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Generalization of the Worst Performance Rule across the Lifespan

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Abstract

The worst performance rule (WPR) predicts that the slowest trials in reaction time (RT) tasks are more strongly related to intelligence than the fastest trials. To date, the WPR was observed mainly in young adults. The present study examined if the WPR holds not only in young adults but also in children and older adults in three kinds of RT tasks (simple RT, choice RT, and inhibition). Results showed that in each age group slowest and fastest trials were related to intelligence but the former correlated with intelligence to a greater extent than the latter. These results support the assumption that the WPR can be generalized across the lifespan.

Generalization of the Worst Performance Rule across the Lifespan

It has been argued that intraindividual variability (IIV) in reaction time (RT) tasks is correlated negatively with intelligence in many age groups, even after controlling for mean RT. Jensen (1982) reported evidence in young adults that IIV in RT tasks correlates negatively with psychometric intelligence and is even a better predictor of *g* than mean RT. In children, many studies have provided support for the link between IIV and intelligence (Beh, Roberts, & Prichard-Levy, 1994; Carlson & Jensen, 1982; Carlson, Jensen, & Widaman, 1983; Jensen & Munro, 1979; but see Li, Lindenberger, Hommel, Aschersleben, Prinz, & Baltes, 2004). Similarly, in older adults many studies have shown that IIV in RT tasks is related to intelligence (for a review, see Hultsch, Strauss, Hunter, & MacDonald, 2008).

As many studies have shown that people with high intelligence tend to demonstrate less IIV in RT tasks than people with low intelligence, it has been suggested that IIV could be the reflection of maladaptive cognitive processes (Hultsch et al., 2008). This statement has been reinforced by other findings. First, it has been shown that patients suffering of frontal lobe lesions demonstrate more IIV than controls (Stuss, Murphy, Binns, & Alexander, 2003). Second, it has been observed that IIV is more important in older adults suffering from dementia than in healthy older adults (Hultsch, MacDonald, Hunter, Levy-Bencheton, & Strauss, 2000). Third, when comparing different age groups, it has been shown that IIV is smaller in young adults than in children and older adults (Williams, Hultsch, Strauss, Hunter, & Tannock, 2005).

So far, it is not clear which cognitive processes produce larger IIV. Two main hypotheses have been suggested. According to the first, the attentional lapse hypothesis (Jensen, 1992), people with low IQs tend to have more attentional lapses than people with high IQs. These attentional lapses then result in more IIV in a RT task because people with low IQs respond most of the time as fast as people with high IQs, but tend to be slower on certain occasions. This theory has received some support. For instance, Adams, Roberts, Milich and Fillmore (2011) showed that IIV in a stop-signal task correlates with performance in a distractibility task in adults with attention-deficit/hyperactivity disorder. McVay and Kane (2012) showed that IIV was linked with mind-wandering. Indeed, participants who reported many task-unrelated thoughts (or attentional lapses) exhibited more IIV in a go-no go task than participants who reported very few task-unrelated thoughts.

According to the executive control theory, reduced IIV is a marker of executive control integrity (West, Murphy, Armilio, Craik, & Stuss, 2002). It has been demonstrated that IIV is correlated with performance in tasks that tap executive control like the antisaccade task (Unsworth, Redick, Lakey, & Young, 2010), a go-no go task (McVay & Kane, 2012) and working memory tasks (Schmiedek, Oberauer, Wilhelm, Süss, & Wittmann, 2007). It means that people who perform well on these tasks tend to have reduced IIV in comparison to people who have lower scores. Moreover, it has been claimed that executive control tasks recruit the frontal lobe region of the brain (West, Murphy, Armilio, Craik, & Stuss, 2002) and studies have shown correlations between IIV and neural activation in this region (Weissman, Roberts, Wisscher, & Woldorff, 2006), and between IIV and white matter lesions in this region (Bunce, Anstey, Christensen, Dear, Wen, & Sachdev, 2007).

Albeit related, these two hypotheses trigger different predictions. According to the attentional lapse hypothesis, mind-wandering can occur in all kinds of tasks and it is not clearly expected that IIV should be stronger in more difficult tasks that involve executive control. On the contrary, as the executive control hypothesis states that IIV is the byproduct of lapses of intention (West et al., 2002), the correlation between intelligence and IIV should be more important in tasks that necessitate executive control than in tasks that don’t require executive control.

Larson and Alderson (1990) suggested that IIV (often expressed as the intraindividual standard deviation computed across trials) is a global score that could be decomposed into different components of the RT distribution. They hypothesized that the relation between IIV and intelligence could be mediated by slowest or worst performance trials (Larson & Alderton, 1990). This hypothesis was named Worst Performance Rule (WPR). To test this hypothesis, individuals' RT distributions were partitioned in an equal number of bands, and each band was correlated with a *gf*/*g*c composite measure. Larson and Alderton (1990) showed that bands involving slow RT trials correlated to a greater extent with psychometric intelligence than bands involving fast RT trials. Whereas Larson and Alderton (1990) observed a negative correlation between worst trials and intelligence in a choice RT task, Kranzler (1992) replicated similar results across three RT tasks (simple RT, choice RT and odd-man-out task). Since then the WPR has been replicated many times in young adults for different tasks (Diasco & Brody, 1993; Schmiedek et al., 2007; Unsworth, et al., 2010; but see Madison, Forsman, Blom, Karabanov, & Ullén, 2009). However, it has received little support in other age groups.

To address the issue of the generalization of the WPR to children, Coyle (2001) used a memory task and worst performance analyses were performed on accuracy data rather than latencies. Results were similar to those from studies conducted with elementary cognitive tasks in young adults. The worst trial (least number of words recalled) correlated more with IQ than the best trial (where most words were recalled). Moreover, the worst trial predicted IQ better than aggregate scores of performance and variability (mean performance and intraindividual standard deviation). However, no study has been conducted to test the generalization of the WPR to children by means of RT tasks. In a mixed sample of young and older adults, Salthouse (1998) showed that fast and slow RTs correlated with intelligence to the same extent. Salthouse (1998) analyzed the WPR over a large age range and as the *g* loadings of cognitive tests may vary across age groups, Salthouse's procedure may have reduced the likelihood to replicate the WPR (Coyle, 2003). To our knowledge, since then only two studies have examined the WPR in older adults. Ratcliff, Thapar, and McKoon (2010) did not replicate the WPR in older or young adults. Finally, a study found converging results with the WPR in older adults (Tse, Balota, Yap, Duchek, & McCabe, 2010). These researchers have shown that performance in the slowest trials of three attention tasks correlated with working memory, episodic memory and processing speed in older adults (Tse, Balota, Yap, Duckek, & McCabe, 2010). As the worst performance should reflect the same processes as IIV and since IIV has been found to be linked with intelligence in the three age groups, it is reasonable to expect that worst trials would correlate with intelligence in the three age groups. Therefore, the first aim of our study was to test the generalization of the WPR to children and older adults.

Studies examining the WPR were conducted mainly in simple and choice RT tasks (for exceptions, see Coyle, 2001, 2003; Madison et al., 2009). This seems surprising for the following reason. According to Jensen (1982), correlations between RT and intelligence should increase as the complexity of the task increases. For example, the correlation between worst performance and intelligence was more pronounced in a choice RT task and an odd-man-out task than in a simple RT task (Kranzler, 1992), suggesting that the more complex the task, the more important the relation between worst performance trials and intelligence (Jensen, 1992). However, as suggested by an anonymous reviewer, the term of complexity is vague and doesn't explain what the processes involved in a task are (see also, Duncan et al, 2008). According to the executive control theory, some tasks seem more complex because they require more executive control. For example, if some tasks require that participants keep actively the task goal in mind to succeed in this task, we'll say the task is more complex than another task that doesn't necessitate the active maintenance of the task goal. The second aim of the present study is to test the hypothesis of an increase in the correlation between RT and intelligence with increasing task complexity, where task complexity is defined as requiring more executive control. In order to do so, the correlations between intelligence and slow trials in a simple RT, choice RT and an inhibition task will be compared.

