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Dispersion in cognitive functioning: Age differences over the lifespan

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ABSTRACT

Introduction: A growing body of research suggests that intraindividual variability (IIV) may bring specific information on cognitive functioning, additional to that provided by the mean. The present paper focuses on dispersion, that is IIV across tasks, and its developmental trend across the lifespan. *Method*: A total of 557 participants (9–89 years) were administered a battery of response time (RT) tasks and of working memory (WM) tasks. Dispersion was analyzed separately for the two types of tasks. *Results*: Dispersion across RT tasks showed a U-shaped age differences trend, young adults being less variable than both children and older adults. Dispersion across WM tasks (using accuracy scores) presented an opposite developmental trend. A cluster analysis revealed a group of individuals showing relatively little dispersion and good overall performance (faster in RTs and better in WM), contrasted with a group of individuals showing a large dispersion in the RT tasks as well as poorer overall performance. All young adults were grouped in the first cluster; children and older adults were distributed in both clusters. *Conclusion*: It is concluded that (a) across-task IIV is relatively large in the entire sample and should not be neglected, (b) children and older adults show a larger dispersion than young adults, but only as far as the RT tasks are concerned, (c) variability in RTs and variability in WM performance do not reflect the same phenomenon.

There is growing evidence in the literature that within-person fluctuations in cognitive performance do not reduce to error variance, but may on the contrary constitute a meaningful indicator of individual differences in cognitive functioning (e.g., de Ribaupierre, 2015; de Ribaupierre et al., 2013; Nesselroade & Salthouse, 2004; Salthouse, 2012; Salthouse & Soubelet, 2014). Intraindividual variability (IIV) can be defined either in terms of within-task transient changes of performance (fluctuations in performance), or in terms of heterogeneity in performance level across multiple tasks administered within a single session or several sessions close in time. The former is termed inconsistency, while the latter refers to dispersion or heterogeneity (MacDonald, Hultsch, & Bunce, 2006). The present paper focuses on dispersion within two sets of abilities and scores, namely processing speed and working memory, in children, young adults, and older adults. More

specifically, we addressed the question of whether and how heterogeneity of cognitive profiles differs with age across the lifespan with respect to reaction times (RTs), on the one hand, and number of recalled items in working memory (WM), on the other hand.

Cognitive heterogeneity has been little studied in developmental psychology, except for very recent studies (see below). It has often been relegated to applied domains, in particular to the field of intelligence testing. A frequent, even if implicit, postulate is that typically functioning individuals should show a homogeneous performance and that heterogeneity is the sign of dysfunctioning. This assumption is due to an overall reliance on mean performance, as well as to the dominant use of univariate designs. For instance, when three studies, each relying on the administration of a single task, show that, on average, the acquisition of three concepts (or of a given type of behavior) is around

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age 9, most researchers will expect that an average 9-year-old will present this behavior on the three tasks; if the child does not, it is frequently concluded that he or she is delayed (advanced) in one of the tasks. Yet, it is to be noted that the three tasks have not been administered to the same children. In older work, using Piagetian-like tasks, de Ribaupierre, Rieben, and Lautrey showed that intraindividual "decalages" (that is, within-individual temporal delays in developing concepts supposed to be at the same complexity level), rather than synchronism, were the rule (e.g., de Ribaupierre, 1993; de Ribaupierre, Rieben, & Lautrey, 1991; Lautrey, de Ribaupierre, & Rieben, 1985). In particular, some of these decalages were in different directions for different children, which clearly points to interindividual differences of a qualitative nature in the developmental trends. Indeed, if Child A shows a more advanced behavior in Task 1 than in Task 2, and if Child B presents the opposite pattern (higher level in Task 2 than in Task 1), this implies that these two children follow different developmental paths. Wohlwill (1973/2013) already long ago stressed the importance to distinguish between the development of a function and the development of an individual.

Even within studies relying on a multivariate design, the focus has often been placed on mean age group differences and on the independence of various functions, based on correlations, rather than on the intraindividual dispersion. The study of dispersion (or of IIV altogether) has often been reserved to applied issues, such as intelligence testing. The motivation is obvious: It is important to assess whether an individual presents a deficit (or, more rarely an advance) in a specific domain, and/or whether the heterogeneity he or she presents is in the norms. A number of applied scientists have argued for quite some time that a profile analysis in intelligence tests such as the Wechsler scales is more fruitful than relying on a global IQ score (Grégoire, 2009; Kaufman, 1979; Mayes & Calhoun, 2004). In this case, and often unknown of the practitioners, it has been shown that IIV is very high, even in the standardization samples. For instance, the average difference between the lowest and the highest score in the WISC is close to 7 or 8 points in school-age children, which represents more than two standard deviations at the group level (the average scaled score in the Wechsler scales is 10, with a standard deviation of 3;

Wechsler, 2000). Most clinicians would of course accept some variation in the Wechsler scores as normal, but would consider that it should not exceed 3 or 4 points (Kaufman, 1979, p. 196). Consequently, they would regard a difference of 7 or 8 points as highly heterogeneous, even pathological, whereas it is the norm.

When studied, IIV has been largely neglected in developmental studies and mostly explored in pathological populations, including in children with attention deficit hyperactivity disorder (ADHD; Castellanos, Sonuga-Barke, Milham, & Tannock, 2006; Fair, Bathula, Nikolas, & Nigg, 2012), Williams syndrome (Porter & Coltheart, 2005), and autism (Mayes & Calhoun, 2008); in adults with schizophrenia (Goldstein, 1990; Joyce, Hutton, Mutsatsa, & Barnes, 2005), or trauma (Stuss, Pogue, Buckle, & Bondar, 1994); or in neurological pathologies such as dementia, Alzheimer or Parkinson diseases (Holtzer, Verghese, Wang, Hall, & Lipton, 2008; Kehagia, Barker, & Robbins, 2010; Morgan, Woods, Delano-Wood, Bondi, & Grant, 2011; Morgan, Woods, & Grant, 2012; Morgan, Woods, Rooney, et al., 2012). In consequence, little is known concerning age differences in dispersion from a lifespan perspective. And yet, it may provide important additional information about typical cognitive development and aging. Age differences in across-task intraindividual variability might, for example, be indicative of qualitative differences in terms of cognitive processes underlying the tasks, or of neurophysiological differences at the basis of these processes. The goal of the present paper was to provide a descriptive view of age differences in dispersion across lifespan.

