Working memory in SLA: Challenges and prospects

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The concept of working memory is usually traced back to the early models of Baddeley & Hitch, and then the more recent frameworks of Cowan, both of which are usefully laid out in this volume. But interest in WM in SLA was also inspired by the work of Just & Carpenter (e.g., Just & Carpenter, 1992) who were the first to explore the involvement of what has been referred to in this volume as Executive Working Memory (EWM) in online language comprehension. Their notion of working memory 'capacity' (WMC), as determined by the amount of 'activation' available to be shared between processing and storage, invites the idea that WMC might form an important cognitive component of language aptitude, and explain why some individuals are better second language learners and processors than others. Tests of WMC are quick and easy to administer, and yet tap into what seem to be deep and fundamental aspects of cognitive functioning. Given that people clearly differ in their performance on such tasks, even in their L1, then surely this variability will relate to their second language processing and learning ability? Practically speaking, tests of WMC could then provide a means for screening, streaming, or tailoring language training to the individual in a theoretically informed and principled way.

The present volume presents a unique, varied, and fascinating insight into the state of WM research in SLA, and it is becoming apparent that any hope that tests of WMC could form the cognitive bedrock of aptitude testing is probably misplaced. The relationship between WMC and second language processing and learning is far more complex and nuanced than originally envisaged. There is now a clear recognition that WM has to be divided into separate components, most relevantly phonological storage and executive control, that the efficiency of each can vary independently, and as such has to be measured independently. And there is growing recognition, as amply evidenced here, that the importance of these different components to learning and processing can, in principle, vary according to domain of language, mode of instruction, input and output modality, proficiency, and age (Wen, this volume). From the perspective of the hope that WM tests would provide a quick and principled test of aptitude, one might despair. On the other hand, I would suggest that we should be inspired by this complexity, because it turns out that the study of the relationship between WM and SLA can provide real leverage in the exploration of underlying cognitive processes. We move beyond thinking of tests of WMC as a basis for aptitude towards using them as a theoretical tool.

In fact, there is a current trend in the field to use individual differences as a means for distinguishing the contribution of different cognitive systems to learning. Interactions between age and instructional treatments or structures can be used to make inferences about underlying learning processes (DeKeyser, 2012). Individual differences in the functioning of declarative and procedural memory, each measured by distinct tests, have been used as a means to explore the contribution of these systems to learning (e.g., Morgan-Short, et al., 2014). The study of WMC therefore fits into this broader, theoretically motivated, style of research in which individual differences provide leverage to prise apart different components of learning and processing mechanisms.

Admittedly we are at the early stages of this enterprise. In fact, one might say that we are still in an initial bottom-up phase in which evidence is accumulating concerning situations in which various working memory measures do and do not correlate with various aspects of language processing and learning. The present collection provides invaluable input to this development. In some cases the pattern of correlations may seem surprising. For example, EWM does not correlate with learning from written feedback (Baralt, this volume), whereas it does with learning from spoken feedback (Sagarra & Abbuhl, 2013). WM only correlates with gains from processing instruction when measured in production, not comprehension (Santamaria & Sunderman, this volume), or with the ability to detect grammatical patterns, but not ungrammatical ones, after training in an intentional mode (Tagiarelli et al., this volume). Such patterns of correlation, to the extent that they chime with past and future research, become valuable explananda for theories of WM and language processing and learning.

Perhaps we should be wary, though, of becoming overly constrained by the nature of the working memory tasks themselves. If the goal is not so much to discover the basis of aptitude, but rather to understand underlying cognitive processes, then we should start with a careful analysis of the cognitive demands of the learning problem. Working memory models provide frameworks for thinking about the interplay between different forms of memory and limited attentional resources during online processing. The starting point for research should therefore be, not, "which of the available working memory tests do I think will explain individual variation in this learning or processing situation?" but rather, "how can I think about this learning situation in terms of this cognitive framework?". Just & Carpenter's research provides a prime example of this kind of top-down approach. They targeted highly *specific* aspects of comprehension, such as anaphor resolution, syntactic complexity, and lexical ambiguity. They started from a principled analysis of the nature of the processing problem, linked it to the components of the WM system, and only then to the demands of the task used to measure the capacity of this system (namely the reading span test). Whatever we think now about their theoretical position, or the actual involvement of WM in online language processing as they conceived it (see for example Waters & Caplan, 1996, for a critique) this seems like a good model of research practice.