In the literature, three alternative methods have been used to partition the RT distribution and to test the WPR: bands (Larson & Alderton, 1990; Kranzler, 1992), percentile ranks (Diascro & Brody, 1993; Salthouse, 1998) and ex-Gaussian parameters (Schmiedek et al., 2007). In the first two methods, RTs are arranged from the fastest to the slowest. Bands are defined by a fixed number of items and the mean of RTs is computed for each band. The number of bands varies according to the number of items (i.e., 4 bands in Kranzler, 1992, to 16 bands in Larson & Alderton, 1990). In the percentile ranks method, nine percentile bands (10^{th}, 20^{th}, 30^{th}, 40^{th}, 50^{th}, 60^{th}, 70^{th}, 80^{th}, and 90^{th} percentiles[1], Salthouse, 1998) or five percentile bands (5th, 25th, 50th, 75th, and 95th percentiles, Diascro & Brody, 1993) are first defined and the mean of RTs is then computed for each percentile band. In the ex-Gaussian distribution approach three parameters are estimated from the RT distribution. Mu (μ) and sigma (σ) reflect the mean and the standard deviation of the Gaussian part of the RT distribution, and tau (τ), reflects the exponential part (i.e., particularly slow trials). Whatever the method used to decompose the RT distribution, each measure (bands, percentiles, ex-Gaussian parameters) is then correlated with a measure of intelligence. Usually, visual inspection of correlations between intelligence and each part of the RT distribution, partial correlations and hierarchical regression analyses are used in order to test the WPR. It can be claimed that support for the WPR is obtained when the magnitude of the correlation with intelligence increases monotonically from the fastest to the slowest RT bands (or percentile ranks) and when the last band (or 90^{th} percentile) provides incremental validity in predicting intelligence, over a) the 10^{th} percentile, b) the 50^{th} percentile, c) the intraindividual mean of

RTs (*IM* RT) and d) the intraindividual standard deviation of RTs (*ISD* RT). When the ex-Gaussian approach is used, support for the WPR comes from the fact that τ correlates more with intelligence than μ and σ (Schmiedek et al., 2007).

Overview of Study and Hypotheses

In this paper, we use data of three different RT tasks (simple RT, choice RT, and inhibition tasks) administered to three age groups (children, young and older adults) from the Geneva Variability Study to test the hypotheses summarized below. In order to study the WPR, the percentile ranks method was chosen for two reasons. First, with this method, it is possible to use the same number of bands even though the number of items varies across tasks. Second, in comparison to the ex-Gaussian parameters, the percentile ranks method allows for more fine-grained analyses. In particular, it allows testing whether the magnitude of the correlation with intelligence increases monotonically from the fastest to the slowest RT percentile ranks, which is not possible with the ex-Gaussian parameters.

We first hypothesized that evidence for the WPR should be observed in children's, young and older adults' performance as attested by monotonically increasing correlations between percentile ranks and intelligence. Moreover, the 90th percentile should account for additional variance in the intelligence score as compared to other predictors (i.e., the 10th percentile, the 50th percentile, *IM* RT, *ISD* RT) when entered in a hierarchical regression model. Second, we hypothesized that correlations between the 90th percentiles and intelligence should increase with increasing task complexity and level of executive control required (Jensen, 1982). The correlations between the 90th percentiles and intelligence should therefore be higher a) in a choice RT task than in a simple RT task, b) in the incongruent trials of an inhibition task than in choice RT, and c) in the incongruent trials of an inhibition task than in the congruent and neutral trials of the same task.

Method

Participants

The sample consisted of 198 children (*M* age = 10.49 years, *SD* = 1.12, range = 9-12 years, 46.5 % female), 137 young adults (*M* age = 21.71 years, *SD* = 2.53, range = 19-33 years, 85.4 % female) and 114 older adults (*M* age = 69.83 years, *SD* = 6.51, range = 61-89 years, 76.7 % female). Children were recruited from primary schools in the Swiss canton of Geneva. Young adults were recruited from the undergraduate psychology student population at the University of Geneva. Older adults were volunteers recruited from the community, either from the University of the Third Age, or through newspaper and association advertisements for pensioners. All participants were native French speakers or fluent in French for at least 5 years. Participants were informed about the purpose of the study, and adults and school authorities provided written consent for participation. Sample descriptives are provided in Table 1.

Insert Table 1

Materials and Procedure

All testing was conducted individually in a quiet room in the laboratory (adults) or in the schools (children). This study included four tasks: two RT tasks (Simple RT and Choice RT task), one inhibition task (Color-naming Stroop task) and one fluid intelligence task (Standard Progressive Matrices (SPM)). All tasks were administered to all participants together with other tasks, in the same order. All materials (except for SPM) were presented on a 35 cm (14 in.) video graphics array color computer monitor and all experiments were piloted by the E-prime software (E-Prime 1.1). For the Color-naming Stroop task, voice onset latency was measured via a voice key, and the responses were recorded on paper by the experimenter. For the two RT tasks, latency and responses were recorded via a button box.

Tasks

RT tasks.

***Simple reaction time task* (SRT, adapted from Hultsch et al., 2000).** Participants had to press a button as quickly as possible when a cross appeared on the screen after a fixation point. The cross appeared in white on a black background in five positions counterbalanced within each block. The inter-stimulus interval (ISI) between the fixation point and the cross varied between 500 ms and 1700 ms counterbalanced within the task. After six practice trials, 120 trials were presented divided into five blocks of 24 trials each. On each trial, the following sequence of events occurred: A white fixation point appeared in the centre of the computer screen for 500, 800, 1100, 1400 or 1700 ms. Then the cross appeared in one of five possible positions and remained there until the onset of the participant's response. The order of blocks and trials within a block was identical for all participants and randomized with two constraints. First, within a block there were no more than two consecutive trials in which the same position was used. Second, within a block for no more than two consecutive trials ISI was the same. Participants' RT and accuracy were registered via a button box. Afterwards, the screen went blank for 1000 ms following the onset of the participants' response. Participants were given the option of taking a break every 24 trials (i.e., between blocks of trials).

***Choice reaction time task* (CRT, adapted from Hultsch et al., 2000).** Three crosses were presented at the left and the right of the centre of the screen. After a delay varying randomly from 500 ms to 1700 ms counterbalanced within the task, one of the crosses changed into a square. Participants were instructed to press a key corresponding to the location of the square (right/left) as quickly as possible. After six practice trials, 120 trials were presented divided into five blocks of 24 trials each. On each trial, the following sequence of events occurred: Three crosses were presented at the left and the right of the centre of the screen. After a delay of 500, 800, 1100, 1400 or 1700 ms, one of the crosses changed into a square and remained until the onset of the participants’ response. The order of blocks and trials within a block was identical for all participants and randomized with four constraints: within a block there were as many right as left trials (i.e., in which the square appeared to the right or to the left), no more than two consecutive trials occurred in which the side was the same, no more than two consecutive trials occurred in which the same cross changed into a square, and no more than two consecutive trials occurred in which a same delay was used. Participants’ RT and accuracy were registered via a button box. Participants were given the option of taking a break every 24 trials (i.e., between blocks of trials).

Inhibition task.

Color-naming Stroop task* (Stroop, 1935).** Participants were instructed to name, as quickly and accurately as possible, the color of each stimulus. The stimuli consisted of four color names (ROUGE, BLEU, VERT, JAUNE[2]) written in red, blue, green, or yellow, depending on the condition (congruent vs. incongruent). In the neutral condition, four different stimuli (^^^^; ++++; *; ””””) were presented in red, blue, green, or yellow. All stimuli were presented on a black background. The Color-naming Stroop task was presented in the three conditions distributed over 18 blocks of 24 trials each[3]. On each trial, the following sequence of events occurred: A white fixation point appeared in the center of the computer screen for 1000 ms. Then the stimulus appeared in the center of the screen and remained until the onset of the participant’s response. Participants were instructed to name the color of each stimulus as quickly and accurately as possible. Afterwards, the screen went blank for 800 ms following the onset of the participant’s response. The order of the blocks and of the trials within a block was identical for all participants and randomized with two constraints. First, within a block, no more than three consecutive trials of the same condition were presented. Second, negative priming was controlled for in that the color word of any given item never matched the color of the succeeding item. In each block, there were eight congruent, eight incongruent, and eight neutral trials. In summary, 144 trials per condition were presented, for a total of 432 items. Participants' RT was registered by a voice key and participants' accuracy was checked by the experimenter on a response sheet. Participants were given the option of taking a break every 24 trials (i.e., between blocks of trials).

Intelligence task

***Raven Standard Progressive Matrices* (SPM, Raven, Court, & Raven, 1998).** This task is a figural test and a measure of abstract perceptual reasoning. Participants were given 20min to complete 5 series of 12 items each. The score used in the current paper was the total number of correct responses ranging from 0 to 60. SPM results are presented in Table 1.

