The empirical reach of the ‘mental whiteboard’: A commentary on Ginsburg et al.

(2017)

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Abstract

In a recent study, Ginsburg and colleagues (2017) explored the boundary conditions of the ordinal position effect, which refers to the horizontal format with which (non-spatial) item sequences have been observed to be represented in working memory. On the basis of 6 experiments on the ordinal position effect, they conclude that serial order in working memory is spatial by nature only if the memoranda are processed semantically. In this commentary we explain why we feel that Ginsburg et al.'s (2017) conclusions are premature, and how they inspire specific guidelines for a more optimal study of 'spatialization' for serial order in working memory.

In a recent study, Ginsburg, Archambeau, van Dijck, Chetail, and Gevers (2017) concluded from a set of 6 experiments on the *ordinal position effect* that serial order coding in working memory (WM) is spatial by nature only if the memoranda are processed semantically. Here we outline how Ginsburg et al.'s (2017) conclusions are premature, and how their study inspires specific guidelines for future work in this domain.

The ordinal position effect¹ refers to an interaction between item retrieval from serial order WM, and spatial processing. Specifically, the later a retrieved item is positioned within a sequence currently maintained in WM, the larger the rightward bias² that it generates in a diagnostic task indented to capture this bias. Having first been demonstrated in a seminal paper by van Dijck and Fias (2011), this effect has by now been replicated across many studies (e.g., Bottini, Mattioni, & Collignon, 2016; De Belder, Abrahamse, Kerckhof, Fias, & van Dijck, 2015; Ginsburg & Gevers, 2015; Ginsburg, van Dijck, Previtali, Fias, & Gevers, 2014; Guida, Carnet, Normandon, & Lavielle-Guida, 2018; Guida, Leroux, Lavielle-Guida, & Noël, 2016; van Dijck, Abrahamse, Acar, Ketels, & Fias, 2014; van Dijck, Abrahamse, Majerus, & Fias, 2013), and has been shown to generalize across different stimulus sets (e.g., numbers, letters, words, color patches) and different diagnostic tasks (e.g., parity judgment, semantic classification, Posner cuing, line bisection, Sternberg task).

The ordinal position effect probes the theoretical position that (formally non-spatial) item sequences in WM are spontaneously maintained in a spatial format. This position has been labelled and developed as the Mental Whiteboard Hypothesis (MWH) by Abrahamse and colleagues (2014, 2017). Hence, the MWH holds that when confronted with the challenge to maintain in mind a brief (and non-spatial) series of

items, the brain internally generates a spatial template – the metaphorical ‘mental whiteboard’ – onto the coordinates of which the items can be temporarily bound. Critically, in doing so, a later and systematic (internal) spatial attention sweep across these coordinates allows the reconstruction of serial order across items.

Besides having a robust empirical foundation in the ordinal position effect, the MWH is broadly compatible with existent theoretical insight across various levels, including its link to the powerful framework of neural reuse (Anderson, 2010, 2014); its potential substantiation of the notion of position markers that is core to many computational models on serial order WM; its smooth assimilation in dominant, attention-based perspectives on WM (Cowan, 1998; Oberauer, 2009); and its compatibility with specific hallmarks of serial order WM such as domain-general serial order coding that is representationally distinct from the item level (Hurlstone, Hitch, & Baddeley, 2014; Majerus & Attout, 2018). Hence, there is all reason to explore the behavior of the ordinal position effect under different manipulations in order to falsify, confirm, and/or further specify the MWH’s core premise that spatial cognition supports serial order working memory.

With their study, Ginsburg and colleagues (2017) aimed to do so across a set of six well-designed experiments. In brief, they showed how the ordinal position effect replicated for verbal but not spatial sequences (Exp. 1-3); how the ordinal position effect arises for both abstract and concrete stimuli, but only if participants reported to have used a strategy of verbalizing the stimuli (Exp. 4); how the ordinal position effect easily survives articulatory suppression (Exp. 5); and finally how the ordinal position effect arises for sequences of pseudo-words only when these are semantically coded (Exp. 6). This is a nice set of findings that not only informs us about the empirical

behavior of the ordinal position effect – which is marginally interesting in itself – but also carries some theoretical relevance. Specifically, as both the phonological loop and attentional refreshing have been proposed as mechanisms of maintenance in verbal WM, the ordinal position effect obtained under conditions of articulatory suppression (i.e., Exp. 5) suggests that spatial coding of serial order is related mainly to the latter of these two maintenance mechanisms (cf. Abrahamse et al., 2017).