In children, apart from the field of intelligence testing, once again explored to characterize pathological subgroups, dispersion in cognitive abilities has been scarcely studied. A recent study explored IIV across a set of cognitive and motor abilities in an impressively large sample of children and young adults aged 8 to 21 years (Roalf et al., 2014), using standard deviation as an index of IIV. Dispersion was the largest in the youngest children, decreased with age, and increased again from 14 years to 21 years of age. Young adults were, however, not as variable as the young children.

Studies concerning dispersion in healthy aging are also relatively rare. Ardila (2007) investigated whether dispersion in the Wechsler Adult Intelligence Scale–Third Edition (WAIS–III;

Wechsler, 2000) subtests, analyzed with a coefficient of variation, differed at different ages. The author observed a higher dispersion in older adults in the subtests measuring reasoning and attention. However, no inferential statistical analyses were reported in this report. Using a standard deviation method, Salthouse and Soubelet (2014) showed recently that older adults presenting a cognitive decline across an average interval of three years had a more heterogeneous profile of cognitive abilities than those who remained stable; conversely, those older adults presenting a larger IIV at the first assessment also showed a larger decline. These results are consistent with previous reports of larger within-person standard deviations at older ages (Christensen et al., 1994; Hilborn, Strauss, Hultsch, & Hunter, 2009).[1] Exploring dispersion in adults over 65, Hilborn and colleagues (2009) showed increased dispersion in the oldest individuals and in individuals having experienced cognitive decline. In that study, an ipsative approach was used, that is individual's performance in a given task was compared to the same individual's mean performance across tasks. Other studies have explored dispersion in diverse cognitive domains using cluster analyses (Gunstad et al., 2006; Mitrushina, Uchiyama, & Satz, 1995; Sylvain-Roy & Belleville, 2014). Sylvain-Roy and Belleville (2014) investigated IIV in attentional control functions (shifting, updating, and inhibition) in both young and older adults. They observed three clusters in both young and older adults, but these clusters were qualitatively different for the two groups. Young adults differed among themselves essentially in terms of mean level of performance (high, intermediate, and low) but their profile was globally homogeneous. In contrast, older adults showed a large dispersion that was driven either by inhibition (high or low) or by updating, the latter function being clearly different from the other two functions. Using a similar method to explore age-related differences in speed abilities, executive functions, and memory, Gunstad et al. (2006) observed two heterogeneous clusters out of three in both middle-aged and older adults. These studies have thus identified clusters composed of overall high- or low-performing individuals, but also subgroups showing relative strengths or weaknesses, suggesting that aging does not impact individuals in a uniform manner across domains.

In summary, there is some evidence that dispersion changes with age and is larger in children and in older adults. However, empirical evidence remains scarce. Moreover, little is known with respect to age-related differences in dispersion across the entire lifespan, that is from childhood to older adulthood using the same tasks. In addition, with the exception of Sylvain-Roy and Belleville (2014), previous studies focused on heterogeneity across a broad range of cognitive abilities, including executive control, episodic memory, reasoning, social cognition, sensorimotor speed, working memory, abstract reasoning, verbal abilities, and spatial abilities. One might also consider dispersion within a narrower set of cognitive functions; in this case, a high level of dispersion would not necessarily reflect strengths or weaknesses in particular cognitive domains but indicate fluctuations of performance within a given ability. Assessing heterogeneity in typical (normal) development is essential for neuropsychologists, as it will contribute to a more complete interpretive framework, making it possible to better identify dysfunctioning cognitive profiles at different moments of life. In addition, it will provide descriptive bases in the understanding of the rate of change of cognitive processes at different moments of life. For example, a higher level of dispersion in children than in young adults might indicate a "decalage" of maturation in the underlying processes.

In the present study, our objective was to explore age differences in dispersion in a set of cognitive tasks from a lifespan perspective. In a first step, we aimed at determining age differences in IIV in processing speed measures and working memory measures, in terms of amplitude of dispersion. There were a number of reasons why we thought that IIV might differ in these two broad sets of tasks. In particular, they do not rely on the same kind of measure, processing speed being assessed using reaction times (RTs) and working memory with accuracy measure (number of recalled items). Also, age differences in within-task IIV (inconsistency) are somewhat more firmly empirically supported in RTs; a number of authors

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[1]Yet, Salthouse and Soubelet (2014) did not observe a link between IIV and age in not-at-risk individuals and therefore suggest that IIV may be indicative of impending pathological aging.

have failed to observe such IIV in accuracy measures (de Ribaupierre, 2015; Robertson, Myerson, & Hale, 2006; Salthouse, 2012). Moreover, there is some evidence in the literature that processing speed and working memory develop independently—correlations are moderate, or two-factor models are more adequate—although concurrently in childhood (de Ribaupierre, Fagot, & Lecerf, 2011; Luna, Garver, Urban, Lazar, & Sweeney, 2004; Mella, Fagot, Lecerf, & de Ribaupierre, 2015).

Considering the few developmental and aging studies of dispersion mentioned above, our expectation was that children's and older adults' profiles would be more heterogeneous than young adults' profiles. Precise predictions concerning dispersion within each of the two domains were difficult to formulate. Because altogether there is more evidence of IIV with respect to RTs, we envisioned with more certitude the presence of variation in dispersion with age in the processing speed tasks than in the WM tasks. It could be argued, however, that the enduring hypothesis of differentiation–dedifferentiation across the lifespan would lead to a prediction of an inverse trend in age differences —that is, a larger dispersion in young adults. According to this hypothesis (Baltes, Staudinger, & Lindenberger, 1999; H. E. Garrett, 1946; Morse, 1993), the importance of a general factor is more important in children and in older adults, pointing to more resemblance across various cognitive functions, than in young adults. In young adults, because the cognitive functions would be more differentiated, greater specificity would be observed, which might result in greater dispersion. This mechanism of differentiation–dedifferentiation is usually coupled with the hypothesis of an increase in interindividual differences with age (from childhood to older adulthood). It should first be stressed that the general hypothesis of differentiation–dedifferentiation is based on the

existence of age differences in correlations across tasks, that is it relies on interindividual differences, and does not speak to the issue of amplitude in dispersion per se. Second, this hypothesis is not firmly backed up by empirical data. Therefore, we continue favoring the hypothesis that variability should be higher in children and older adults, at least as concerns RTs. In a second step, we aimed at identifying general profiles of dispersion and at exploring whether these profiles present different characteristics.