Statistical Analyses

For all tasks, only the latencies for correct responses were analyzed. Moreover, improbable RTs (below 150 ms for the SRT and CRT tasks and below 200 ms for the Color-naming Stroop task) and extreme RTs were eliminated from the analyses. Improbable values were determined with the cutoffs found in Hultsch, MacDonald and Dixon (2002) and Spieler, Balota and Faust (2000). For extreme values, we wanted to use the same cutoff for the three age groups and chose extreme values to be sure to eliminate only outliers. For the Color-naming Stroop task, we chose 2000 ms (Spieler, Balota and Faust, 2000). For the other tasks, we chose 1000 ms for the SRT and 1500 ms for the CRT in order to eliminate only improbable trials (even with the criterion of eliminating trials above the mean and 3 SD, we are below these cutoffs).

This excluded for children 1.3 %, 4.3% and 12 %, for young adults 0.4%, 1.3% and 3.7%, and for older adults 1.2%, 2.8% and 7.2% of the data for the SRT, CRT and Color-naming Stroop tasks, respectively.

For each task, the correct response latencies were then ordered from fastest to slowest in order to determine the percentiles (i.e, from the 10th percentile to the 90th percentile). Thus, nine scores were available for each participant and task. The 10th percentile values correspond to the fastest and the 90th percentile values to the slowest RTs. In the Color-naming Stroop task, the nine percentiles were created separately for congruent trials, neutral trials, and incongruent trials.

Results

IM RT and *ISD* RT for each task are presented in Table 2. Means and standard deviations of percentiles for each task are presented in Table 3 for children, in Table 4 for young adults, and in Table 5 for older adults. In each age group there was an increase in RT from the 10th percentile to the 90th percentile. Participants in each age group were slower to respond in the Color-naming Stroop task than in simple or choice RT tasks.

Insert Table 2, 3, 4 and 5

In agreement with Coyle's suggestion (2003), as intersubject variance grows linearly from the 10th percentile to the 90th percentile (Tables 3, 4 and 5), Spearman's rank-order correlation (rho) was used instead of Pearson's correlation coefficient (*r*). Figures 1, 2 and 3 display Spearman's rank-order correlations between percentiles and the number of correct responses in the SPM task, respectively for children, young and older adults. Correlations were negative and increased between percentiles and SPM from the 10th percentiles to the 90th percentiles. In all tasks and for each age group, the magnitude of the correlation between RT and SPM was (almost) perfectly rank-ordered from the 10th percentile to the 90th percentile.

Insert Figure 1, 2 and 3

Four sets of hierarchical regression analyses were conducted separately in the three age groups in order to test the assumption that the 90th percentiles are better indices of intelligence than other indices derived from RT distributions (10th percentiles, 50th percentiles, *IM* RTs, and *ISD* RTs) [4]. First, in order to test the relative contribution of the 10th percentiles and the 90th percentiles in the prediction of SPM: a) the 90th percentiles for all five RT tasks were entered in the first block, followed by the 10th percentiles for the five RT tasks in the second block, and b) the 10th percentiles for all five RT tasks were entered in the first block, followed by the 90th percentiles for the five RT tasks in the second block. Second, in order to test the relative contribution of the 50th percentiles and the 90th percentiles to the prediction of SPM scores: a) the 90th percentiles for all five RT tasks were entered in the first block, followed by the 50th percentiles for the five RT tasks in the second block, and b) the 50th percentiles for all five RT tasks were entered in the first block, followed by the 90th percentiles for the five RT tasks in the second block. Third, in order to test the relative contribution of the *IM* RTs and the 90th percentiles to the prediction of SPM: a) the 90th percentiles for all five RT tasks were entered in the first block, followed by the *IM* RTs for the five RT tasks in the second block, and b) the *IM* RTs for all five RT tasks were entered in the first block, followed by the 90th percentiles for the five RT tasks in the second block. Fourth, in order to test the relative contribution of the *ISD* RTs and the 90th percentiles to the prediction of SPM scores: a) the 90th percentiles for all five RT tasks were entered in the first block, followed by the *ISD* RTs for the five RT tasks in the second block, and b) the *ISD* RTs for all five RT tasks were entered in the first block, followed by the 90th percentiles for the five RT tasks in the second block.

Table 6 shows the percentage of variance explained in SPM by variables in the second block over and above variables entered in the first block.

Insert Table 6

First, results show that when the 90th percentiles were entered first, they explained an important and significant amount of variance in SPM in the three age groups (i.e., 22 % for children, 14% for young adults, and 20 % for older adults). Moreover, other indices derived from the RT distributions (10th percentiles, 50th percentiles, *IM* RTs and *ISD* RTs) did not account for an additional significant amount of variance in SPM over and above the 90th percentiles, except the 50th percentiles and the *IM* RTs for children (7 %, $p < .01$ and 6 %, $p < .05$). Second, results show that when each index derived from the RT distributions (10th percentiles, 50th percentiles, *IM* RTs and *ISD* RTs) was entered first, it explained an important and significant amount of variance in SPM in the three age groups. When the 10th percentiles were entered in the first step, they explained 10 % of variance in SPM for children and 12 % for older adults. For young adults, the 10th percentiles did not account for a significant amount of variance in SPM. When the 90th percentiles were entered in the second step, they accounted for an additional and significant amount of variance in all three age groups (i.e, 14 % for children and for young adults, 9 % for older adults). When the 50th percentiles were entered in the first step, they explained 22 % of variance in SPM for children and 20 % for older adults. For young adults, the 50th percentiles did not account for a significant amount of variance in SPM. When the 90th percentiles were entered in the second step, they accounted for an additional and significant contribution of variance only for children (6 %) and young adults (11%). When the *IM* RTs were entered in the first step, they explained 21 % of variance in SPM for children, 9 % for young adults, and 21 % for older adults. When the 90th percentiles were entered in the second step, they accounted for an additional and significant amount of variance only for children (6 %) and young adults (9 %). When the *ISD* RTs were entered in the first step, they explained 22 % of variance in SPM for children, 12 % for young adults, and 15 % for older adults. When the 90th percentiles were entered in the second step, they accounted for an additional marginally significant 8% of variance for older adults. A complete correlation matrix of all measures used in the hierarchical regression analyses for each age group is presented in the Appendices A, B and C.

To address whether the correlation between worst performance trials and intelligence increases as a function of task complexity, partial correlations between the 90th percentiles and SPM were conducted in each age group. Results are displayed in Table 7. The correlation between SPM and the 90th percentile in CRT remained significant when the 90th percentile in SRT was partialed out in children ($pr(195) = -.193, p < .01$) and in older adults ($pr(111) = -.378, p < .001$), meaning that the 90th percentile in CRT accounted for more variance in SPM than the 90th percentile in SRT. The correlation between SPM and the 90th percentile in the incongruent trials of the Color-naming Stroop task remained significant when the 90th percentile in CRT was partialed out in children ($pr(195) = -.231, p < .01$) and in older adults ($pr(111) = -.196, p < .05$), meaning that the 90th percentile in incongruent trials of the Color-naming Stroop task accounted for more variance in SPM than the 90th percentile in CRT. The correlation between SPM and the 90th percentile in the incongruent trials of the Color-naming Stroop task remained significant when the 90th percentile in the congruent trials of the Color-naming Stroop task was partialed out in children ($pr(195) = -.263, p < .01$) and in older adults ($pr(111) = -.250, p < .01$), meaning that the 90th percentile in incongruent trials of the Color-naming Stroop task accounted for more variance in SPM than the 90th percentile in the congruent trials of the Color-naming Stroop task. However, the correlation between SPM and the 90th percentile in the incongruent trials of the Color-naming Stroop task dropped below significance when the 90th percentile in the neutral trials of the Color-naming Stroop task was partialed out in the three age groups.

Insert Table 7

Discussion

The objectives of this study were twofold. We first aimed at replicating the WPR in young adults and generalizing it to children and older adults. Across age groups, and in each of the five tasks, the correlation between RT percentile ranks and intelligence increased from the 10th percentile to the 90th percentile. Hierarchical regression analyses confirmed the superiority of the 90th percentiles over other RT distribution indices (except *ISD* RTs) in explaining variance in intelligence (i.e., scores in SPM). The finding that the 10th percentiles never accounted for significant variance over and above the 90th percentiles in explaining variance in intelligence indicates that intelligence is more strongly linked to the slow part of the RT distribution than to the fast part of the RT distribution. Although the 90th percentiles explained more variance in intelligence than lower percentiles, they failed to predict intelligence over and above general indices of IIV (*ISD* RTs). The reverse was also true, that is the *ISD* RTs did not predict intelligence over and above the 90th percentiles. In most cases, global indices of IIV and worst performance were similar in the magnitude of variance they explained in intelligence. This might be due to the large amount of shared variance between the *ISD* RTs and the 90th percentiles (see Appendices A, B and C).