Yet, Ginsburg et al. take their main conclusions one step further. They reflect on (especially) the absence of a ordinal position effect across core conditions for 5 out of 6 experiments (i.e., all experiments besides Experiment 5), and reasonably consider that the lack of semantic processing is the common denominator across these conditions. Hence, they conclude that item sequences are only maintained in WM in a spatial format “if the items memorized in WM are semantically coded by the participants” (p. 647) – thus sharpening the MWH’s core premise of a role for spatial cognition in serial order working memory. In the remainder of the present commentary, we outline why we believe that this conclusion is premature – and even unnecessarily complicates matters. Below we will first discuss some relevant theoretical considerations that seemed to have been neglected in the framework sketched by Ginsburg et al. (2017). Next, we will present a brief critique on the specific results of their Experiments 1-3, 4, and 6. Together, these theoretical and empirical considerations should make clear why we believe that the main conclusions by Ginsburg et al. (2017) are difficult to defend at this stage. Finally, we round up with a more constructive note on how the Ginsburg et al. (2017) study inspires the need for more specific guidelines for future work in this domain.

A major flaw in the reasoning presented in the work by Ginsburg et al. (2017) is their failure to systematically distinguish between an empirical marker and the theory that it inspired – that is, between the ordinal position effect and the notion that serial order in WM is maintained in a spatial format (i.e., the MWH). As a result, Ginsburg et al. (2017) directly transfer the left-to-right directional feature of the ordinal position effect to the theoretical level. For example, they formulate the MWH as ‘the creation of horizontal spatial position markers to encode ordinal information in WM’ (p. 647). Yet, at least in papers in which we have served as lead authors, we were always careful to *not* limit our theoretical position to the horizontal axis per se, because so far the ordinal position effect has been explored exclusively along the horizontal axis. It is currently not known what other types of spatial coding are used – or can be brought into play upon demand – in support of serial order WM. Indeed, with regard to the mental whiteboard metaphor, the critical aspect of the ordinal position effect is the spatial format of serial order information; the left-to-right direction as observed in Western participants is informative only in as much we are interested in, for example, precisely how the mental whiteboard is ‘filled in’ (e.g., Guida, Megreya, et al., 2018).

Based on the mental whiteboard as it was put forward (Abrahamse et al., 2014, 2016, 2017), it should be clear that binding items to an internal template can occur (at least) via either the horizontal or the vertical axis (or a combination of these) – and in two directions per axis. Even though such flexibility, as implied by the hypothesis, is awaiting dedicated empirical scrutiny, the first indications in support of such flexibility have been reported. For example, Guida, Megreya et al. (2018) showed that Arabic speakers use the horizontal axis for serial order coding, but in the reversed direction as compared to speakers of Western languages (i.e., from right to left). Hence, the left-to-right direction is not universal, and reading direction shapes the use of the mental

whiteboard. Moreover, Guida et al. (under review) demonstrated within-subject flexibility in spatial coding: The mental format of an item sequence adopts the direction of item presentation on the screen, with left-to-right versus right-to-left mental representations resulting from corresponding presentation conditions. Finally, there is tentative support for coding *outside* the horizontal axis. First, Nairne and Dutta (1992) reported support for the use of the vertical axis in serial order processing. Specifically, participants were presented with pairs of items (i.e., shapes), each of which occurred either first or second in time as well as either above or below a fixation point. Subsequent recall performance was found to be best for sequences in which item presentation was congruent with the direction of reading, that is, with first and second items mapped onto top and bottom locations, respectively. Second, in their work on visuo-spatial bootstrapping, Darling and colleagues (Darling, Allen, & Havelka, 2017; Darling & Havelka, 2010) showed how presentation of a number sequence via a keypad display (based on the mobile phone ‘T9’ keypad) supports memory performance as compared to central presentation of all items.

Hence, whereas it may be tempting to take the absence of the ‘classic’ (left-to-right) ordinal position effect to indicate an absence of spatial coding for serial order (a trap we may have ourselves fallen victim to, recently; Guida, Megreya, et al., 2018), the above indications for flexibility instigate the alternative that the explored group of participants systematically coded order in (still) a spatial format – but different from the (horizontal) axis being tested (e.g., along the vertical axis). Moreover, a clear testing of the MWH requires the consideration of individual differences, as participants may each code for serial order in their own, idiosyncratic spatial format (for example guided by preferences, experiences, and/or task-related cues) – such that at the group level no systematicity is observed. A recent study by Cooperrider, Marghetis, and Núñez (2017)

speaks to this issue. These authors note how linear order is omnipresent in the organization of both our cognitive and physical worlds, and showed that the intuition of ‘linear ordering in space’ manifests itself already in populations that lack exposure to conventional representations exhibiting linear order (e.g., calendrical systems, linear measurement tools, writing). Indeed, they observed spatial coding of linear order in individually idiosyncratic manners. Hence, overall, *absent* ordinal position effects can only generate valid theoretical implications as far as testing considered both the horizontal and vertical spatial axes, as well as individual differences.