Method

Participants

The sample consisted of 557 participants, distributed into five age groups: 100 children aged from 9 to 10 years (mean = 9.5, SD = .50), 101 participants aged from 11 to 12 years (mean = 11.49, SD = .50), 137 young adults aged from 18 to 30 years (mean = 21.71, SD = 2.53), 117 older adults aged from 59 to 69 years (mean = 64.90, SD = 2.64), and 102 participants aged 70 to 89 years (mean = 76.22, SD = 4.61). Eighteen participants were discarded from the analyses because they did not complete the entire protocol. A description of the final sample (N = 539) is provided in Table 1.

Children were recruited from urban primary schools in Geneva with the authorization of the Department of Public Instruction of the Canton of Geneva. The young adults were undergraduate psychology students at the University of Geneva, participating for course credit. The older adults were volunteers recruited from the community, either from the University of the Third Age of Geneva or through newspaper and association advertisements for pensioners. All participants

Table 1. Sample characteristics.

Characteristic	C1 (n = 100) (38% female)		C2 (n = 99) (55% female)		YA (n = 136) (85% female)		OA1 (n = 111) (76% female)		OA2 (n = 93) (76% female)	
	M	SD	M	SD	M	SD	M	SD	M	SD
Age (years)	9.50	0.50	11.50	0.50	21.71	2.53	64.94	2.59	76.33	4.53
Education (years)	—	—	—	—	13.5	2.12	12.11	3.54	11.03	2.94
Fluid intelligence[a]	34.14	8.39	39.79	6.89	52.12	4.91	39.78	7.25	32.76	9.43
Vocabulary score[b]	—	—	—	—	34.67	3.26	38.15	4.34	37.3	4.84

Note. M = group's mean; SD = group's standard deviation; C1 = younger group of children; C2 = older group of children; YA = young adults; OA1 = younger group of older adults; OA2 = older group of older adults.
[a]Fluid intelligence measured by the Progressive Matrices (Raven, 1938). [b]Level of vocabulary measured by the Mill Hill (Deltour, 1993).

were native French speakers or fluent in French and had normal or corrected-to-normal vision.

The study was approved by the ethical committee of the Faculty of Psychology and educational sciences of the University of Geneva. All participants gave written informed consent, and older adults received a small amount of money as a compensation for their transportation costs.

Materials and procedure

Both young and older adults were administered the same battery of tasks (Mella et al., 2015) in our laboratory during two sessions, one week apart. An additional session was sometimes necessary for older adults to complete the entire battery of tasks. Sessions lasted about 1.5 hours. Children were evaluated in a quiet room of their school, during school hours. They were administered the same tasks as adults during four or five sessions lasting about 45 min, distributed over 2–3 weeks. All tasks were individually administered on a DELL computer, using E-prime (Schneider, Eschman, & Zuccolotto, 2002), in the same order for each participant to facilitate interindividual comparisons of intraindividual variability.

Processing speed

Seven tasks of varying complexity were used to assess the speed of processing. A complete description of the tasks (except for the Arrow task) is provided in Mella et al. (2015); they are only briefly summarized here. In the simple reaction time (SRT) task, adapted from Hultsch, MacDonald, Hunter, Levy-Bencheton, and Strauss (2000), participants had to press a button as quickly as possible when a target appeared in one of five positions. Two choice reaction time tasks were presented: the Lines Judgment (LI) task, adapted from Vernon (1987), in which participants had to rapidly decide which of two vertical lines was longer; and the Cross-Square (CS) task (Hultsch et al., 2000), in which participants were presented two groups of three crosses and had to detect on which side one of the crosses changed into a square. Two complex visual processing tasks were presented: an adaptation of the Wechsler Digit Symbol task (DI; adapted from Salthouse & Berish, 2005), in which participants had to determine whether a symbol–number pair was similar to a reference

matrix presented in the upper part of the screen, and the Letter Comparison (LC) task (Salthouse & Prill, 1987), in which two series of letters (consisting of six, LC6, or nine, LC9, consonants) were presented, and participants had to decide whether they were identical or not. Finally, two tasks classically used as a measure of resistance to interference were given: an adaptation of the Stroop Color Word task (ST; Stroop, 1935) and the Arrow task (AT). In the Stroop task, participants had to name the color of words or symbols presented on a screen. Three conditions were given: neutral (symbols), congruent (e.g., blue written in blue), and incongruent (e.g., blue written in red). The Arrow task (Salthouse, Toth, Hancock, & Woodard, 1997) consisted of right (→) and left (←) pointing arrows presented along the medial-horizontal axis of the computer screen in one of three locations: left, right, or center. This resulted into three experimental conditions (congruent, incongruent, and neutral) defined by the relationship between the location and direction of each arrow (same, opposite, or center, respectively). Participants were required to indicate the direction to which the arrow pointed, using a two-button device (left/right). In total, processing speed was analyzed across 12 conditions assessing RTs.

Working memory (WM)

Two tasks were used for WM assessment, also described in detail in Mella et al. (2015): one verbal (the Reading Span test, RS; de Ribaupierre & Bailleux, 1995; de Ribaupierre, Ghisletta, & Lecerf, 2006; Robert, Borella, Fagot, Lecerf, & De Ribaupierre, 2009) and one presenting both a verbal and a visuospatial component (the Matrices task; de Ribaupierre, et al., 2006; Lecerf & de Ribaupierre, 2005). In both tasks, the difficulty level was adjusted to the participant's memory span (n) assessed beforehand. In the RS task, participants were instructed to read a series of sentences (from 2 to 7, depending on the participants' n span) on the computer screen and to decide whether each sentence was semantically correct or not. In parallel, they were asked to memorize the final word of each sentence and to orally recall all of them at the end of the series. There were two conditions: level n (RSn) and level $n+1$ (RSn1), each consisting of 12 trials. The score used in the

present study was the mean number of correctly recalled words by condition.

