immediate response visual search condition to a 1-back condition where heavy demands on working memory were introduced). We build upon this work by varying the quantitative demands on attentional resources but not the cognitive operations required for the decision component of the task.

To summarize, in the present study we focus on RT inconsistency and age with the expectation that increasing task demands with respect to the decision component will magnify age differences as a function of the number of response choices available. Because task requirements for motor responding are identical for each condition, it is unlikely that variability in this component of the task will differ across conditions. With regard to the accumulating effects of fatigue, inconsistency is likely to increase with task duration, particularly among older adults in the 8-choice condition where task demands are most pronounced.

### Method

Partial data from an earlier study of age, physical condition and psychomotor performance (Bunce, 2001) were used in the present investigation. The sample, measures, and procedures are summarized here only as they pertain to this report.

#### Participants

Twenty-four younger men aged 20 to 30 years, and 24 older men, aged 60 to 85 years were recruited for the study. Group means and standard deviations for age, years of education, and verbal intelligence are presented in Table 1. Verbal intelligence was measured through the vocabulary test of the Wechsler Adult Intelligence Scale-R (Wechsler, 1981), scored according to standard procedures.

#### Serial Choice Reaction Time Task

Decision and motor RTs were recorded separately, similar to procedures employed elsewhere (e.g., Stollery, 1987). Eight red light-emitting diode (LED) lights (10 mm diameter; Kingbright USA Corp.) were positioned in an equidistant, 180-degree arc (170 mm radius) around a central non-latching push response button (20 mm diameter; Maplin Electronics). Each light had a similar button positioned adjacently on the inside of the arc (35 mm between centers of button and LED). The lights and buttons were mounted on an external response plinth (495 mm x 355 mm) linked to a PC where response data were logged.

Stimulus onset (illumination of one of the eight lights) was triggered by pressing the central button, and stimulus offset by pressing the button adjacent to the illuminated light. Participants were instructed to press the central return button immediately following stimulus offset, thereby immediately triggering stimulus onset for the next trial. The RT between stimulus onset (pressing the central return button) and stimulus offset (canceling the illuminated light) was designated the decision RT, and the response latency between stimulus offset and stimulus onset (triggered by pressing the central return button) as the motor RT. The percentage of errors for decision RTs was also recorded.

Each participant performed a 2-choice, 4-choice, and 8-choice version of the RT task, counter-balanced within each age group. In each condition, 20 practice trials were administered, followed by the 300 experimental trials from which decision and motor RTs were calculated. Participants were instructed to respond as quickly and as accurately as possible. Within each condition, decision and motor RTs were divided into three blocks of 100 trials for subsequent time-on-task analyses.

### Procedure

Participants attended the laboratory by appointment. Biographical details were recorded and physiological measures taken for another aspect of the study (see Bunce, 2001). Participants then performed the serial choice RT tasks. At the end of the one-hour testing session, participants were debriefed and paid £5 sterling.

### Data processing procedures

Before measures of inconsistency were computed, data distributions for the decision and motor components in each block of the three choice RT conditions were inspected for extremely fast or slow latencies. These outliers may reflect various sources of error (e.g., accidental key presses, task interruption). Outliers were trimmed according to the following criteria: (a) lower bounds for legitimate responses were set to 150 ms for the decision component and 100 ms for the motor component according to minimal response times suggested by prior research (Hultsch et al., 2002); and (b) upper bounds were established by computing the mean and standard deviation separately for each age group (young and old), task condition (2, 4, and 8 choice), block (1, 2, and 3), and task component (decision and motor) dropping any trials exceeding the mean by three or more SDs. Incorrect response trials were also removed. The number of trials dropped across the Persons x Trials data matrix was small relative to total number of observations (14,400 cases per task condition

and component): Decision 2-choice = 4.5%; Decision 4-choice = 4.1%; Decision 8-choice = 3.9%; Motor 2-choice = 4.8%; Motor 4-choice = 4.0%; Motor 8-choice = 2.8%. To avoid statistical problems associated with missing data, missing values were imputed using a regression procedure where estimates were based on the relationships among responses across trials within respective block, condition, and component. Because removing outliers and imputing the resulting missing values reduces variability, this procedure represents a conservative approach for investigating inconsistency.

