Intelligence 69 (2018) 158–168

Contents lists available at ScienceDirect

Intelligence

journal homepage: www.elsevier.com/locate/intell

# The characterization of attention resource capacity and its relationship with fluid reasoning intelligence: A multiple object tracking study

Domenico Tullo[a,*], Jocelyn Faubert[b], Armando Bertone[a]

[a] Department of Education & Counselling Psychology, McGill University, 3700 McTavish Street, Montréal, QC H3A 1Y2, Canada
[b] École d'optométrie, Université de Montréal, 3744, rue Jean-Brillant, Montréal, QC H3T 1P1, Canada

ARTICLE INFO

*Keywords:*
Multiple object-tracking
Attention resource capacity
Fluid reasoning intelligence
Cognitive load

ABSTRACT

Multiple object-tracking (MOT) paradigms have the potential to highlight attention resource capacities. However, there is a dearth in research exploring the relationship between individual differences in MOT capability and higher-level cognition, such as intelligence. Previous research has demonstrated that manipulating task demands, or the task's cognitive load, can help describe this relationship. Therefore, we assessed the relationship between performance on a 3D-MOT task at different levels of cognitive load (average speed for tracking 1, 2, 3 and 4 target objects out of 8 total objects), and fluid reasoning intelligence measured by the Wechsler Abbreviated Scale of Intelligence-2nd edition (WASI-II). Also, we compared MOT performance between intellectual styles classified as: (i) low, medium or high fluid reasoning IQ, and (ii) fluid reasoning or verbal styles. As expected, speed scores decreased as target objects increased. This trend represents a proxy for attentional resource capacity as manipulations to both speed and target objects are able to highlight individual differences in available attentional resources. Furthermore, MOT capability at high load (4-targets) was the best predictor of fluid reasoning intelligence compared to lower loads (1–3 targets), and individuals with a fluid reasoning style and/or medium-high fluid reasoning intelligence outperformed individuals with a verbal style and low fluid reasoning IQ, respectively. These results describe the underlying commonalities between fluid reasoning intelligence and attention resource capacity, extending previous findings with working memory capacity. This study demonstrates that examining MOT as a measure of attention, rather than a phenomenon, can illustrate the potential to repurpose the use of this task to characterize attentional resource capacity.

## 1. Introduction

The relationship between cognitive capabilities and intelligence has been explored since the inception of intelligence-based measures (Heitz, Unsworth, & Engle, 2005). Primarily, this relationship has favoured the use of working memory capacity to examine how individual differences in these capacities are associated with intelligence (Engle, Kane, & Tuholski, 1999). For example, research by Kyllonen and Christal (1990) demonstrated that individual differences in working memory capacity were highly related to general intelligence, where larger capacities were associated with higher overall intelligence. Advances in further exploring this research question suggested a robust relationship to fluid reasoning intelligence, rather than general intelligence (Conway, Kane, & Engle, 2003; Engle et al., 1999; Heitz et al., 2005). Although research has targeted working memory capacity to explain this relationship, Engle et al. (1999) and Engle (2002) argue that controlled attention is ultimately, working memory capacity. Specifically, working memory is the ability to direct and sustain attention to relevant information, while ignoring irrelevant information (Engle et al., 1999). Thus, there is a need to examine whether an attentional task can help define the relationship between cognitive capacity and fluid reasoning intelligence.

Describing the relationship between attention and intelligence has proved to be difficult as both attention and intelligence are hierarchical in nature, consisting of multiple subcomponents (Heitz et al., 2005; Schweizer, 2005; Schweizer, Zimmermann, & Koch, 2000). For example, Schweizer and Moosbrugger (2004) emphasized the importance of using sustained attention as the main predictor of intelligence. Although, they along with others report a significant relationship (Crawford, 1991; Roberts, Beh, Spilsbury, & Stankov, 1991; Schweizer et al., 2000; Schweizer & Moosbrugger, 2004; Stankov, Roberts, & Spilsbury, 1994), another similar study has found contradicting results (Rockstroh & Schweizer, 2001). Similarly, the research exploring the relationship between distributed attention and intelligence have also produced opposing findings: with those supporting this relationship (Roberts et al., 1991; Roberts, Beh, & Stankov, 1988; Stankov, 1988)

* Corresponding author.
*E-mail address:* domenico.tullo@mail.mcgill.ca (D. Tullo).

https://doi.org/10.1016/j.intell.2018.06.001
Received 15 January 2018; Received in revised form 5 June 2018; Accepted 12 June 2018

and others failing to find support (Fogarty & Stankov, 1988; Lansman, Poltrock, & Hunt, 1983). The instability of the results stemming from the examination of a single sub-component of attention has shifted the focus to a single measure of attention that accesses multiple sub-components of attention (Schweizer, Moosbrugger, & Goldhammer, 2005). Therefore, a single, accurate measure, comprised of multiple facets of attention, such as a Multiple Object-Tracking (MOT) task could further describe the relationship between visual attention capacity and intelligence.

MOT was introduced to cognitive science three decades ago by Pylyshyn and Storm (1988). The task involves visually tracking multiple objects (targets) moving around a space while ignoring other physically indistinguishable objects (distractors). A thorough dissection of the MOT paradigm has suggested that this task can tap into selective, distributed, and sustained domains of attention (see Scholl, 2009 for review). This task can account for these subcomponents of attention as it requires the participant to (i) selectively attend to target objects while ignoring distractor objects, (ii) distribute attention throughout multiple objects, and (iii) sustain this effort throughout the length of the trial (Pylyshyn & Storm, 1988). Originally, this paradigm was designed to demonstrate that attention can be allocated to multiple sources at the same time (Pylyshyn & Storm, 1988). Since then, research in MOT has explored the underlying mechanisms involved in visual tracking, and their absolute limits (Scholl, 2009). One area of research in MOT has focused on measuring the maximum number of target objects an individual can track (Alvarez & Franconeri, 2007; Cowan, 2001; Fougnie & Marois, 2006; Viswanathan & Mingolla, 2002). Particularly, this manipulation of target objects can be repurposed to examine the relationship to higher-level cognition rather than exploring the absolute limits of visual tracking. Moreover, this manipulation of target objects in MOT studies parallels research exploring the relationship between individual differences in working memory capacity and intelligence.