In the Matrices task, a 5×5 grid containing some cells that either were blackened (visuospatial condition) or contained words (verbal–spatial condition) was presented to the participants. In the visuospatial condition, participants had to recall the position of the black cells and to replace them on a blank grid by touching the screen. In the verbal–spatial condition, participants had to recall both the words and their positions. The visuospatial test comprised two conditions: level n (SPn) and level $n+1$ (SPn1); and the verbal–spatial condition comprised two conditions for the positions and two conditions for the words: level $n+1$ (MDPn1, MDWn1) and level $n+2$ (MDPn2, MDWn2). The score used here was the mean number of correctly recalled positions or words.

In addition to these tasks, measures of fluid (Raven Progressive Matrices; Raven, 1938) and crystallized (Mill Hill Vocabulary Test; Deltour, 1993) abilities were assessed. Both WM and RT tasks were spread out in the different testing sessions in order to ensure that heterogeneity of performance was not related to the day of testing.[2]

Analyses

Data preparation for RTs

Only RTs for correct responses were considered. They were trimmed as follows: extremely fast responses (RTs below 150 ms for SRT, LI, and CS tasks; 200 ms for ST and AT; and 500 ms for LC and DI tasks) and extremely slow responses (RTs above 1000 ms for SRT, 1500 ms for LI and CS tasks; 2000 ms for inhibition tasks; 5000 ms for LC and 12,000 ms for the DI task) were removed.[3] Cleaning of the data resulted in an average loss of 1.06% of the data (0.003% to 3.79% depending on the task and the age group).

Measures of within-person variability

Individual means (iMs)[4] were computed for each task separately and for each condition when necessary. Two sets of analyses were carried out to explore age-related differences in within-person dispersion: One consisted in analyzing the magnitude of dispersion by computing the within-individual standard deviation across tasks; the other analyses aimed at assessing whether qualitatively different profiles of dispersion could be defined on the basis of ipsatized scores. All these analyses were performed using the five age groups defined above (C1: children aged 9–10 years, C2: children aged 11–12, YA: young adults, OA1: younger group of older adults; OA2: older group of older adults).

Age differences in the amplitude of dispersion

The first analysis aimed at exploring to what extent the magnitude of dispersion in response speed and in working memory is influenced by age group. It is important to dissociate variability from mean level, in order to assess whether dispersion shows age differences independently

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[2]Order was identical for all individuals, to ensure that task order and individual differences were not confounded. The RT and the WM tasks were alternated within each testing session. The administration of both RT and WM tasks in the same testing session was systematic in the adults, who usually needed only two sessions. If an additional session was needed, it was devoted to assess fluid and crystallized intelligence. One of the WM tasks was repeated in Sessions 1 and 2 (the RSpan), and repeated measure analyses of variance (ANOVAs) showed no significant effect of the day of testing for young and older adults. Some children needed up to four or five testing sessions, in particular to accommodate to the classroom schedule. It is therefore possible that some of them underwent only a WM task on one testing session (notably the matrices that are quite long). Yet, most children were also administered the two kinds of tasks in a given session.

[3]It was judged preferable to use identical cutoff values for all age groups. As one of the referees remarked, this could lead to inflating IIV in young adults as, for this group, more extreme values would be allowed. In view of the results, this does not seem to constitute a problem.

[4]Note that the tasks were built so as to also assess within-task variability or inconsistency (sufficient number of trials in each experimental condition). In the present study, focused on dispersion, only the mean performance for each task is considered; the same analyses can of course be (and have been) conducted on measures of inconsistency (intraindividual standard deviations) but are not presented in this paper, for the sake of space and simplicity.

from age differences in the level of performance; it is well known indeed that standard deviations of high mean values (such as response times in older adults, relative to young adults) are also larger. Thus, mean scores on each of the tasks (iMs) were first residualized for age-group effects[5] in order to control for age-related differences in the average level of performance (Bielak, Hultsch, Strauss, MacDonald, & Hunter, 2013; Hultsch, MacDonald, & Dixon, 2002). Second, residualized scores were standardized over the total sample in order to have the same metrics and were transformed into T-scores (T-iMs) to avoid negative values.

Intraindividual standard deviations (T-iSDs) across tasks were then computed as an index of dispersion, distinguishing the two types of tasks: T-iSD-WM based on the T-iM scores in the WM tasks (8 scores) and T-iSD-RT based on the T-iM scores in the RT tasks (12 scores). A one-way analysis of variance (ANOVA) was carried out on each T-iSD to examine age effects in dispersion.

Analysis of profiles of dispersion

The second analysis aimed at determining whether groups of individuals could be defined in terms of the type and amplitude of dispersion of their scores and whether these groups showed different characteristics. A cluster analysis was used to examine profiles of dispersion across all tasks, with the aim to explore the relation between these profiles and the cognitive performance. Effects of overall profile elevation were removed by ipsatizing T-iM scores: Each T-iM was subtracted from the individual's mean performance across tasks. Absolute values of these deviations from the individual mean were used for the cluster analysis, so that each individual's profile of abilities represents a pattern of within-individual dispersion across tasks. In order to insure a similar weight to all the tasks and not bias the analysis because a task comprises three conditions when another task has only one, conditions were grouped or selected when relevant. Conditions were averaged[6] in the LC task (6 letters and 9 letters), the RS task (n and n+1), the visuospatial

conditions of the Matrices task (n and n+1), and the verbal–spatial conditions of the Matrices task (n+1 and n+2), separately for the words and for the positions. For the Stroop and Arrow tasks, the three conditions could not be averaged as they are assumed to rely on different processes. In the present analyses, only the incongruent conditions were kept as an index of complex speed. Therefore, the cluster analysis was run on a total of 11 ipsatized differences (seven for the RT tasks and four for the WM tasks). To avoid inflating spuriously dispersion, individuals who presented an extreme T-score (larger than four standard deviations, i.e., a T-score of 10 or lower, or of 90 and beyond) were discarded for these analyses. These were 17 individuals, distributed across all age groups.

The determination of the number of clusters was motivated by the idea of trying to distinguish at least individuals presenting little variability from those presenting high variability. Therefore, a two-cluster solution was preferred. A k-means analysis using IBM SPSS Statistics 21 was performed to determine final case location in the separate subgroups. This analysis converged in 16 iterations, with a minimal distance between initial centers of 60.15. It allowed us to determine which individuals were variable and which ones were stable across tasks, and then to test whether dispersion was linked to individual mean level of performance. To do so, one-way ANOVAs were conducted testing the effect of cluster category on mean performance (T-iMs) in RT tasks and in WM tasks, separately.