Following the procedure developed elsewhere (Hultsch et al., 2002), measures of inconsistency were “purified” to eliminate potential confounding influences (e.g., age differences in mean RT). The measure of inconsistency was computed as the intraindividual standard deviation (ISD) about each individual’s mean RT. Because the ISD increases in direct relation to age-related increases in mean RT, it was desirable to partial out systematic age group differences from ISD measures. Otherwise, greater ISDs in older persons may simply reflect the fact that older adults were on average slower than younger adults. Similarly, RTs may vary according to verbal intelligence, or trial-to-trial variance within a block, or physical condition as demonstrated in the original study (Bunce, 2001). To control for these potential confounds, we employed a split-plot regression procedure where the dependent RT measure was regressed on the main effects and all corresponding higher-order interactions of the potential confounding variables. This approach to investigating inconsistency amounts to analyzing the residuals from a Groups by Occasions mixed-model ANOVA where the effects associated with age group, trials (1 to 300), condition, task component, verbal intelligence, physical condition, and all higher-order interactions were partialled from participants’ RT scores (i.e., residual scores were statistically independent of preexisting group differences for these influences). Prior to computing ISDs, residual scores were converted to  $T$  scores ( $\text{mean} = 50$ ,  $\text{SD} = 10$ ) to facilitate comparisons across groups.

### Results

T-tests revealed significant ( $t_s = 2.65$  to  $28.38$ ,  $p_s < .02$ ) group differences for each of the biographical variables described in Table 1. However, pre-existing differences for age group and verbal intelligence, and their associated interactions, were partialled out using the regression procedure. The ISDs were subjected to a multivariate analysis of variance (MANOVA) where age served as the between-subjects factor (young vs. old), and condition (2, 4, 8 choice condition), block (Blocks 1 to 3), and task component (decision vs. motor) as within-subjects factors. Where appropriate, simple tests and Bonferroni adjusted T-tests were

used to decompose all significant interactions. Inconsistency data according to age group, condition, block, and task component are presented in Table 2.

Table 1 and Table 2 about here

Although the main effect for age was nonsignificant ( $F = 1.02, p > .31$ ), the effect for task component was statistically reliable,  $F(1,46) = 61.06, \eta^2 = .570, p < .001$ . Mean trends suggested that inconsistency in decision RTs ( $M = 7.13$ ) was greater than inconsistency in motor RTs ( $M = 5.55$ ). This task main effect was further modified by a significant Age x Task component interaction,  $F(1,46) = 12.66, \eta^2 = .216, p = .001$ . Simple tests detected a significant age difference for decision ( $F = 7.87, p < .01$ ) but not motor RT ( $F = 0.10, p > .75$ ). Figure 1 shows this interaction where age differences in ISDs for decision relative to motor RTs can be clearly seen.

Figure 1 about here

There was also a significant main effect for condition,  $F(2,92) = 44.43, \eta^2 = .491, p < .001$ , where inconsistency became greater as task demands increased. Although age did not further modify this main effect, a statistically reliable Task component x Condition interaction was obtained,  $F(2,92) = 16.33, \eta^2 = .262, p < .001$ . This interaction is demonstrated in Figure 2 where a dissociation in variability for decision relative to motor responding is evident as task demands become greater. T-tests revealed that all between-condition comparisons were statistically reliable ( $ts = 6.44$  to  $10.62, ps < .01$ ) for the decision component. For the motor component, only the comparison between 2-choice and 4-choice conditions failed to surpass conventional levels of significance ( $t = 1.55, p > .12$ ). Remaining comparisons were significant ( $ts = 2.80$  and  $3.70, ps < .05$ ), albeit of diminished effect size relative to the decision component. The three-way Age x Task component x Condition interaction was not significant ( $F = 0.34, p > .69$ ).