Against the above theoretical background, let us now return to the specific experimental results by Ginsburg et al. (2017). First, Experiments 1-3 showed no left-to-right (re)coding for sequences of 4 black dots displayed on an (invisible) 8 x 8 matrix. Yet, the MWH does not imply the need for such recoding: The mental whiteboard can be flexibly used across the horizontal and vertical axis to encode locations on the basis of the coordinates with which items were physically presented (i.e., the black dots location), and with pathway information being used to reconstruct order information. The MWH postulates spatial cognition to be reused for serial order WM – it does not imply the *reversed* impact of specific directional shapers in serial order WM (such as for example reading direction) starting to dictate how intrinsically spatial configurations are mentally constructed. Hence, in the design used by Ginsburg et al. (2017) for Experiments 1-3, we would predict spatial biases that reflect the physical location of presentation rather than a recoded left-to-right direction. Unfortunately, the corresponding analyses were not reported by Ginsburg et al. (2017). Overall, there is little support in the Ginsburg et al. (2017) study to refute the possibility that serial order across spatial locations (thus without any semantic component)

involves the mental whiteboard; ordinary ‘pathway’ information is sufficient – and arguably even more logical to be used – for the maintenance of serial order.

Second, Ginsburg et al. (2017) report an ordinal position effect only for verbalized abstract drawings, and not for non-verbalized ones (Experiment 4). Here the limited testing conditions discussed above are relevant, as no consideration is given to coding along the vertical axis and/or individual differences in spatial coding. This renders it difficult to interpret the results: the absence of the ordinal position effect does not necessarily refute the use of spatial coding in the non-verbalized condition. Indeed, instead of reflecting a critical role for semantic processing *per se*, the Experiment 4 findings may well be explained from the assumed role of reading direction in shaping the filling in of the mental whiteboard (i.e., Guida, Megreya, et al., 2018). Hence, verbalization triggers the language system, and as such generates systematic left-to-right spatial coding for a group of Western participants due to their shared reading experience. Without such verbalization-induced systematicity across participants, interpreting an absence of the ordinal position effect would require more comprehensive testing, as another kind of spatial coding could have been used.

Third and last, Ginsburg et al. (2017) report on the absence of an ordinal position effect for not-semantically-related pseudo-words (Experiment 6). How come these written items – clearly probing reading and its corresponding direction – did not systematically show left-to-right spatial coding across participants? We believe that the Experiment 6 results suffer from a specific confound between semantic processing on the one hand, and the possibility of chunking for pseudo-words on the other. Previous studies hint at the notion that the (left-to-right) ordinal position effect could be limited by the size of WM (Guida, Carnet, et al., 2018; Huber, Klein, Moeller, & Willmes,

2016). It is possible that in Experiment 6, the sequence length may have effectively exceeded this threshold; indeed when processing the pseudo-words, participants may have been forced to use more than one slot in WM to encode and maintain each pseudo-word. Given that Ginsburg et al. (2017) used 4-word sequences, with multiple slots used per word, the WM span may have been exceeded. But if participants somehow succeeded in finding semantic meaning in pseudo-words, this may have enabled more effective chunking of the letters for each pseudo-word, allowing one word per slot. This would explain why the typical *left-to-right* ordinal position effect is conditional on the semantic transformation on pseudo-words. For non-semantic coding (and above-span sequence length) conditions, use of the mental whiteboard may differ. Indeed, Ginsburg et al. (2017) report an almost significant interaction between serial order and spatial processing for the no-semantic content condition, which at closer inspection indicated that the positions 2 and 3 in the sequence were responded to faster with the right hand while no difference between left and right responses was observed for the positions 1 and 4. This already hints at spatial coding that just does not follow the systematicity of the ordinal position effect.

Overall, we believe that Ginsburg et al.'s (2017) paper is very strong in design and data, but presence versus absence of the empirical ordinal position effect only theoretically informs us about the MWH as far as it comprehensively targets its basic premises. In the latter respect, we feel that Ginsburg et al.'s (2017) paper requires follow up. At this stage, their conclusion that semantic coding is pivotal for spatial tagging in WM to occur, may just as well be replaced by a conclusion that better matches the neural reuse flavor that is core to the MWH: the precise spatial configuration with which a subject mentally maintains an item series (whether objects or more abstract items) is dependent on various experiential factors, such as

presentation modality, presentation manner, reading direction, and/or individual preferences. Indeed, such an explanation will maintain the general notion that serial order coding in WM works according to the same principles for the verbal and visuospatial domains – a notion that broadly matches empirical findings across the literature (see Hurlestone et al., 2014). Why complicate matters? At the same time, the true value of the Ginsburg et al.'s (2017) study may be its implicit implication that future research in this domain requires both a more comprehensive coverage of internal space across horizontal and vertical axes (e.g., via eye movement recordings; cf. Rinaldi, Brugger, Bockisch, Bertolini, & Girelli, 2015), and a dedicated consideration of individual differences. Only then can we expect true progress with new knowledge (within reasonable doubt) in terms of determining the empirical reach of the Mental Whiteboard Hypothesis.

Footnotes

1. The ordinal position effect has also been referred to as Spatial Positional Association Response Codes or SPOARC effect (Guida & Lavielle-Guida, 2014).
2. While Western participants show a left-to-right bias, Arab speakers show a reversed bias (Guida, Megreya, et al., 2018).

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