Results

Table 2 provides a description of the raw data.

Dispersion across tasks

Dispersion was altogether quite important. Figure 1 reports the mean dispersion by age group. In children, the difference between the lowest and the highest T-score (within-individual maximum – minimum range) was on average

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[5]Analyses were also computed on a subsample using scores residualized for practice and fatigue effects (item and block effects) in addition to age effect and their relative interactions. These analyses yielded extremely similar results, with correlations between scores close to .99.

[6]It is worth noting that there was no Age × Condition interaction, indicating that the averaged conditions showed a similar developmental trend.

Table 2. Summary of raw data in RT and WM tasks.

Characteristics	C1		C2		YA		OA1		OA2	
	M	SD	M	SD	M	SD	M	SD	M	SD
SRT	381.93	74.89	336.12	51.81	272.9	39.3	324.52	77.08	341.41	64.75
LI	605.59	97.56	520.15	76.12	372.62	43.60	445.74	64.69	470.94	75.22
CS	536.80	106.33	453.24	86.30	325.79	39.38	418.98	67.31	446.21	81.29
DI	1924.67	396.48	1536.93	402.08	1041.79	221.82	1576.07	308.71	1772.82	379.89
LC_6	4038.80	1323.61	3213.18	985.40	1837.85	424.86	2790.35	643.99	3194.14	936.94
LC_9	5493.01	1646.70	4687.25	1336.96	2799.40	656.78	4073.17	975.24	4647.15	1233.62
ST-N	829.83	160.46	754.95	135.37	592.32	92.08	751.79	122.51	835.49	171.12
ST-C	838.75	139.63	756.51	120.98	605.50	83.18	707.28	99.33	756.67	130.37
ST-I	1118.72	311.39	981.19	194.79	747.73	119.80	983.08	182.76	1147.36	272.73
AT-N	502.71	159.21	448.52	153.88	357.64	133.50	532.02	150.32	561.87	193.73
AT-C	498.07	128.63	433.66	100.10	330.32	63.27	450.86	96.18	475.96	107.26
AT-I	594.04	191.39	523.60	181.80	394.13	123.83	601.28	220.03	630.28	203.99
SPn	3.10	1.19	3.68	1.39	5.33	1.41	3.41	1.14	3.13	0.92
SPn1	3.72	1.30	4.42	1.56	6.15	1.53	3.97	1.15	3.60	0.94
MDPn1	3.00	0.83	3.40	0.74	4.80	0.95	3.44	0.79	3.12	0.69
MDPn2	3.07	0.84	3.55	1	5.20	1.10	3.69	1.03	3.18	0.84
MDWn1	2.56	0.77	3.20	0.53	4.06	0.61	3.55	0.64	3.31	0.61
MDWn2	2.52	0.75	3.21	0.60	4.24	0.67	3.65	0.74	3.36	0.73
RSn	1.89	0.43	2.19	0.59	2.83	0.76	2.58	0.81	2.32	0.67
RSn1	2.08	0.51	2.49	0.60	3.27	0.70	2.93	0.79	2.67	0.68

Note. M = group's mean; SD = group's standard deviation; RT = reaction time; WM = working memory. For RT tasks means (SDs) are given in ms; for WM tasks, they correspond to the mean number (SD) of correct responses. C1 = younger group of children; C2 = older group of children; YA = young adults; OA1 = younger group of older adults; OA2 = older group of older adults; SRT = simple reaction time task; LI = line comparison task; CS = Cross Square task; DI = Digit Symbol task; LC = Letter Comparison task [with 6 letters (LC_6) or 9 letters (LC_9)]; ST-N = Stroop task neutral condition; ST-C = Stroop task congruent condition; ST-I = Stroop task incongruent condition; AT-N = Arrow task neutral condition; AT-C = Arrow task congruent condition; AT-I = Arrow task incongruent condition; RSn = reading span task, span n; RSn1 = reading span task, span n+1; SPn = simple Matrices task, span n; SPn1 = simple Matrices tasks, span n+1; MDPn1 = double Matrices task, number of positions, span n+1; MDPn2 = double Matrices task, number of positions, span n+2; MDWn1 = double Matrices task, number of words, span n+1; MDWn2 = double Matrices task, number of words, span n+2.
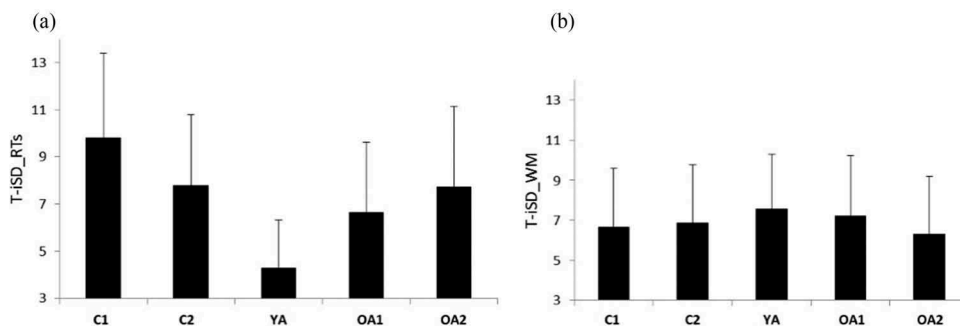

Figure 1. Mean individual standard deviation (T-iSD) across (a) reaction time (RT) tasks, and (b) working memory (WM) tasks by age group. C1 = younger group of children; C2 = older group of children; YA = young adults; OA1 = younger group of older adults; OA2 = older group of older adults. Young adults have more homogeneous performances in RT tasks than children and older adults. Conversely, they have more heterogeneous performances in WM tasks than the oldest group of older adults. The vertical bars represent standard deviations.

19.78 (C1) and 17.95 (C2) in RT tasks, and 16.50 (C1) and 16.76 (C2) in WM tasks. In young adults, the average range between the minimal and the maximal score was 16.45 and 15.82, for RT tasks and WM tasks, respectively. In older adults, the average range between the minimal and the maximal score was 20.55 (OA1) and 16.49 (OA2) for RT tasks and 17.47 (OA1) and 15.47 (OA2) for WM tasks. In all age groups, the mean ranges corresponded to one and a half/two iSDs.