Figure 2 about here

The main effect of Block was significant,  $F(2,92) = 5.79, \eta^2 = .112, p = .004$ . Inconsistency increased from Block 1 to Blocks 2 and 3. Neither the Age x Block ( $F = 0.23,$



$p > .79$ ), nor Task component  $\times$  Block ( $F = 1.70$ ,  $p > .18$ ) interactions were significant. However, the Condition  $\times$  Block interaction was statistically reliable,  $F(4,184) = 2.59$ ,  $\eta^2 = .053$ ,  $p = .042$ . Figure 3 demonstrates that for the 2-choice condition, where task demands are at their lowest, inconsistency does not vary greatly across the course of the task. However, an effect for time-on-task appears in the 4-choice condition, and is further amplified for the 8-choice condition involving the greatest task demands. Simple t-tests confirmed that inconsistency varied with time-on-task in the higher task demand condition. Within-condition comparisons for the 2- and 4-choice conditions yielded no significant group differences ( $t_s = 2.16$  and  $2.34$ ,  $p_s > .05$ ). However, for the 8-choice condition, comparisons of Blocks 1 and 2 ( $t [47] = 2.74$ ,  $p < .05$ ) and Blocks 1 and 3 ( $t [47] = 4.51$ ,  $p < .01$ ) were significantly different (whereas Blocks 2 and 3 did not differ,  $t = 1.00$ ,  $p > .32$ ).

Figure 3 about here

Qualifying the significant two-way interactions, the three-way Age  $\times$  Task component  $\times$  Block interaction was significant,  $F(2,92) = 9.77$ ,  $\eta^2 = .064$ ,  $p = .05$  (see Figure 4). It is evident that when comparing motor RTs in young and old across blocks, the variation is modest. A series of T-tests indicated that all age comparisons across block were nonsignificant ( $t_s = 0.05$  to  $0.54$ ,  $p_s > .58$ ). In contrast, the decision component showed an increase in age-related variability as a function of block. T-tests for the decision component found that age differences were significant for Block 3 ( $t [46] = 3.44$ ,  $p < .01$ ), but not for Blocks 1 and 2 ( $t_s = 2.16$  and  $2.34$ ,  $p_s > .05$ ). It appears that increasing task demands magnifies age differences in variability with time-on-task for decision RTs, but not for motor RTs. Importantly, the dissociation between decision and motor components appears age-related.

Figure 4 about here

However, the previous dissociation should be considered within the context of a significant four-way Age  $\times$  Task component  $\times$  Block  $\times$  Condition interaction,  $F(4,184) = 2.83$ ,  $\eta^2 = .058$ ,  $p = .03$ . This interaction was probed within each level of task component. For the decision component, the Condition  $\times$  Block interaction was significant in the older group ( $F[4,184] = 3.54$ ,  $p = .01$ ,  $\eta^2 = .070$ ), but not in the younger group ( $F = 0.34$ ,  $p > .85$ ).

For the older group, T-tests examined between-block differences in decision RT inconsistency within each of the three conditions. No comparisons were statistically reliable for the 2-choice and 4-choice RT conditions ( $t_s = .038$  to  $1.40$ ,  $p_s > .17$ ). Within the 8-choice condition, the comparison between Blocks 1 and 3 was significant ( $t [23] = 4.06$ ,  $p < .01$ ). It appears therefore, that in conditions of high task demands, older persons' decision RTs became more inconsistent as the task progressed. In contrast, although RT variability for the decision component increased for young persons from the 2-choice to the 8-choice RT condition, performance did not vary significantly with task duration within any of the conditions. The age differences in decision RT inconsistency as a function of task demands and task duration are shown in the upper half of Table 2.

Finally, with regard to motor RT, the Condition  $\times$  Block interaction failed to reach statistical significance in the older group ( $F = 0.89$ ,  $p > .46$ ), but did in the younger group ( $F[4,184] = 2.45$ ,  $p = .048$ ,  $\eta^2 = .051$ ). T-tests in the younger group did not yield any significant comparisons between-blocks within the 2-choice and 4-choice conditions ( $t_s = 0.07$  to  $1.24$ ,  $p_s > .22$ ). However, the comparison between Blocks 1 and 3 in the 8-choice condition was statistically reliable ( $t [23] = 4.46$ ,  $p < .01$ ). Whereas older persons become more inconsistent in decision RTs with greater task demands and task duration, younger individuals showed a weaker trend towards greater inconsistency for motor RTs during the final block of trials in the 8-choice condition. This dissociation is evident when comparing the upper and lower halves of Table 2.