Concerning age group differences related to the WPR, the magnitude of the variance explained in SPM by each of the five 90th percentiles seems larger in children and older adults than in young adults. However, results must be considered with some caution due to the restricted variance of SPM scores in young adults (ceiling effect). In comparison, there was no ceiling effect in SPM scores in children and older adults. This implies that the correlation between worst (slowest) performance and intelligence might well be lower in young adults than in the other age groups merely because interindividual differences were less pronounced in this group in comparison to children and older adults.

The second aim of this study was to test the complexity hypothesis in relationship with the WPR. Indeed, we observed in children and older adults that the 90th percentile in choice RT explained more variance in intelligence than the 90th percentile in SRT. Likewise, the 90th percentile in incongruent trials of an inhibition task explained more variance in intelligence than the 90th percentile in congruent trials of that task and the 90th percentile in CRT. These findings corroborate Jensen's claims (1982) that there is an increase in the correlation between intelligence and RT with increasing complexity of the task. Note that the fact that this pattern is not observed in young adults, could be due to the ceiling effect mentioned above.

Coyle (2003) reported some alternative hypotheses (or methodological biases) which have to be ruled out in our data before considering the WPR of theoretical importance: presence of outliers in RT, lack of variance in the fast trials, problems of reliability, skewness and confound between worst performance and trial novelty. First, it has been reported that outliers (very fast or very slow trials) could increase or decrease the correlation with intelligence. Some arguments can be addressed to this issue. The WPR has been replicated in many studies. It seems implausible that outliers could be responsible for the WPR across many studies. Moreover, in our study, trials above 1000 ms for SRT, above 1500 ms for CRT, and above 2000 ms for the three conditions in the Color-naming Stroop task were deleted in order to eliminate outliers. Yet, slow trials correlated more with intelligence than fast trials and mean RT. If the WPR was a product of outliers, an increase in the correlation between RT and intelligence would not be observed from the fastest trials to the slowest trials.

Second, it has been claimed that the WPR might occur because of the variance compression in the fast trials. Indeed, it has been shown that interindividual differences are more important in the slow tail than in the fast tail of the RT distribution (Coyle, 2003). In our data, variance was also lower in the fast percentiles than in the slow percentiles. More precisely, there was an increase in the interindividual standard deviation from the 10th percentile to the 90th percentile. Nevertheless, we found evidence for the WPR using Spearman's rank-order correlation. In comparison to Pearson's correlation, Spearman's rank-order correlation is less influenced by interindividual variance. Therefore it is unlikely that the evidence for the WPR observed in our data can be attributed to variance compression only.

Third, it has been suggested that the WPR might result from a lack of reliability in fast trials. To rule out this possibility, we conducted split-half reliability analyses for the 10th percentiles and 90th percentiles in each RT task and each age group with the Spearman-Brown correction. As can be seen in Table 8, correlations ranged from $r = .93$ to $r = .99$ for the 10th percentiles, and from $r = .91$ to $r = .98$ for the 90th percentiles. It could be concluded that fast trials are not less reliable than slow trials.

Insert Table 8

Fourth, it has been argued that the WPR could be a by-product of the positive skew of RT distributions. One way to eliminate this assumption is to demonstrate that skewness of RT tasks is not correlated with intelligence (or less correlated than the 90th percentile). We conducted such analyses in the three age groups. Only two correlations between skewness[5] in RT tasks and intelligence were significant ($r = .21$, $p < .01$ for the correlation between skewness in the neutral condition in the Color-naming Stroop task and SPM in children, and r

= .19, $p < .01$ for the correlation between skewness in the incongruent condition in the Color-naming Stroop task and SPM in children). In comparison, only one correlation was not significant between the 90^{th} percentile and the SPM (SRT in older adults). This indicates that it is not the positive skew per se which produces the WPR.

Fifth, the issue of trial novelty was addressed by Coyle (2003). It could be the case that worst performance occurs mainly in the first trials of the RT task; WPR could then be the consequence of the novelty of the task. However, Coyle (2001) demonstrated that worst performance occurs evenly across trials. We conducted such analyses in the three age groups. Results showed that worst performance trials occurred evenly across trials. Detailed results are available upon request.

Another artifact suggested by Larson and Alderton (1990) to explain the WPR is the post-error slowing hypothesis. When people make errors in RT tasks, RT in the following trial is much slower (Rabbitt & Rodgers, 1977). If people who are less intelligent make many errors, the relation between intelligence and their slowest RT could be artificially produced by their post-error slowing. Larson and Alderton (1990) showed that slow trials resulted more often from post-error trials than fast trials but that slow trials involved only 6 % of post-error trials. In our study, the post-error slowing hypothesis can be discarded for the SRT task because no errors were committed in that task. For the CRT and the Color-naming Stroop task, we eliminated all post-error trials and reanalyzed the data. Only one difference emerged from the results. When the *ISD* RTs were entered in the first step in children, the 90^{th} percentiles failed to account for an additional and significant amount of variance for older adults. Detailed results are available upon request.

Since in the present study, participants ranged from 9 to 12 years, from 19 to 33 years, and from 61 to 89 years, there is a possibility that the WPR could constitute a by-product of the age disparity in each age group. Therefore, we conducted additional hierarchical regression analyses with age entered in step 1 and the 90^{th} percentile for all tasks in step 2 separately for each age group. For children, age explained 19 % of variance in SPM, whereas the 90th percentiles accounted for an additional 8 % of variance over and above age ($p < .01$). For young adults, age explained 2 % of variance in SPM, whereas the 90th percentiles accounted for an additional 14 % of variance over and above age ($p < .001$). For older adults, age explained 22 % of variance in SPM, whereas the 90th percentiles accounted for an additional 13 % of variance over and above age ($p < .01$). These results suggest that the WPR is not (only) a matter of age-related differences but also of interindividual differences in each age group.

Given that we could rule out many methodological biases potentially linked to WPR studies, we conclude that the WPR seems of theoretical interest. These results are in line with the executive control hypothesis but not with the attentional lapse hypothesis. If the attentional lapse hypothesis was correct, we would have expected to observe correlations of same magnitude between intelligence and the 90th percentiles in the different tasks. However, the relationship between the 90th percentiles and intelligence is more important in the CRT than in the SRT and in the incongruent trials of the Color-naming Stroop task than in the congruent trials of the Color-naming Stroop or the CRT. Our results are then in line with recent findings in the neuroscience that show that slow trials (Weissman et al., 2006) and IIV in RT tasks (Kelly, Uddin, Biswal, Castellanos, & Milham, 2008) are correlated with less activation in the frontal cortex and more activation of the default-mode network. It seems that inefficient deactivation of the default-mode network results in particularly slow trials and greater IIV.

It is difficult to reconcile our data with those of Salthouse (1998) and Ratcliff and colleagues (2010). Our study differs from Salthouse's study in numerous points. Salthouse (1998) used processing speed tasks to investigate the WPR (digit digit and digit symbol). To our knowledge, no study examined the correlation between intelligence and slow trials in this kind of tasks in young adults. Perhaps, this kind of task is not suitable to find the WPR. Indeed, Jensen (1982) showed that the correlation between intelligence and RT tasks disappears when response times are greater than 1000ms. Furthermore, no information is given on the trimming procedure in Salthouse's data. If no trimming procedure was used, it is not surprising to find no support for the WPR. In this case, slow trials could represent noise and would not correlate with intelligence. In regard to Ratcliff, Thapar and McKoon (2010), their tasks are also very different from those usually used in the WPR literature (numerosity discrimination, recognition memory, lexical decision). The number of trials in each task was also very impressive (1200 trials in the numerosity discrimination task, 832 trials in the recognition memory task and 2100 trials in lexical decision task). In comparison, 120 trials for the SRT and CRT tasks and 432 trials in Color-naming Stroop task have been used in our study. Here are the number of trials used in the other studies: 75 trials (Unsworth et al., 2010), between 20 and 36 trials (Kranzler, 1992), 80 trials (Larson & Alderton, 1990). It is conceivable that in Ratcliff, Thapar and McKoon (2010), worst trials do not reflect attentional lapses but fatigue. In support of this view, they did not find support for the WPR in their sample of young adults.