The ANOVAs conducted to test age differences on the T-iSD of RT tasks, on the one hand, and of WM tasks, on the other hand, showed significant age effects [$F(4, 538) = 53.82$, $p < .001$, $\eta^2 = .29$; $F(4, 538) = 3.36$, $p = .01$, $\eta^2 = .03$, respectively], pointing to an age difference in the amplitude of the dispersion (see Figure 1). The effect of age was much stronger in RT tasks than in WM tasks. Post hoc comparisons (Tukey) showed that young adults presented a significantly smaller dispersion across

RT tasks than both groups of children and both groups of older adults (all ps <.001). The youngest children (C1) showed a significantly larger dispersion across RT tasks than all the other groups. Older children (C2) presented a larger dispersion than OA1 (p <.05), but they were similar to the group of OA2. No significant difference was observed between the two groups of older adults. Concerning WM tasks, post hoc comparisons (Tukey) showed that young adults presented a significantly larger dispersion than OA2 (p < .05). No other significant difference was observed. Even though there were fewer group-by-group significant differences in WM tasks, the difference in age trends for the two types of tasks was striking.[7] Sex effects[8] were also investigated in each age group, but ANOVAs showed no significant effect on RTs or on WM.

Cognitive profile analyses

Figure 2 presents the results of the k-mean analysis in two clusters for the entire set of tasks. Cluster 1 (n = 376; 72%) exhibited little dispersion across all

tasks. Cluster 2 (n = 146; 28%) exhibited high dispersion across RT tasks and little dispersion across WM tasks (Figure 2a). Overall, whatever the age group, there were more individuals in the "less variable" cluster than in the "variable across RT tasks" cluster. Figure 2b displays how individuals were distributed according to their age group. Consistent with the ANOVA conducted on RT tasks, almost all young adults belonged to the "less variable" cluster (one was classified in Cluster 2), while children and older adults were more distributed in both clusters. A significant chi-square was obtained, $\chi^2(4)$ = 122.21, p < .001, indicating that the distribution significantly differed across age groups.

Relation between cognitive profile and mean performance

Results of the ANOVAs performed on the mean T-score showed a significant main effect of the cluster category [RT tasks, $F(1, 521)$ = 72.22, p < .001, η^2 = .12; WM tasks, $F(1, 521)$ = 16.96, p < .001, η^2 = .03], indicating that individuals
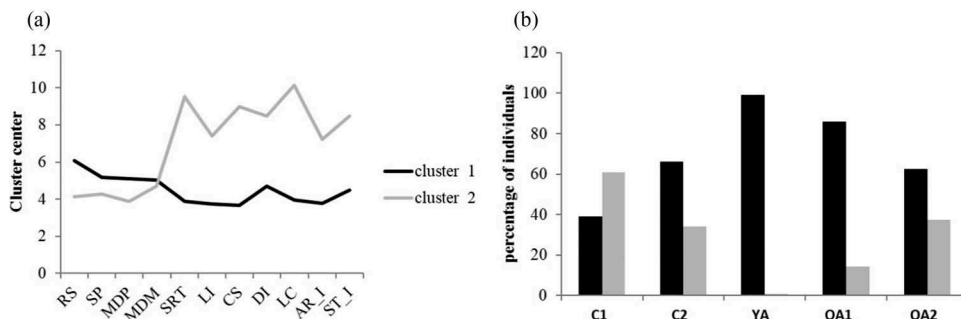

Figure 2. Profiles of dispersion across all tasks. (a) Results of the cluster analyses with a two-factor solution distinguishing a cluster of little variable individuals (Cluster 1) from a cluster of individuals highly variable in reaction time (RT) tasks and not in working memory (WM) tasks (Cluster 2). Absolute values of the deviations from individual means were used for the cluster analyses. RS = Reading Span; SP = simple Matrices task; MDP = double Matrices task, position condition; MDW = double Matrices task, word condition; SRT = simple reaction time; LI = line comparison; CS = Cross Square; DI = Digit Symbol; LC = Letter Comparison; AR_I = incongruent condition of the Arrow task; ST_I = incongruent condition of the Stroop task. (b) Percentage of participants in both clusters according to the age group. C1 = children of 9–10 years; C2 = children of 11–12 years; YA = young adults; OA1 = older adults aged less than 70 years; OA2 = older adults aged 70 years or more.

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[7]An anonymous reviewer pointed to the fact that there were fewer tasks/conditions in the WM tasks than in the RT tasks and that it might lead to greater dispersion in the RT tasks. We therefore computed additional analyses of dispersion in RT tasks but only across two tasks/six conditions (Stroop and Arrow tasks, all conditions), similarly to WM. Similar age differences were observed—that is, performance of young adults was significantly less variable in RT tasks and more variable in wM measures than performance of children or of older adults. The smaller range of dispersion in WM cannot therefore be attributed to the smaller number of WM conditions.

[8]We did not have any expectation concerning gender effects but we follow the American Psychological Association (APA) guidelines stating that, where available, gender effects should be reported.

belonging to Cluster 1 (less variable) were faster in RT tasks and more efficient in WM tasks than Cluster 2 individuals (highly variable across RT tasks).

Note that almost all young adults belonged to Cluster 1. Additional analyses excluding young adults were then conducted to remove a possible effect of this particular age group. Results were similar to those obtained with the entire sample [$F(1, 387) = 69.13$, $p < .001$, $\eta^2 = .15$; $F(1, 387) = 21.69$, $p < .001$, $\eta^2 = .05$], for the mean in RT tasks and in WM tasks, respectively, indicating that, whatever the age group, Cluster 1 individuals (less variable across tasks) were faster and more efficient than Cluster 2 individuals (highly variable across RT tasks).

Discussion

The goal of the present study was to provide an overview of age-related differences in cognitive dispersion from childhood to older adulthood. Heterogeneity of profiles was considered within two broad classes of cognitive tasks: response speed and working memory. First, note that dispersion was generally very large, in all groups. Results showed age effects in dispersion, suggesting different rates of development of underlying processes according to the life period. Unexpectedly, age-related effects on dispersion were different depending on whether RT tasks or WM tasks were considered. Furthermore, the amplitude of dispersion was related to the average level of processing speed and performance in working memory, which highlights the valuable contribution of dispersion in the understanding of general cognitive functioning.