Two notable methods used in previous research to investigate this relationship are highlighted by (i) manipulating the working memory task's demands (i.e., manipulations in cognitive load) as well as (ii) examining performance on these working memory tasks between intellectual styles (Gevins & Smith, 2000). Manipulating a task's cognitive load can help to understand differences across individuals. In Engle et al.'s (1999) review, the authors suggest that indvidual differences in working memory capacity were demonstrated by studies that tested performance at both high and low levels of the task's cognitive load. Markedly, performance in conditions of high load are better able to explain scores on intelligence-based measures than conditions of low load (Alnæs et al., 2014; Engle, 2002; Engle et al., 1999). This idea is also supported by Gevins and Smith (2000), where a paradigm similar to the *n-back* was used to examine the impact task demands had on explaining the relationship between cognitive capacity and intelligence. Their study consisted of testing participants in a condition of high load; participants had to respond to images presented two images beforehand (i.e., 2-back condition), and conditions of low load; participants had to respond to an image presented when it matched the first image presented in the sequence. Their results also revealed that performance in conditions of high load were better predictors of intelligence than performance in conditions of low load.

Furthermore, examining the underlying differences between intellectual styles has also been demonstrated to be explanatory of individual differences in working memory capacity (Gevins & Smith, 2000). An individual with an intellectual style is defined as having a preference and/or bias towards either fluid reasoning intelligence or verbal intelligence. For example, an individual with a substantially greater fluid reasoning IQ score would be classified as possessing a fluid reasoning intellectual style. Whereas, an individual with a substantially greater verbal IQ score would be classified as having a verbal intellectual style (Gevins & Smith, 2000). Gevins and Smith (2000) classified participants into a *verbal group* if an individual's score on the verbal component of the Wechsler Adult Intelligence Scale - Revised was significantly greater than the nonverbal subscale score, and vice-versa. There were no significant differences on the working memory task between the nonverbal and verbal groups. However, their null-finding may be attributed to the high intelligence scores in the sample, where the average IQ was 121. Additionally, the researchers divided participants into three groups based on their intelligence scores as either: low, medium or high, which was relative to the sample. Their results revealed that the high- and medium-IQ groups were better at the working memory task compared to the low-IQ group. Although this finding supports the notion that working memory capacity is related to intelligence, the large memory component in the modified *n-back* task can be problematic in validating this relationship (Ackerman, Beier, & Boyle, 2005).

The condition of low load in Gevins and Smith's (2000) modified *n-back* task can be interpreted as a test of memory rather than working memory. This is problematic as memory has been found to bias the relationship between intelligence and working memory capacity due to the similarity in the construction of intelligence-based measures and memory-based measures of working memory (see Ackerman et al., 2005). This questions whether the underlying mechanisms in the cognitive capacities were properly identified, and if the measures of working memory capacity and intelligence were biased by memory (Ackerman et al., 2005).

Borrowing this methodology from research exploring individual differences in working memory capacity can help describe individual differences in attentional capacity via intelligence. MOT paradigms can provide an unbiased measure of attention as manipulating the task's cognitive load does not change the nature of the task across conditions. For instance, tracking one object is believed to access the same reserve of cognitive resources as tracking two through eight objects (Alvarez & Franconeri, 2007).

Just as working memory is capacity-limited, visuo-attentional processing is also capacity-limited (Pylyshyn & Storm, 1988); therefore, task performance suffers when task demands are greater than the individual can process (Sweller, 1994). Currently, there is an ongoing debate attempting to define this attentional capacity limit, as measured by MOT (see Suchow, Fougnie, Brady, & Alvarez, 2014 for review). Defining the limits of MOT capability has been split between the slot-based theory and resource-based theory (Suchow et al., 2014). The slot-based model posits that individuals are limited to a distinct number of target objects that they can simultaneously attend to; and thus, the task becomes impossible to successfully complete once the number of target objects is beyond the maximum number of slots available (Cowan, 2001; Luck & Vogel, 1997).

The opposing resource-based view claims that MOT capability is dependent on a pool of limited resources, which is divided across task demands, such as the number of target objects (Alvarez & Cavanagh, 2004). Therefore, if all available attentional resources are needed to track one target item at a fast speed, then only that item is captured by the individual's attention. However, if the MOT trial is *easy*, that is, items are moving at a slow speed and/or are distant from one another, then there may be leftover attentional resources available. This leftover can be assigned to additional objects or other cognitive weights associated with tracking capability. According to this theory, defining MOT performance through an item limitation alone lacks an explanation of other factors that influence the cognitive load of the visual tracking task (Alvarez & Franconeri, 2007).

The debate between the slot and resource-based theories eclipse the importance of further exploring the relationship between visual attention and separate cognitive processes (Suchow et al., 2014). This debate explains why the majority of research in this specific field explores MOT as a phenomenon, (i.e., how MOT capability is possible) rather than exploring MOT as an attention-based tool to examine the relationship of visual tracking capability with other higher-level processes, like intelligence. By exploring MOT as a paradigm, adopting the resource-based theory would be ideal in demonstrating the relationship between