### Discussion

The present investigation of age differences in RT inconsistency possesses several novel features. First, inconsistency was computed separately for the decision and motor components of an RT task. Second, inconsistency measures were calculated for three consecutive blocks of trials, allowing the effects of fatigue to be investigated. Third, the three experimental conditions (2, 4, and 8 choice) manipulated the quantitative demands on attentional resources without qualitatively altering the cognitive operations required to perform the task in each condition. Finally, a regression procedure was adopted that controlled for individual differences in age, verbal intelligence, physical condition, and trial-to-trial within block variability, prior to the calculation of inconsistency measures.

The major finding of the study was that age differences in inconsistency dissociated according to the task component under investigation. For decision responding, inconsistency

was greater for older adults, particularly during the last block of trials in the condition placing greatest demands upon attentional resources. This suggests that the effects of higher task demands and fatigue combined to amplify inconsistency in older adults. Although this decision RT trend was not evident for younger persons, a weaker trend toward increased inconsistency for motor responding was detected in the younger group. Unexpectedly, this was evident in the 8-choice condition during the last block of trials.

The finding of greater inconsistency among older adults in the present investigation is in line with several earlier studies (e.g., Anstey, 1999; Fozard et al., 1994; Hulstsch et al., 2002; Salthouse, 1993; West et al., 2002). Current results extend previous ones by showing that inconsistency in older adults was attributable to the decision rather than the motor component of the task. This finding is consistent with the view that age-related increases in the variability of neurobiological processes supporting the decision component are responsible for the behavioral findings of greater inconsistency in older adults (Li, Lindenberger, & Sikström, 2001; Myerson et al., 1999; Welford, 1980). Our findings also suggest that those neurobiological processes are subject to greater variability when task demands are higher (perhaps a function of restrictions in attentional resources). This finding is consistent with those of West and colleagues (2002). However, interpretation of their findings was complicated as it is unclear whether the increased inconsistency observed was due to a quantitative increase in task demands per se, or the qualitative shift in the cognitive operations required in the respective task conditions. Our experimental manipulation helped clarify this issue, as task demands were manipulated through quantitatively varying the number of choices available in the decision component, rather than altering the cognitive operations required in performing the task. Our data confirm that inconsistency increases in conditions placing higher demands on attentional resources, and that this effect is greater in older adults. Further, we speculate that the mechanisms mediating the drain on attentional resources relate to executive control. Although the operational characteristics of the task did not formally manipulate executive demands, the increase in the number of available response options from 2 to 8-choices decreased the probability of a stimulus occurring (from .5 to .125) thereby increasing the requirement to inhibit inappropriate responses. This, combined with the wider field of view required in conditions of greater choice, and the continuous responding demanded by the task (300 trials without pause), is likely to have placed considerable demands on attentional resources. It seems probable therefore, that as the number of choices increased, and as the task progressed, so did the demands on executive control.

To our knowledge, this is the first study to assess inconsistency as a function of fatigue associated with time-on-task and age. For the decision component in older adults, the data suggest that not only does inconsistency increase with task duration, but that this trend is stronger in the condition of highest task demands. This is consistent with the view that the neurobiological mechanisms that underlie behavioral measures of inconsistency become more variable (or are taxed to a greater extent) as the level of fatigue increases. Moreover, these findings are in line with earlier work focusing apparent lapses in attention during continuous mental work (Bertelson & Joffe, 1963; Bills, 1931; Broadbent, 1958). This is not only of theoretical interest, but has certain practical implications, particularly in safety-critical situations. Specifically, if fatigue is allowed to accumulate in demanding situations (e.g., road vehicle driving), the elevated inconsistency of cognitive processes may give rise to attentional lapses with dangerous behavioral consequences. As fatigue effects were differentially apparent for older adults, specific guidelines encouraging the elderly to take frequent breaks for demanding activities may be appropriate.