Age differences in dispersion

As concerns RT tasks, young adults showed more homogeneous profiles than children and older adults. This finding suggests that dispersion in response speed throughout the lifespan is characterized by a U-shaped curve, children's performance becoming more homogeneous across different response speed tasks as they grow up while older adults' performance becomes more

heterogeneous again as they age. This observation is similar to the results reported by Roalf et al. (2014) who observed the greatest heterogeneity in young children, relative to older children or to young adults, particularly in speed tasks. However, Roalf et al. also observed that only the youngest children (8–9 years of age) showed a larger dispersion than young adults, whereas in our data young adults were significantly less heterogeneous than all children. Yet, there were no adolescents in our sample, which would be a more critical test of a potential difference[9] between Roalf et al.'s study and the present one. Results are also close to those obtained as concerns another form of IIV, namely inconsistency, which refers to within-task fluctuations of performance (de Ribaupierre et al., 2006; Li et al., 2004; Williams, Hultsch, Strauss, Hunter, & Tannock, 2005; Williams, Strauss, Hultsch, & Hunter, 2007). A positive relation between inconsistency and dispersion has been reported, indicating that individuals more variable across tasks are also more variable across time, within a task (Hilborn et al., 2009). In line with this report, similar age differences are observed between inconsistency and dispersion in response speed. Keeping in mind the warning that cross-sectional data should not be interpreted as reflecting individual changes, we can speculate that inconsistency in response speed and dispersion across RT tasks follow similar developmental pathways.

In contrast, and unexpectedly, dispersion across WM tasks showed a reverse pattern in age effects: Young adults showed a larger dispersion in their accuracy performance than children and older adults. Age differences were less marked, however, than in RT tasks. This observation supports prior hypotheses that IIV in processing speed and IIV in accuracy performance present different characteristics (Salthouse, 2012) and suggests that dispersion across RT tasks and dispersion across WM tasks are driven by different processes.

A simple, and seemingly obvious, potential explanation for such a difference in the age-related trends of dispersion (response speed versus memory performance) could be that this reversal is due to a scaling effect, a smaller range allowing less variability of response than a larger one. One could possibly argue that when scores are high (e.g.,

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[9]Incidentally, it is also worth repeating that we did not observe a gender difference in any of the age groups, contrarily to Roalf et al. (2014) who reported a larger IIV in males.

longer RTs or a higher number of memorized items), greater variation is possible. Conversely, in WM tasks, individuals with a span of two or three have little possibility of variation in their accuracy performance, contrary to individuals with a span of five or six. According to this line of reasoning, children and older adults might show more variation in their RTs than young adults because they are slower, as well as less variation in WM tasks because their WM capacity is smaller. There is a counterargument to this straight conclusion, however. Dispersion was computed on the basis of T-scores, that is on interindividual differences. Moreover, before being standardized, RTs were residualized for age group. Thus, dispersion reflects the deviation between the best and the worst positions held in his or her own age group by a given individual and is independent from the absolute performance; also the potential range is the same across all tasks.

These findings appear to be inconsistent with those of Hilborn et al. (2009), who observed higher dispersion in the older group of older adults than in the younger one. Dispersion in that study was analyzed across more diverse measures of cognitive functioning than in the present work, mixing WM, inductive reasoning, verbal fluency, vocabulary, and story recognition, as well as RTs in visual speed processing tasks. Little is known about dispersion in accuracy measures only. As was mentioned in the introduction, there are some studies showing that age-related differences in inconsistency are less clear for accuracy scores than for RTs. Exploring inconsistency in a sample of older adults, Li, Aggen, Nesselroade, and Baltes (2001) reported a positive correlation between IIV in memory performance and age, pointing to a larger variability in memory performance in older than in young adults. However, comparing IIV in RTs and memory performance in healthy older adults and in older adults diagnosed with mild dementia, Hultsch and colleagues (2000) found memory performance to be less sensitive to IIV than RTs. More recently, Salthouse (2012) explored the characteristics of IIV in performance accuracy in comparison with inconsistency in RTs. He reports that variability in accuracy across three sessions has different properties from variability in RTs across multiple trials within a single session. Specifically, measures of within-person variability in performance accuracy obtained from different cognitive tests correlated weakly with one another, and

showed very low stability across time and near-zero correlations with longitudinal change in cognitive abilities, contrary to what has been reported with measures of inconsistency in RTs. This was true of several tasks. Note, however, that variability was measured on the basis of few measures (tasks or trials), which raises a question of reliability. There have also been reports of older adults showing greater IIV in false memory (Murphy, West, Armilio, Craik, & Stuss, 2007). But IIV in this study was not explored per se; rather the authors found an interaction between the day of testing and the number of intrusions. Vandermorris, Murphy, and Troyer (2013) also report an age-related increase in IIV in associative WM tasks. But IIV was computed on the basis of RTs in WM tasks, and not on accuracy. In another study, Wegesin and Stern (2004) studied the interblock IIV in memory performance in young and older women, using postmenopause estrogens or not. Analyzing the coefficient of variation (the standard deviation divided by the mean performance) both in RTs and in accuracy, the authors found that older women showed greater inconsistency across blocks than younger women. The sample was, however, very small (15 participants by group). Exploring a sample of more than 500 individuals, Fagot, Borella, and de Ribaupierre (2015) reported that while children and older adults presented, as expected, higher inconsistency than young adults in RT measures, this was not the case in a WM task; in this case, young adults tended to present a larger inconsistency than children and older adults.

Thus, dispersion in response speed and dispersion in performance accuracy seem to constitute two different forms of variability, probably indicative of different underlying processes. This is supported by the results of the cluster analysis. Indeed, the two-factor solution distinguished individuals exhibiting little dispersion across all tasks and individuals presenting a high level of dispersion across RT tasks only, pointing again to the difference between the two types of tasks. Not only did young adults present a larger dispersion than the other age groups, but also the dispersion for the WM tasks was larger in Cluster 1 (those profiles more homogeneous in terms of RTs) than in Cluster 2. Children and older adults who had a more heterogeneous profile than young adults in RT tasks showed a more homogeneous profile in WM tasks. Interestingly, individuals presenting a larger heterogeneity of performance in RT tasks

showed less efficient cognitive profiles—that is, less rapidity in RT tasks and poorer performance in WM tasks, suggesting that heterogeneity is associated with lower cognitive functioning. This result was also observed when removing young adults from the sample—all pertaining to the less variable cluster.