Strengths of our study include the cross-replication of the WPR in three different age groups, and the use of multiple tasks and conditions within a task varying in complexity (each task including more than one hundred trials). Therefore, our findings seem robust. However, a number of limitations have to be acknowledged. First, generalization of the WPR across the lifespan is limited by the fact that we have studied only three age groups and have not considered age as a continuous variable. Second, contrary to other studies examining the WPR in young adults with the Advanced Progressive Matrices, only the SPM was used as a proxy of intelligence. It resulted in a ceiling effect for the SPM in young adults. However, this task was chosen for two reasons. The SPM is one of the more *g* loaded cognitive tests, at least for children and older adults and one of the rare tests suited for children, young adults and older adults. Furthermore, albeit less g-loaded than in other age groups, the SPM is still considered a task that measures fluid reasoning in young adults (Conway, Cowan, Bunting, Therriault, & Minkoff, 2002). Finally, our results support the existence of the WPR in young adults, which was only shown with the Advanced Progressive Matrices in previous published studies.

In conclusion, this study replicated previous findings showing that the worst performance in RT tasks is related to intelligence in young adults. We found also that the worst performance correlated with intelligence in children and older adults. Moreover, worst performance in RT tasks of varying complexity was as good as or even better than the best performance, the mean performance or a global indicator of IIV in predicting intelligence in the three age groups. Finally, we found that the magnitude of the correlations between the worst performance and intelligence increases with increasing task complexity in children and older adults.

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Footnotes

[1] The 10th percentile represents the best performance trials whereas the 90th percentile represents the worst performance trials

[2] Red, blue, green and yellow in French

[3] The Color-naming Stroop task was conducted in two sessions, about 1 week apart, to reduce participants' burden given the large multivariate battery of cognitive tests included in the Geneva Variability Study. Each session contained nine blocks of 24 trials each. Each session started with nine practice trials (three items per condition), with stimuli and timing identical to those of the experimental blocks.

[4] The analysis was conducted first on the raw data and then on the rank-ordered data. As results don't differ between both analyses, only results for the raw data are presented here.

[5] Skewness was computed with SPSS 16.

Table 1

Sample Descriptives

	Children	Young Adults	Older Adults
N	198	137	114
Age	10.49	21.71	69.83
	(1.12)	(2.53)	(6.51)
Age range	9-12	19-33	61-89
% females	46.5	85.4	76.7
SPM	36.91	52.15	36.86
	(8.21)	(4.91)	(8.79)

Note. The group standard deviation is presented in parentheses. SPM: Standard Progressive Matrices.

Table 2

Response Times by Task and Age Group: Intraindividual Means and Standard Deviations

		SRT	CRT	Stroop N	Stroop C	Stroop I
Children	*IM* RT	359.94	495.24	841.45	799.22	1020.98
		(69.24)	(105.71)	(146.92)	(138.04)	(185.16)
	ISD RT	94.54	157.65	226.63	213.35	260.42
		(25.71)	(50.93)	(68.05)	(60.53)	(61.87)
Young Adults	*IM* RT	272.89	325.69	594.78	605.74	720.89
		(39.16)	(39.26)	(75.85)	(82.92)	(102.31)
	ISD RT	59.25	76.43	107.12	119.07	151.33
		(17.83)	(23.06)	(33.32)	(32.71)	(40.44)
Older Adults	*IM* RT	335.17	431.52	722.93	729.50	927.22
		(73.38)	(66.71)	(112.91)	(122.54)	(173.61)
	ISD RT	79.22	114.03	138.56	148.47	190.13
		(23.48)	(28.96)	(51.24)	(46.08)	(51.61)

Note. Cells present group means and standard deviations (in parentheses) of the intraindividual means (*IM* RT) and intraindividual standard deviations of RTs (*ISD* RT). SRT: Simple RT task, CRT: Choice RT task, Stroop N: Neutral condition in Color-naming Stroop task, Stroop C: Congruent condition in Color-naming Stroop task, Stroop I: Incongruent condition in Color-naming Stroop task.

Table 3

Response Times by Percentile and Task for Children: Means and (Standard Deviations)

	SRT	CRT	Stroop N	Stroop C	Stroop I
10th percentile	265.92	332.33	605.75	564.09	713.96
	(45.54)	(58.62)	(102.49)	(107.91)	(169.03)
20th percentile	285.77	367.32	671.83	637.06	815.28
	(52.89)	(73.62)	(105.14)	(110.95)	(167.31)
30th percentile	303.18	398.17	717.09	687.70	885.73
	(59.39)	(82.98)	(111.05)	(115.87)	(174.17)
40th percentile	320.57	429.39	758.57	731.13	942.02
	(65.54)	(91.97)	(120.03)	(122.11)	(179.17)
50th percentile	339.20	461.81	800.90	771.89	999.74
	(71.98)	(99.61)	(132.90)	(130.23)	(186.24)
60th percentile	361.14	497.70	849.46	816.16	1060.57
	(77.84)	(109.33)	(149.44)	(141.32)	(196.75)
70th percentile	387.24	542.94	909.20	869.34	1129.64
	(84.19)	(123.82)	(173.58)	(154.58)	(213.35)
80th percentile	422.09	603.09	996.34	941.85	1221.50
	(89.48)	(144.58)	(209.54)	(178.28)	(231.45)
90th percentile	481.3	704.16	1143.26	1071.28	1367.20
	(99.64)	(180.59)	(254.18)	(222.55)	(255.37)

Note. SRT: Simple RT task, CRT: Choice RT task, Stroop N: Neutral condition in Color-naming Stroop task, Stroop C: Congruent condition in Color-naming Stroop task, Stroop I: Incongruent condition in Color-naming Stroop task.

Table 4

Response Times by Percentile and Task for Young Adults: Means and (Standard Deviations)

	SRT	CRT	Stroop N	Stroop C	Stroop I
10th percentile	215.44	251.81	471.35	464.71	541.72
	(26.48)	(23.49)	(73.60)	(83.91)	(112.93)
20th percentile	228.09	266.47	517.17	516.79	610.77
	(30.34)	(26.66)	(69.32)	(80.63)	(101.23)
30th percentile	238.61	279.97	546.27	549.72	654.51
	(34.14)	(30.31)	(67.54)	(79.47)	(94.07)
40th percentile	248.98	293.78	569.55	577.51	687.66
	(37.67)	(33.12)	(67.84)	(77.94)	(94.58)
50th percentile	259.68	309.10	590.41	602.10	716.81
	(39.94)	(37.39)	(70.86)	(81.14)	(99.15)
60th percentile	272.51	326.34	610.86	626.12	746.91
	(42.87)	(41.43)	(74.52)	(83.08)	(104.16)
70th percentile	288.98	346.96	635.27	653.13	781.25
	(46.42)	(46.15)	(79.63)	(87.32)	(109.71)
80th percentile	311.61	373.45	666.60	687.65	826.73
	(49.66)	(52.80)	(87.77)	(91.59)	(119.11)
90th percentile	347.09	419.09	718.92	745.54	901.52
	(55.32)	(62.64)	(106.35)	(106.39)	(134.21)

Note. SRT: Simple RT task, CRT: Choice RT task, Stroop N: Neutral condition in Color-naming Stroop task, Stroop C: Congruent condition in Color-naming Stroop task, Stroop I: Incongruent condition in Color-naming Stroop task.

Table 5

Response Times by Percentile and Task for Older Adults: Means and (Standard Deviations)

	SRT	CRT	Stroop N	Stroop C	Stroop I
10th percentile	253.35	309.23	577.11	561.53	721.58
	(55.74)	(47.11)	(95.32)	(107.20)	(163.27)
20th percentile	272.32	337.52	624.86	617.32	790.13
	(62.46)	(54.09)	(91.79)	(107.02)	(158.20)
30th percentile	287.71	362.89	654.24	655.67	832.13
	(68.24)	(58.46)	(90.97)	(110.61)	(162.55)
40th percentile	302.84	387.55	680.21	685.90	870.37
	(72.79)	(61.83)	(95.02)	(114.45)	(164.43)
50th percentile	318.93	413.24	705.79	716.03	909.20
	(76.29)	(64.48)	(99.49)	(117.21)	(165.53)
60th percentile	336.68	438.55	734.32	747.62	949.87
	(79.83)	(69.22)	(108.40)	(124.46)	(173.58)
70th percentile	359.87	468.81	766.50	785.31	997.08
	(83.45)	(74.68)	(118.68)	(134.53)	(184.69)
80th percentile	391.63	507.67	811.00	834.28	1058.37
	(87.41)	(81.19)	(139.04)	(148.81)	(204.2)
90th percentile	440.00	576.30	889.79	910.95	1167.69
	(99.45)	(96.91)	(174.49)	(168.81)	(231.5)

Note. SRT: Simple RT task, CRT: Choice RT task, Stroop N: Neutral condition in Color-naming Stroop task, Stroop C: Congruent condition in Color-naming Stroop task, Stroop I: Incongruent condition in Color-naming Stroop task.

