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EDITORIAL

Slow processing speed: a cross-disorder phenomenon with significant clinical value, and in need of further methodological scrutiny

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In the current issue of European Child and Adolescent Psychiatry, Braaten and colleagues aim to examine the relevance of processing speed (PS) in relation to various neuropsychiatric conditions within the same cohort. This is unique in the sense that so far, most studies have examined PS deficits in single conditions, hampering the ability to compare PS between groups. As is the case in the current study, PS is commonly defined as 'the time it takes for an individual to perceive, process and respond to a stimulus', although a consensus definition of PS has not been reached [3]. As well clarified by the authors, PS has been frequently investigated in youth with Attention-Deficit/Hyperactivity Disorder (ADHD). In a recent meta-analysis by several of the same authors, it was concluded that slower PS among youth with ADHD was strongly associated with several clinical and functional correlates including weaker academic skills, poorer adaptive skills, increased self-reported anxiety, and overestimates of social competence [3]. The authors further outline evidence for lower PS in youth with other psychiatric conditions, such as autism spectrum disorder (ASD), psychotic disorders, and major depressive disorder. In their analyses of slow PS on the Wechsler PS Index in $n = 751$ youth (ages 6–21 years) referred for neuropsychiatric evaluation, all clinical groups (ADHD, psychosis, ASD, mood disorders, anxiety disorders, conduct disorder, and oppositional defiant disorder) showed PS decrements, with the psychosis, ASD and ADHD-I groups being predictive for decrements ≤ 1 SD below average. Reduced PS also appeared a viable severity index: having multiple comorbidities was associated with even greater risk for slow PS. Structural equation modelling showed that slow PS had direct negative effects on academic achievement functioning (numerical operations) and indirect effects on word reading through working memory. Overall, the authors clearly illustrate the relevance of slow PS in relation to various childhood-onset psychiatric conditions and the impact on daily life (i.e. academic achievement) in this vulnerable population.

The findings of Braaten et al. [2] are well aligned with other studies documenting the cross-disorder nature and clinical relevance of PS in childhood neuropsychiatric conditions. In addition, better PS may be predictive of greater treatment effects and smaller risk for future peer problems [1, 19]. Also in neurological conditions, PS has been found at increased prevalence and to be associated with and/or predictive of clinically relevant measures. For instance, in very pre-term children, reduced PS is commonly reported to be associated with inattentive and overactive/impulsive behaviour in middle childhood [13]. Also in paediatric epilepsy, PS is often lower, even in those with intact general cognitive abilities, and can adversely affect learning and problem-solving [14]. The relevance of slow PS extends into adulthood and elderly age as well as it is well known that PS slows with age. In healthy aging, this may be related to reductions in white matter integrity especially in the frontal and parietal lobes [11]. Slow PS was also found to be predictive of future falls in older adults with a fall history [4]. Furthermore, in relation to pathological ageing (Alzheimer's disease), reduced PS was related to reduced regional cerebral blood flow in temporo-parietal regions, suggesting slow PS to be sensitive towards the severity of the underlying brain pathology in this disease [20].

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Notwithstanding the clear clinical relevance of PS, the precise nature of processing speed, and how and why it relates to poor functional outcomes remains unclear. For example, studies have shown that the age-related developmental curve of PS in children with and without learning disabilities does not differ, questioning the causal role of PS in the development of functional difficulties [21]. Thus, it is important to look at the definition itself, which is already extremely broad (‘the time it takes for an individual to perceive, process and respond to a stimulus’). Frequently PS has been operationalized using two subtests of the Wechsler Intelligence Scales: Coding and Symbol Search. Both subtests require visual scanning of abstract symbols of small size within a 2-min time window. A total score is calculated by distracting the missed and false responses from the correct responses [NB an identical total score can thus be achieved by two strongly diverging ways of processing the task: performing the tasks very hastily with many errors and on a slow(er) speed with no errors]. Coding also requires fine motor skills for reproducing the abstract symbols. In addition, short-term memory skills are often used to memorize (at least several of) the associations between the stimuli (digits) and responses (symbols). Symbol Search barely taxes fine motor skills and short-term memory since responses include basic stripes and every trial includes new information. However, interference control is needed to avoid responding to stimuli that look like the target, but are not identical. As such, even one of the most commonly used indices to operationalize PS is somewhat heterogeneous and involves complex cognitive processes that are often not regarded as components of PS as ‘simple/basic’ speed measure. It may be exactly this composite measure of multiple cognitive processes (speed of visual scanning, speed and precision of fine motor skills, speed and capacity of short-term memory, interference control) that explains the high clinical relevance of PS as documented in many studies. This heterogeneous and complex cognitive nature of PS is not always acknowledged and may hamper conclusions regarding the mechanisms of PS in relation to functional impairments.