Our expectation was to observe a greater IIV in children and older adults than in young adults, but we also mentioned that it was more difficult, based on the literature, to predict the age trend of dispersion in WM tasks. Indeed, two rather contradictory interpretations of the meaning of a large dispersion have been offered in the literature, both of which find support in the present results. On the one hand, a high level of dispersion in response speed is taken for indicative of lower cognitive control, similarly to studies on inconsistency in RTs (Hultsch et al., 2000; Li et al., 2001). Our findings suggest that a high level of dispersion in RT tasks is indicative of lower cognitive functioning, similarly to studies about inconsistency in RTs (Hultsch et al., 2000; Li et al., 2001). This observation is consistent with the proposition that greater dispersion across cognitive domains may reflect poorer sustained cognitive control across the different cognitive tests (Hilborn et al., 2009; Hultsch et al., 2002; Morgan, Woods, Rooney, et al., 2012). Higher levels of dispersion may be related to fluctuations in the efficiency of general executive control. From a physiological point of view, IIV may rely on less efficiency in the brain functioning. This hypothesis would be consistent with recent reports on brain development and aging. Brain imaging studies have indeed reported a link between variability in RTs and structural or functional brain characteristics (Fjell, Westlye, Amlien, & Walhovd, 2011; Garrett, Kovacevic, McIntosh, & Grady, 2011, 2013; Mella, de Ribaupierre, Eagleson, & de Ribaupierre, 2013; Moy et al., 2011; Tamnes, Fjell, Westlye, Ostby, & Walhovd, 2012). More specifically, white matter integrity in young and older adults' brain has been linked to IIV in RTs but not in WM performance (Mella et al., 2013). Note, however, that these interpretations concern within-task rather than across-task IIV, that is inconsistency rather than dispersion.

On the other hand, larger dispersion has also been understood as reflecting greater cognitive specialization (e.g., Roalf et al., 2014). This latter suggestion, compatible with our results with WM tasks, is reminiscent of the differentiation–dedifferentiation hypothesis (Baltes, Cornelius, Spiro, Nesselroade, & Willis, 1980; Baltes et al., 1999) . Yet, as we discussed in the introduction, this hypothesis is based on correlational evidence (greater importance of a general factor in childhood and older adulthood) and does not directly address the question of intraindividual variability. Moreover, dedifferentiation and larger dispersion may coexist (unless the correlation is close to 1). Incidentally, we also computed correlations among the T-scores and the absolute differences used to analyze dispersion. Interestingly, these correlations —stronger among WM tasks, on the one hand, and RT tasks, on the other hand—were lower in children than in young adults and older adults. Another hypothesis that could be advanced with respect to higher dispersion across RT tasks than across WM tasks in older adulthood is related to Baltes' SOC (selection, optimization and compensation) model (Baltes et al., 1999). It could perhaps be the case that older adults favor the quality of their response (i.e., not making errors) over the speed. As a result, their performance would be rather stable across WM tasks, but would fluctuate more in RT tasks. Yet, this hypothesis remains at the present time purely speculative and does not account for the greater stability of children across WM tasks. Besides, it probably better applies to within-task IIV (inconsistency) than to across-task IIV.

More work is needed in the same direction, but exploring other cognitive domains, before firm conclusions can be drawn. Research focusing on the underlying mechanisms and their rate of development across the lifespan will be essential to better understand the potential theoretical and clinical significance of the observed age differences in dispersion. The present research highlights the importance of considering separately dispersion in response speed and dispersion in accuracy measures such as WM performance. There is some consensus that IIV in RTs, whether inconsistency or dispersion, follows a U-shaped trend across the lifespan and reflects less efficient cognitive functioning. In contrast, IIV in accuracy responses is not as strongly linked with age differences and is not systematically associated with less efficient

cognition. It could even prove to be beneficial, for instance by allowing flexibility among various processes (see also Siegler, 1994, for IIV in problem solving in children).

Limitations

One limitation of the present study, shared with all cross-sectional studies, is that the observed age-related differences in IIV do not reflect developmental change but only developmental (or age) differences and may be based on cohort effects. Findings from longitudinal studies are usually supportive of an increased IIV with aging in terms of inconsistency, although there are very few such studies. Thus, we cannot rule out the possibility of generational effects between children and other age-groups. Yet, our lifespan approach makes this possibility less likely. A longitudinal study would nevertheless be needed to disentangle this issue. Another limitation of the present study is that indices of IIV are based on interindividual differences (*T*-scores), by the standardization procedure used. Yet, this procedure is shared with all the studies that compare different tasks for the same individuals, and we do not know of any other procedure making it possible to compare performances across different tasks in order to compute an index of variability across tasks. A third limitation of the present study, also shared with most studies in psychology, concerns the modality of recruitment of young adults. They were indeed all students of psychology, while children and older adults were recruited from the Geneva community. Caution should therefore be taken in the generalization of the results concerning age differences. It is, however, to be noted that homogeneity of the sample does not give any indication concerning within-individual heterogeneity of profiles. Moreover, it does not help explaining the observed age differences between dispersion in speed processing and dispersion in working memory. Finally, and perhaps more importantly for a fuller comprehension of IIV, it is worth stressing that only two WM tasks were used in the present study. Results might have been different if more tasks had been used, as well as a larger range of cognitive tasks (e.g., fluid intelligence, crystallized intelligence, episodic memory tasks) as far as accuracy measures are concerned. Age differences in dispersion in other cognitive domains should therefore be explored to give light on the observed discrepancy between developmental trajectory of dispersion in RT and in WM.

Conclusion

To conclude, the findings of the present study challenge the well-established view of older adults being systematically more variable than young adults and suggest that IIV in speed processing and IIV in accuracy performance do not have the same underlying psychological and biological processes. Moreover, they demonstrate the importance of intraindividual variability in the general population. This is important as far as psychological or neuropsychological assessment of individuals is concerned. Dispersion in processing speed could prove to be a sensitive index of general cognitive functioning, whereas dispersion in accuracy might be more ambiguous, pointing to either a more efficient (like in the present study) and less efficient (in other studies) functioning. In this sense, dispersion offers interesting additional information beyond mean-level performance across age groups. More work is needed in other cognitive domains before norms could be established.

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Disclosure statement

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