Table 6

Summary of Hierarchical Regression Analyses of SPM and Reaction Time Distribution Components for each Age Group

Model	Variables	Children		Young Adults		Older Adults	
		R^2	ΔR^2	R^2	ΔR^2	R^2	ΔR^2
1	90th percentiles	.22***	.22***	.14**	.14**	.20***	.20***
	10th percentiles	.25***	.03	.18**	.04	.22**	.01
2	90th percentiles	.22***	.22***	.14**	.14**	.20***	.20***
	50th percentiles	.28***	.07**	.19**	.05	.23**	.03
3	90th percentiles	.22***	.22***	.14**	.14**	.20***	.20***
	IM RTs	.28***	.06*	.18**	.04	.24**	.04
4	90th percentiles	.22***	.22***	.14**	.14**	.20***	.20***
	ISD RTs	.25***	.03	.17***	.03	.24**	.04
5	10th percentiles	.10**	.10**	.04	.04	.12*	.12*
	90th percentiles	.25***	.14***	.18**	.14**	.21**	.09*
6	50th percentiles	.22***	.22***	.08	.08	.20***	.20***
	90th percentiles	.28***	.06**	.19**	.11**	.23**	.04
7	*IM* RTs	.21***	.21***	.09*	.09*	.21***	.21***
	90th percentiles	.27***	.06**	.18**	.09*	.25**	.04
8	*ISD* RTs	.22***	.22***	.12**	.12**	.15**	.15**
	90th percentiles	.24***	.02	.16**	.04	.24**	.08†

Note. SPM = Raven Standard Progressive Matrices. † $p = .051$* $p < .05$, **$p < .01$, ***$p < .001$.

Table 7

Partial Correlations between the 90th Percentiles in RT Tasks and the SPM

	Children	Young Adults	Older Adults
CRT.SPM | SRT	-.193**	-.112	-.378**
Stroop I.SPM | CRT	-.231**	-.152	-.196*
Stroop I.SPM | Stroop C	-.263**	-.153	-.250**
Stroop I.SPM | Stroop N	-.116	.049	-.102

Note. CRT.SPM | SRT refers to the correlation between the Raven Standard Progressive Matrices (SPM) and the 90th percentile in CRT after statistically controlling for the variance in the 90th percentile in SRT. **$p < .01$. *** $p < .001$.

Table 8

Split-half Reliabilities for the 10th Percentiles and 90th Percentiles by Task and Age Group

Task	Variable	Children	Young adults	Older adults
SRT	10th Percentile	.98***	.98***	.99***
	90th Percentile	.95***	.93***	.97***
CRT	10th Percentile	.95***	.96***	.97***
	90th Percentile	.94***	.91***	.94***
Stroop N	10th Percentile	.94***	.94***	.94***
	90th Percentile	.95***	.96***	.96***
Stroop C	10th Percentile	.95***	.95***	.97***
	90th Percentile	.94***	.96***	.98***
Stroop I	10th Percentile	.93***	.94***	.96***
	90th Percentile	.96***	.95***	.97***

Note. SRT: Simple RT task, CRT: Choice RT task, Stroop N: Neutral condition in Color-naming Stroop task, Stroop C: Congruent condition in Color-naming Stroop task, Stroop I: Incongruent condition in Color-naming Stroop task. *** $p < .001$.

Figure 1. Correlations between successive percentiles in the 5 RT tasks and SPM in children

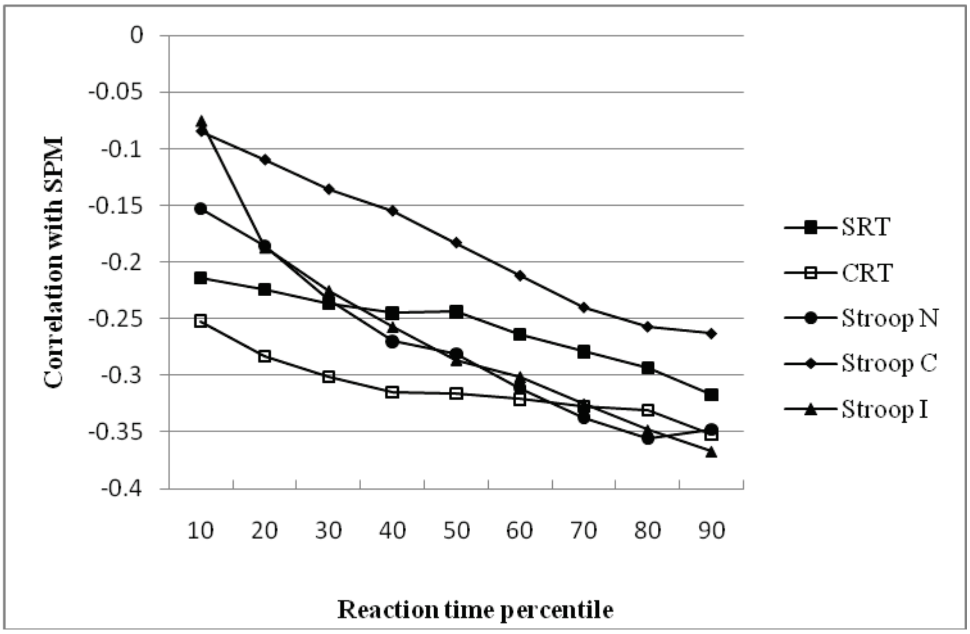


Figure 2. Correlations between successive percentiles in the 5 RT tasks and SPM in young adults

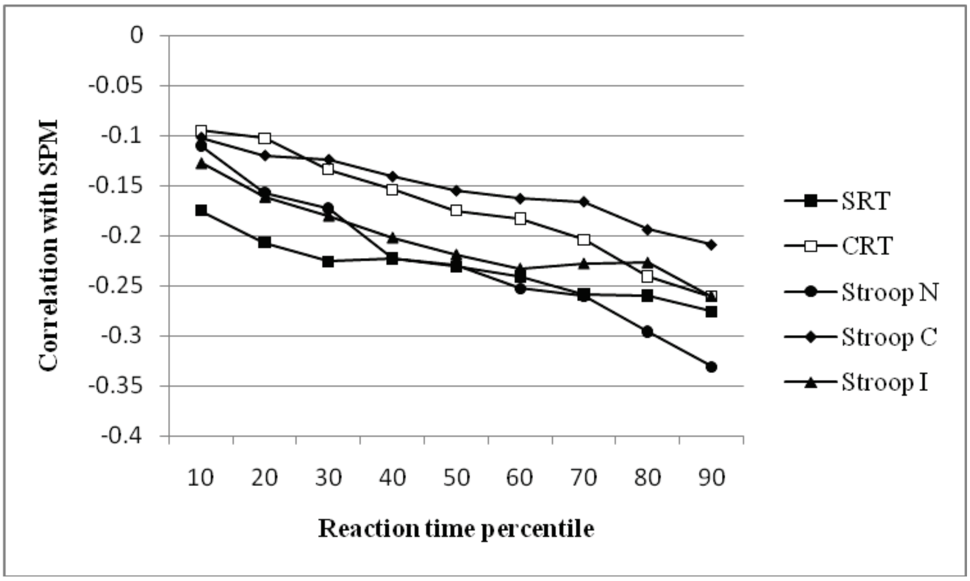
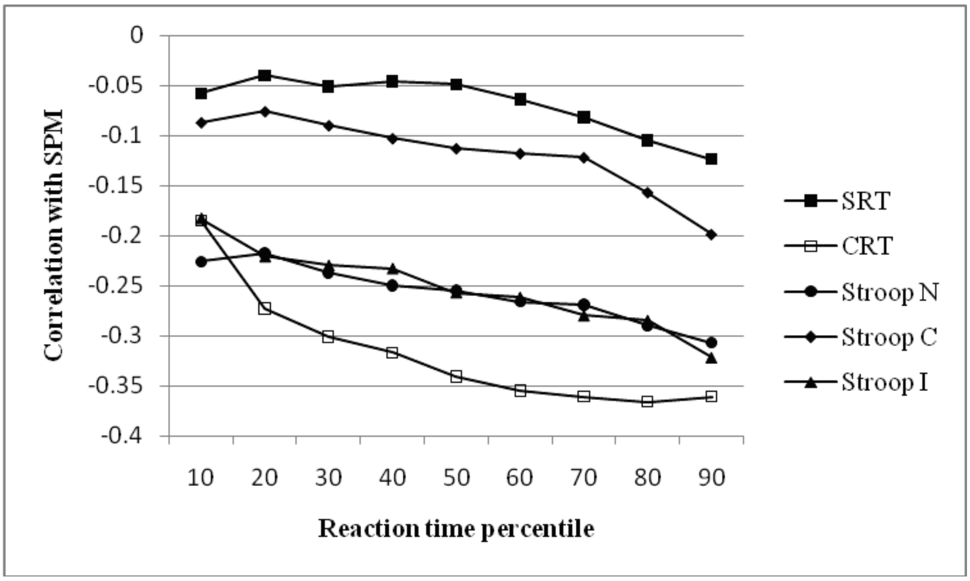