A somewhat unexpected finding was that younger persons' motor responding became more inconsistent as task demands increased, and with time-on-task. The reason for this finding is not immediately clear, although it should be noted that the effect size for the motor Condition x Block interaction in younger adults ( $\eta^2 = .05$ ) was smaller than that associated with the decision Condition x Block interaction for older persons ( $\eta^2 = .07$ ). If this trend turns out to be reliable, one possible explanation is that for the 8-choice decision component, relative to older adults, younger persons' RT variability was more consistent from block to block. It is possible that such consistency in responding across blocks for decision RTs in younger adults came at the expense of increased inconsistency from block to block in motor responding. In other words, a trade-off may have meant resources allocated to maintaining performance related to the decision component depleted those available for motor responding, the deleterious consequences of which were manifest in circumstances of higher task demands and fatigue. However, as no information was recorded as to whether participants prioritized respective components of the task, we are unable to confirm this hypothesis. Given the foregoing however, it is important to emphasize that the main findings of the present study concerned the lower-order interactions. Not only was the four-way interaction unexpected, but issues relating to sample size, and the complexities of statistically decomposing such an interaction make interpretation particularly difficult. Therefore, this finding should be interpreted with caution.

It is worth commenting on the design of the task that drew upon procedures elsewhere (e.g., Stollery, 1987). An important feature was that continuous speeded responding was required throughout the task. Decision time began when the participant pressed the home key, and ended when the appropriate stimulus key was pressed. Motor time was determined by the time taken to return to the home key. Although alternative versions of the task have been used (e.g., decision time determined by time from stimulus onset to home key release, and motor time by home key release to stimulus key offset), the continuous nature of the present task had the advantage of preventing short “rest” pauses between trials that are possible in the alternative paradigm. Specifically, as time pressure is absent in those paradigms for the period between stimulus offset and initiating the next trial, it is possible for participants to delay initiation of the following trial thereby gaining short rest pause. As this was likely to moderate a major factor of interest in the present study, accumulated fatigue and associated demands on attentional resources, the continuous responding version of the task was preferable.

This study possesses some limitations that should be acknowledged. The first is that research elsewhere (Rabbitt, Osman, Moore, & Stollery, 2001) suggests that within-session RT variability is greater in older adults of lower relative to higher fluid intelligence. Although we controlled for variation in verbal intelligence, this measure is more resistant to age-related decline than measures of fluid ability. Therefore, we cannot rule out the possibility that fluid intelligence may have influenced our findings. Also, older adults recorded lower verbal intelligence scores than younger adults, raising the possibility that this variable may have influenced between-group differences in RT variability. However, we do not believe this to be the case as the regression procedure statistically controlled for age-related variance attributable to verbal intelligence, as well as higher-order interactions with other variables in the study. Finally, our conclusions relating to the influence of fatigue on inconsistency were drawn in the absence of an independent measure of task fatigue. Although self-reports of fatigue were not possible given the continuous block design of the present study, assessment of perceptions of fatigue following completion of the 300 trials in each condition would have strengthened our conclusions. Future research might consider concurrent electrophysiological monitoring of arousal in order to make inferences about the effects of fatigue on inconsistency.

To conclude, age differences in inconsistency vary as a function of task component, task demands and fatigue related to time-on-task. The findings are consistent with the view that age differences in the inconsistency of decision responding are influenced by increased

variability in neurobiological mechanisms in older adults. That higher task demands and fatigue exacerbate inconsistency in older adults has important theoretical and practical implications. Regarding the former, it suggests that age-related declines in neurological structures and processes might precipitate an increase in attentional lapses (Bunce et al., 1993) or fluctuations in executive control (West et al., 2002). Practically, this suggests that frequent breaks should be taken by older adults when performing extended monitoring tasks, particularly in safety-critical situations where task or executive demands are high.