Rather than looking at the PS index of the Wechsler batteries, PS has been operationalized in many studies as reaction time measures, for example, in ‘baseline’ conditions of cognitive tasks such as the Stroop or Trail Making Task. In many instances, study-specific constructed PS components have been used, based on factor analysis or principal component analysis on a variety of paper–pencil and/or computer-based tasks. In studies administering computer-based tasks, mean reaction time (MRT), reaction time variability (RTV) and/or more refined measures based on the ex-Gaussian reaction time distribution are commonly used to index PS. Again, although reaction time measures correlate significantly across (even widely diverse) cognitive tasks [6], they cannot be interpreted in isolation from the task-specific demands. Further, there are suggestions that slow PS may, in fact, be the result of a larger response variability with the distribution showing infrequent ultra-slow responses (also called ‘lapses’ of attention) that are driving the higher mean response times [9]. Finally, mathematical models such as the drift diffusion model (e.g. [16]. can be used to decompose a single distribution of response times on a simple task into constituent cognitive components such as boundary separation, stimulus encoding, drift rate (or information accumulation) and response execution. Recent work suggests strongest associations between cognitive abilities and drift rate [12], illustrating the considerable promise of neurocognitive psychometrics to aid better understanding of PS [17].

Another important factor to consider is that task-specific parameters and instruction given to the participant have a direct influence on measures based on reaction times as well as on the balance between speed and accuracy, also known as the speed–accuracy trade-off. Speed and accuracy are often interrelated and it may vary per task whether speed or accuracy is the more elementary in processing. Processing ‘speed’ may, therefore, not cover the full content of what is actually being measured in most studies on this topic. Rather, Processing Capacity (PC) may be a more accurate label. Halford et al. [7] defined PC as ’the limit of the available resources’. Resources allocated to a task vary as a function of task demands and resources invested by—and available to—an individual. Within a short time frame, PC is essentially constant and individually determined, but it will vary over time as a function of physiological state, task demands, diurnal rhythms, and substance intake [7]. Indirect evidence of both the multifaceted nature of PS and the role of PC comes from Kievit et al. [8], who modelled the relationship between fluid intelligence and two reaction measures (mean and 1/sd) across three tasks (simple reaction time, choice reaction time and uncued reaction time, where no explicit request for speediness was given). In a simultaneous path model, they found that five out of six measures all explained unique variance in fluid intelligence, jointly explaining 58.6% of the variance, illustrating the multidimensional nature of PS. Notably, response time for the uncued task was *negatively* related to fluid intelligence, suggesting that those with highest fluid intelligence were those who responded quickly and reliably when told to do so, but not when they were not. It has further been hypothesized that if children’s PC (or the efficiency and adaptive flexibility with which they use their available capacity) develops with increasing age, they are increasingly able to process large amounts of information in parallel when task demands are complex [10]. This, in turn, is crucially important for the mental representation of concepts of higher relational complexity essential to abstract thinking/intelligence [7]. Indeed, Schubert et al. [15] showed that Event-Related Potentials

(ERPs), another source of measures of processing speed, were almost perfectly correlated (90.1% variance) with a latent intelligence factor. Strikingly, this was the case especially for those ERPs associated with later, more complex, information processing (P300). The associations with early ERP components were both weaker and reversed in sign, suggesting the heterogeneity and specificity of PS are present at the neural level already. These results suggests that smarter individuals do not have a general, but a very specific advantage in the speed of higher order information processing, explained by a more efficient transmission of information from frontal attention and working memory processes to temporal–parietal processes of memory storage [15].

We conclude that PS is an important cross-disorder clinically relevant cognitive measure, which is in need of further scrutiny, given the heterogeneous and sloppy operationalization. Depending on task demands, PS may in some cases, in fact, reflect fluid intelligence. Taking this into account may help us to get more insight into the genetic and neural mechanisms relating PS to poor functional (i.e. academic) outcomes in children with various neuropsychiatric conditions (e.g.[5]. This knowledge may help in finding ways to ameliorate these problems, for example, by accommodating these children during their learning process, or (although so far transfer effects are not proven robust) using specific PS modality training [18].

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