Figure 3. Correlations between successive percentiles in the 5 RT tasks and SPM in older adults



Appendix A

Complete Correlation Matrix for all RT Indices and SPM in Children. Decimal Points Omitted

		1	2	3	4	5	6	7	8	9	10	11	12	13
1	SRT 10th percentile		94	77	92	32	58	51	47	53	36	16	28	25
2	SRT 50th percentile	94		91	99	54	61	60	58	62	48	20	35	35
3	SRT 90th percentile	77	91		94	79	55	62	65	64	59	27	43	46
4	SRT *IM* RT	92	99	94		62	61	61	60	63	51	22	37	38
5	SRT *ISD* RT	32	54	79	62		31	48	55	50	55	18	35	44
6	CRT 10th percentile	58	61	55	61	31		90	76	89	52	22	37	32
7	CRT 50th percentile	51	60	62	61	48	90		93	99	76	22	42	43
8	CRT 90th percentile	47	58	65	60	55	76	93		96	91	22	43	49
9	CRT *IM* RT	53	62	64	63	50	89	99	96		82	23	43	45
10	CRT *ISD* RT	36	48	59	51	55	52	76	91	82		18	37	46
11	Stroop C 10th percentile	16	20	27	22	18	22	22	22	23	18		86	68
12	Stroop C 50th percentile	28	35	43	37	35	37	42	43	43	37	86		90
13	Stroop C 90th percentile	25	35	46	38	44	32	43	49	45	46	68	90	
14	Stroop C *IM* RT	27	34	43	36	37	34	41	44	42	39	86	99	94
15	Stroop C *ISD* RT	20	30	39	32	43	25	39	47	41	49	25	60	84
16	Stroop N 10th percentile	16	21	28	23	22	19	20	21	21	18	91	83	68
17	Stroop N 50th percentile	27	36	45	38	40	30	36	40	38	37	80	92	87
18	Stroop N 90th percentile	25	34	46	38	46	29	39	46	42	46	62	83	88
19	Stroop N *IM* RT	25	34	44	36	42	28	36	41	38	40	78	90	88
20	Stroop N *ISD* RT	18	28	39	31	47	22	35	44	38	47	30	60	75
21	Stroop I 10th percentile	13	17	23	18	18	15	16	19	18	16	87	80	67
22	Stroop I 50th percentile	22	30	41	34	40	25	35	41	37	40	74	89	88
23	Stroop I 90th percentile	18	26	39	30	43	24	35	42	37	43	62	80	87
24	Stroop I *IM* RT	21	28	39	32	39	24	33	39	35	39	77	89	88
25	Stroop I *ISD* RT	11	18	29	22	41	17	30	38	32	42	5	35	57
26	SPM	-20	-23	-32	-28	-37	-23	-31	-35	-33	-37	-5	-15	-25

		14	15	16	17	18	19	20	21	22	23	24	25	26
1	SRT 10th percentile	27	20	16	27	25	25	18	13	22	18	21	11	-20
2	SRT 50th percentile	34	30	21	36	34	34	28	17	30	26	28	18	-23
3	SRT 90th percentile	43	39	28	45	46	44	39	23	41	39	39	29	-

														32
4	SRT *IM* RT	36	32	23	38	38	36	31	18	34	30	32	22	-28
5	SRT *ISD* RT	37	43	22	40	46	42	47	18	40	43	39	41	-37
6	CRT 10th percentile	34	25	19	30	29	28	22	15	25	24	24	17	-23
7	CRT 50th percentile	41	39	20	36	39	36	35	16	35	35	33	30	-31
8	CRT 90th percentile	44	47	21	40	46	41	44	19	41	42	39	38	-35
9	CRT *IM* RT	42	41	21	38	42	38	38	18	37	37	35	32	-33
10	CRT *ISD* RT	39	49	18	37	46	40	47	16	40	43	39	42	-37
11	Stroop C 10th percentile	86	25	91	80	62	78	30	87	74	62	77	5	-5
12	Stroop C 50th percentile	99	60	83	92	83	90	60	80	89	80	89	35	-15
13	Stroop C 90th percentile	94	84	68	87	88	88	75	67	88	87	88	57	-25
14	Stroop C *IM* RT		67	83	93	86	92	64	80	91	84	92	40	-18
15	Stroop C *ISD* RT	67		31	61	76	65	83	28	66	74	65	75	-30
16	Stroop N 10th percentile	83	31		86	68	85	36	86	77	67	80	13	-13
17	Stroop N 50th percentile	93	61	86		92	99	71	77	90	85	91	45	-26
18	Stroop N 90th percentile	86	76	68	92		95	90	60	87	89	87	64	-33
19	Stroop N *IM* RT	92	65	85	99	95		77	75	91	88	92	50	-28
20	Stroop N *ISD* RT	64	83	36	71	90	77		32	70	79	69	77	-34
21	Stroop I 10th percentile	80	28	86	77	60	75	32		78	64	82	0	-5
22	Stroop I 50th percentile	91	66	77	90	87	91	70	78		93	99	54	-25
23	Stroop I 90th percentile	84	74	67	85	89	88	79	64	93		95	75	-34
24	Stroop I *IM* RT	92	65	80	91	87	92	69	82	99	95		53	-25
25	Stroop I *ISD* RT	40	75	13	45	64	50	77	0	54	75	53		-38
26	SPM	-18	-30	-13	-26	-33	-28	-34	-5	-25	-34	-25	-38	

Appendix B

Complete Correlation Matrix for all RT Indices and SPM in Young Adults. Decimal Points Omitted

		1	2	3	4	5	6	7	8	9	10	11	12	13
1	SRT 10th percentile		94	78	92	25	53	59	60	61	44	45	49	51
2	SRT 50th percentile	94		88	98	39	53	62	64	64	49	46	52	54
3	SRT 90th percentile	78	88		94	67	45	58	64	61	56	39	48	52
4	SRT *IM* RT	92	98	94		52	51	62	66	64	53	46	53	56
5	SRT *ISD* RT	25	39	67	52		9	22	34	26	42	23	31	36
6	CRT 10th percentile	53	53	45	51	9		91	76	90	46	23	35	33
7	CRT 50th percentile	59	62	58	62	22	91		91	98	63	32	45	45
8	CRT 90th percentile	60	64	64	66	34	76	91		95	81	34	47	47
9	CRT *IM* RT	61	64	61	64	26	90	98	95		73	32	46	46
10	CRT *ISD* RT	44	49	56	53	42	46	63	81	73		25	34	36
11	Stroop C 10th percentile	45	46	39	46	23	23	32	34	32	25		81	69
12	Stroop C 50th percentile	49	52	48	53	31	35	45	47	46	34	81		94
13	Stroop C 90th percentile	51	54	52	56	36	33	45	47	46	36	69	94	
14	Stroop C *IM* RT	52	54	49	55	31	33	44	46	45	34	85	99	95
15	Stroop C *ISD* RT	31	33	35	35	26	21	28	28	29	24	0	44	65
16	Stroop N 10th percentile	46	47	40	47	24	25	33	35	34	28	92	76	67
17	Stroop N 50th percentile	53	56	53	58	35	41	51	54	53	43	76	92	86
18	Stroop N 90th percentile	52	55	51	56	33	39	49	51	50	42	63	82	85
19	Stroop N *IM* RT	54	57	52	58	34	39	48	51	50	42	79	90	87
20	Stroop N *ISD* RT	28	31	34	34	31	24	32	37	34	34	12	45	57
21	Stroop I 10th percentile	35	36	32	36	22	14	21	26	22	22	88	73	64
22	Stroop I 50th percentile	41	45	41	46	26	28	36	41	38	33	65	83	81
23	Stroop I 90th percentile	40	43	40	44	25	25	33	38	36	34	56	77	79
24	Stroop I *IM* RT	42	45	40	46	26	25	33	38	35	32	72	84	82
25	Stroop I *ISD* RT	17	20	20	21	14	15	21	25	23	27	-10	28	41
26	SPM	-17	-21	-26	-24	-24	-11	-16	-25	-20	-26	-10	-15	-18