## References

- Anstey, K. J. (1999). Sensorimotor and forced expiratory volume as correlates of speed, accuracy, and variability in reaction time performance in late adulthood. *Aging, Neuropsychology, and Cognition*, *6*, 84-95.
- Bertelson, P., & Joffe, R. (1963). Blockings in prolonged serial responding. *Ergonomics*, *6*, 109-116.
- Bills, A.G. (1931). Blocking: A new principle of mental fatigue. *American Journal of Psychology*, *43*, 230-245.
- Broadbent, D.E. (1958). *Perception and communication*. Elmsford, NY: Pergamon Press.
- Bunce, D.J. (2001). The locus of Age x Health-Related Fitness interactions in serial choice responding as a function of task complexity: central processing or motor function? *Experimental Aging Research*, *27*, 103-122.
- Bunce, D.J., Warr, P., & Cochrane, T. (1993). Blocks in choice responding as a function of age and physical fitness. *Psychology and Aging*, *8*, 26-33.
- Cerella, J. (1985). Information processing rate in the elderly. *Psychological Bulletin*, *98*, 67-83.
- Fozard, J. L., Verduyn, M., Reynolds, S. L., Hancock, P. A., & Quilter, R. E. (1994). Age differences and changes in reaction time: The Baltimore Longitudinal Study of Aging. *Journal of Gerontology: Psychological Sciences*, *49*, P179-P189.
- Fuentes, K., Hunter, M. A., Strauss, E., & Hulstsch, D. F. (2001). Intraindividual variability in cognitive performance in persons with chronic fatigue syndrome. *The Clinical Neuropsychologist*, *15*, 210-227.
- Gordon, B. & Carson, K. (1990). The basis for choice reaction time slowing in Alzheimer's disease. *Brain and Cognition*, *13*, 148-166.
- Hendrickson, A. E. (1982). The biological basis of intelligence Part I: Theory. In H. J. Eysenck (Ed.), *A model for intelligence* (pp. 151-196). Berlin: Springer-Verlag.
- Hetherington, C. R., Stuss, D. T., & Finlayson, M.A.J. (1996). Reaction time and variability 5 and 10 years after traumatic brain injury. *Brain Injury*, *10*, 473-486.
- Hulstsch, D. F., MacDonald, S.W.S., & Dixon, R. A. (2002). Variability in reaction time performance of younger and older adults. *Journal of Gerontology: Psychological Sciences*, *57B*, P101-P115.
- Hulstsch, 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, UK: Oxford University Press.
- Hultsch, D. F., MacDonald, S.W.S., Hunter, M. A., Levy-Bencheton, J., & Strauss, E. (2000). Intraindividual variability in cognitive performance in older adults: Comparison of adults with mild dementia, adults with arthritis, and healthy adults. Neuropsychology, *14*, 588-598.
- Jensen, A. R. (1982). Reaction time and psychometric g. In H. J. Eysenck (Ed.), A model for intelligence (pp. 93-132). Berlin: Springer-Verlag.
- Knotek, P. C., Bayles, K. A., & Kaszniak, A. W. (1990). Response consistency on a semantic memory task in persons with dementia of the Alzheimer type. Brain and Language, *38*, 465-475.
- Li, S-C., & Lindenberger, U. (1999). Cross-level unification: A computational exploration of the link between deterioration of neurotransmitter systems and dedifferentiation of cognitive abilities in old age. In L-G Nilsson & H. Markowitsch (Eds.), Cognitive neuroscience and memory (pp. 103-146). Toronto: Hogrefe & Huber.
- Li, S-C., Lindenberger, U., & Sikström, S. (2001). Aging and cognition: from neuromodulation to representation. Trends in Cognitive Science, *5*, 479-486.
- Myerson, J., Hale, S., Wagstaff, D., Poon, L. W., & Smith, G. A. (1990). The information-loss model: A mathematical theory of age-related cognitive slowing. Psychological Review, *97*, 475-487.
- Rabbitt, P., Osman, P., Moore, B., & Stollery, B.T. (2001). There are stable individual differences in performance variability, both from moment to moment and from day to day. Quarterly Journal of Experimental Psychology, *54A*, 981-1003.
- Salthouse, T. A. (1991). Theoretical perspectives on cognitive aging. Hillsdale, NJ: Lawrence Erlbaum.
- Salthouse, T. A. (1993). Attentional blocks are not responsible for age-related slowing. Journal of Gerontology: Psychological Sciences, *48*, P263-P270.
- Stollery, B.T. (1987). Effects of 50 Hz electric currents on vigilance and concentration. British Journal of Industrial Medicine, *44*, 111-118.
- Stuss, D. T., Pogue, J., Buckle, L., & Bondar, J. (1994). Characterization of stability of performance in patients with traumatic brain injury: Variability and consistency on reaction time tests. Neuropsychology, *8*, 316-324.



- Stuss, D. T., Stethem, L.L., Hugenholtz, H., Picton, T., & Richard, M.T. (1989). Reaction time after head injury: Fatigue, divided and focused attention, and consistency of performance. Journal of Neurology, Neurosurgery, and Psychiatry, *52*, 742-748.
- Wechsler, D. (1981). WAIS-R: manual: Wechsler adult intelligence scale-revised. New York: Harcourt Brace Jovanovich
- Welford, A. T. (1980). Relationships between reaction time and fatigue, stress, age and sex. In A. T. Welford (Ed.), Reaction times (pp. 321-354). New York: Academic Press.
- West, R., Murphy, K. J., Armilio, M. L., Craik, F.I.M., & Stuss, D. T. (2002). Lapses of intention and performance variability reveal age-related increases in fluctuations of executive control. Brain and Cognition, *49*, 402-419.

Author notes

David Hultsch and Stuart MacDonald were supported, respectively, by a grant and a research fellowship from the Canadian Institutes of Health Research. We would like to thank Rob Davis for technical assistance.

Address correspondence to David Bunce, Department of Psychology, Goldsmiths College, University of London, London, SE14 6NW, UK. E-mail: [d.bunce@gold.ac.uk](mailto:d.bunce@gold.ac.uk)

Table 1

Means (SDs) for biographical variables by age group

Variables	Young (n = 24)	Old (n = 24)
Age (years)	25.46 (2.72)	69.29 (7.06)
Education (years)	16.33 (2.14)	9.93 (1.89)
Verbal intelligence	55.00 (10.49)	45.46 (14.22)

Table 2

Intraindividual-Standard Deviations (SDs) for Decision and Motor RTs as a Function of Age, Condition and Block

		<u>Block 1</u>	<u>Block 2</u>	<u>Block 3</u>
<u>Decision component</u>				
2-choice condition	Young	5.02 (1.03)	5.16 (1.27)	4.88 (1.23)
	Old	6.78 (2.10)	6.68 (2.43)	6.37 (1.98)
4-choice condition	Young	6.14 (1.57)	6.77 (1.38)	6.10 (1.14)
	Old	7.22 (2.61)	7.65 (2.45)	7.81 (2.84)
8-choice condition	Young	8.15 (1.67)	8.36 (2.10)	8.03 (1.56)
	Old	8.27 (2.36)	9.26 (2.62)	9.62 (2.23)
<u>Motor component</u>				
2-choice condition	Young	4.66 (2.25)	5.17 (3.11)	4.75 (3.33)
	Old	5.07 (2.86)	5.35 (2.91)	5.13 (3.07)
4-choice condition	Young	5.39 (2.41)	5.84 (2.80)	5.87 (2.82)
	Old	5.08 (2.62)	4.96 (3.17)	5.60 (3.40)
8-choice condition	Young	5.61 (1.83)	6.30 (2.58)	7.31 (2.57)
	Old	5.60 (2.28)	6.25 (2.71)	6.02 (2.66)

Note. Intraindividual standard deviations presented as T-scores.

Figure Captions

Figure 1. RT inconsistency as a function of age and task component.

Figure 2. RT inconsistency as a function of task component and condition.

Figure 3. RT inconsistency as a function of task condition and response block.

Figure 4. RT inconsistency as a function of age, task component, and response block.