		14	15	16	17	18	19	20	21	22	23	24	25	26
1	SRT 10th percentile	52	31	46	53	52	54	28	35	41	40	42	17	-17
2	SRT 50th percentile	54	33	47	56	55	57	31	36	45	43	45	20	-21

3	SRT 90th percentile	49	35	40	53	51	52	34	32	41	40	40	20	-26
4	SRT *IM* RT	55	35	47	58	56	58	34	36	46	44	46	21	-24
5	SRT *ISD* RT	31	26	24	35	33	34	31	22	26	25	26	14	-24
6	CRT 10th percentile	33	21	25	41	39	39	24	14	28	25	25	15	-11
7	CRT 50th percentile	44	28	33	51	49	48	32	21	36	33	33	21	-16
8	CRT 90th percentile	46	28	35	54	51	51	37	26	41	38	38	25	-25
9	CRT *IM* RT	45	29	34	53	50	50	34	22	38	36	35	23	-20
10	CRT *ISD* RT	34	24	28	43	42	42	34	22	33	34	32	27	-26
11	Stroop C 10th percentile	85	0	92	76	63	79	12	88	65	56	72	-10	-10
12	Stroop C 50th percentile	99	44	76	92	82	90	45	73	83	77	84	28	-15
13	Stroop C 90th percentile	95	65	67	86	85	87	57	64	81	79	82	41	-18
14	Stroop C *IM* RT		46	80	91	84	92	46	77	83	78	86	26	-16
15	Stroop C *ISD* RT	46		2	41	56	41	76	5	48	56	44	69	-19
16	Stroop N 10th percentile	80	2		80	68	85	14	87	67	60	74	-5	-12
17	Stroop N 50th percentile	91	41	80		92	98	55	71	86	81	86	34	-22
18	Stroop N 90th percentile	84	56	68	92		94	75	62	85	85	85	50	-30
19	Stroop N *IM* RT	92	41	85	98	94		58	76	86	82	88	33	-23
20	Stroop N *ISD* RT	46	76	14	55	75	58		14	56	64	53	73	-28
21	Stroop I 10th percentile	77	5	87	71	62	76	14		72	63	81	-10	-13
22	Stroop I 50th percentile	83	48	67	86	85	86	56	72		95	98	49	-20
23	Stroop I 90th percentile	78	56	60	81	85	82	64	63	95		95	65	-23
24	Stroop I *IM* RT	86	44	74	86	85	88	53	81	98	95		43	-20
25	Stroop I *ISD* RT	26	69	-5	34	50	33	73	-10	49	65	43		-17
26	SPM	-16	-19	-12	-22	-30	-23	-28	-13	-20	-23	-20	-17	

Appendix C

Complete Correlation Matrix for all RT Indices and SPM in Older Adults. Decimal Points Omitted

		1	2	3	4	5	6	7	8	9	10	11	12	13
1	SRT 10th percentile		94	77	93	27	52	40	29	40	10	10	16	17
2	SRT 50th percentile	94		89	99	47	56	47	37	47	16	14	21	24
3	SRT 90th percentile	77	89		93	77	53	50	43	50	23	19	28	29
4	SRT *IM* RT	93	99	93		55	57	50	40	50	19	15	23	26
5	SRT *ISD* RT	27	47	77	55		33	43	46	43	36	14	25	31
6	CRT 10th percentile	52	56	53	57	33		91	78	91	43	37	42	47
7	CRT 50th percentile	40	47	50	50	43	91		91	99	63	33	40	47
8	CRT 90th percentile	29	37	43	40	46	78	91		95	83	33	45	54
9	CRT *IM* RT	40	47	50	50	43	91	99	95		71	35	45	53
10	CRT *ISD* RT	10	16	23	19	36	43	63	83	71		20	37	49
11	Stroop C 10th percentile	10	14	19	15	14	37	33	33	35	20		87	73
12	Stroop C 50th percentile	16	21	28	23	25	42	40	45	45	37	87		93
13	Stroop C 90th percentile	17	24	29	26	31	47	47	54	53	49	73	93	
14	Stroop C *IM* RT	16	22	28	24	27	45	43	48	47	39	88	99	95
15	Stroop C *ISD* RT	18	26	30	27	34	38	42	49	47	50	19	53	77
16	Stroop N 10th percentile	16	18	26	21	23	41	38	38	40	26	91	78	66
17	Stroop N 50th percentile	18	25	36	28	38	53	54	54	56	42	78	82	78
18	Stroop N 90th percentile	21	29	39	32	41	55	58	58	61	50	64	73	78
19	Stroop N *IM* RT	20	26	36	30	38	54	56	56	58	44	78	81	79
20	Stroop N *ISD* RT	15	23	31	26	38	43	50	52	52	51	26	44	60
21	Stroop I 10th percentile	15	19	29	22	29	40	41	44	45	38	82	76	69
22	Stroop I 50th percentile	12	19	31	23	37	40	44	48	48	44	72	78	79
23	Stroop I 90th percentile	12	20	30	23	38	38	44	48	47	46	61	69	75
24	Stroop I *IM* RT	13	19	31	23	36	40	44	49	48	45	75	79	79
25	Stroop I *ISD* RT	5	12	19	14	31	19	26	31	28	35	1	24	41
26	SPM	2	0	-6	-2	-17	-25	-35	-37	-36	-34	-12	-16	-22

		14	15	16	17	18	19	20	21	22	23	24	25	26
1	SRT 10th percentile	16	18	16	18	21	20	15	15	12	12	13	5	2
2	SRT 50th percentile	22	26	18	25	29	26	23	19	19	20	19	12	0
3	SRT 90th percentile	28	30	26	36	39	36	31	29	31	30	31	19	-6
4	SRT *IM* RT	24	27	21	28	32	30	26	22	23	23	23	14	-2
5	SRT *ISD* RT	27	34	23	38	41	38	38	29	37	38	36	31	-17

6	CRT 10th percentile	45	38	41	53	55	54	43	40	40	38	40	19	-25
7	CRT 50th percentile	43	42	38	54	58	56	50	41	44	44	44	26	-35
8	CRT 90th percentile	48	49	38	54	58	56	52	44	48	48	49	31	-37
9	CRT *IM* RT	47	47	40	56	61	58	52	45	48	47	48	28	-36
10	CRT *ISD* RT	39	50	26	42	50	44	51	38	44	46	45	35	-34
11	Stroop C 10th percentile	88	19	91	78	64	78	26	82	72	61	75	1	-12
12	Stroop C 50th percentile	99	53	78	82	73	81	44	76	78	69	79	24	-16
13	Stroop C 90th percentile	95	77	66	78	78	79	60	69	79	75	79	41	-22
14	Stroop C *IM* RT		57	80	83	76	83	48	78	81	73	82	27	-17
15	Stroop C *ISD* RT	57		16	43	59	47	71	26	51	58	49	64	-27
16	Stroop N 10th percentile	80	16		87	75	88	34	87	79	69	82	11	-19
17	Stroop N 50th percentile	83	43	87		93	99	66	82	88	81	88	38	-28
18	Stroop N 90th percentile	76	59	75	93		96	85	75	90	88	89	56	-32
19	Stroop N *IM* RT	83	47	88	99	96		72	84	91	85	91	42	-30
20	Stroop N *ISD* RT	48	71	34	66	85	72		42	69	75	66	75	-31
21	Stroop I 10th percentile	78	26	87	82	75	84	42		88	77	90	13	-19
22	Stroop I 50th percentile	81	51	79	88	90	91	69	88		94	99	50	-26
23	Stroop I 90th percentile	73	58	69	81	88	85	75	77	94		95	70	-33
24	Stroop I *IM* RT	82	49	82	88	89	91	66	90	99	95		49	-27
25	Stroop I *ISD* RT	27	64	11	38	56	42	75	13	50	70	49		30
26	SPM	-17	-27	-19	-28	-32	-30	-31	-19	-26	-33	-27	-30	