With the benefit of emerging insights into the role of WM in SLA researchers should now be in a position to take the kind top-down approach exemplified by Just & Carpenter. The challenge is to frame research questions in terms of a detailed cognitive analysis of a specific learning or processing problem. This can then be used to motivate the selection of individual differences measures in order to test the validity of the cognitive analysis. The starting point should be a consideration of the targeted linguistic features or regularities. What type of information is critical to the learning problem? Clearly phonology is important for vocabulary learning, but in certain areas of grammar it is important too (e.g. in learning morphological paradigms, picking up on agreement regularities). Presumably it is not so important for learning word order regularities, where more abstract syntactic and semantic information will be critical. In this case we might consider the possibility that there is a separable, and independently measurable, semantic STM capacity that is more relevant (Freedman & Martin, 2001; R. C. Martin, Shelton, & Yaffee, 1994). How important is order, as opposed to item information? The ability to retain sequence information is critical to learning novel word forms (as sequences of phonemes), and syntactic structures (as sequences of grammatical categories or meanings), and there is good evidence that, at least within phonological memory, item and order information can be dissociated, and the ability to retain them measured independently (Majerus, et al., 2008). To what extent will storage of item information be supported by existing long-term memory representations from the L1 or L2? Clearly, greater long-term memory support provides more opportunities for chunking, easing the storage demands on WM.

With regard to the learning or processing task, how important is temporary maintenance of information in WM? Presumably storage demands will be high when the task involves listening or speaking (Skehan, this volume), but low when the task involves written input or output. WM storage demands will be high when learners are required to compare across instances of language to form hypotheses during continued online processing, but low when they rely on implicit learning to unconsciously extract regularities. We should therefore think about assessing the contribution of implicit and explicit learning processes, for example by using think aloud procedures (Leow, et al., 2014) or measurement of implicit and explicit knowledge (Rebuschat, 2013) in order to examine interactions with WM measures (see Tagarelli et al, this volume, for an example).

How important is rapid attention switching, say between form and meaning? Possibly very important in learning through interaction, or attempting to learn vocabulary or grammar in a meaning-focused activity, assuming that the learning target depends on information at the level of form. Should we then be thinking about testing attention switching ability independently (Unsworth & Engle, 2008)? How automated, or modularised, are the underlying processing operations that underlie the task? One reason for not finding correlations with WM, particularly in sentence processing, is because the underlying processes are automatized / proceduralised, and hence make minimal demands on resources. Could we include independent measures of automaticity (Segalowitz, 2003) in order to examine interactions with WM? Again, critical here is the relationship to the L1, because processing of L1-like structures is more native-like and automatic (van Hell & Tokowicz, 2010).

In all of this we should not forget the importance of attention in models of WM (see Cowan, this volume; Bunting & Engle, this volume) and its pivotal role in both explicit (Schmidt, 2001), but also implicit (Williams, 2013) learning. Critical to both forms of learning is the assumption that in order to forge new associations in memory the relevant pieces of information need to be simultaneously active within the focus of attention (Cowan, this volume). When analysing learning situations, then, we need to consider, first, what the critical associations are (e.g. between forms and meaning, or forms and forms), the likelihood of bringing the relevant information into joint attentional focus (as determined, say, by the emphasis on form or meaning in the task, or by the distance between the relevant forms), and the role of different aspects of the WM system in bringing this about (e.g., rapid switching of attention between form and meaning, maintenance of phonological, syntactic, or semantic information during on-line processing).

Given all of the above, it is perhaps not surprising that where relationships between EWM and learning have been found it has been in relation to explicit, rather than implicit, learning situations (Kempe, Brooks, & Kharkhurin, 2010; Mackey, et al., 2002; K. I. Martin & Ellis, 2012, Tagarelli et al., this volume). This is presumably because EWM tasks tap the conscious maintenance of information during on-line processing in much the same way that explicit learning requires conscious maintenance of instances of input and hypotheses during listening and speaking tasks. This raises the question of what underlies variation in learning outcomes in implicit learning situations. Recent research suggests a connection between domain-general statistical learning ability and first language processing (Conway, et al., 2010) and first language proficiency (Misyak & Christiansen, 2012). At present, though, it is unclear what underlies this ability, how it should be conceived of within our cognitive models, or what contribution it makes to SLA. One would expect that the integrity of phonological storage would be relevant, at least for certain learning problems, because of the necessity to store the data from which generalisations are supposedly extracted. Although relationships between PSTM and grammar learning have been obtained, these relate to situations where learning was likely to be explicit, rather than implicit (French & O'Brien, 2008; K. I. Martin & Ellis, 2012; Williams & Lovatt, 2003). There is evidence for a correlation in the context of artificial grammar learning

(Karpicke & Pisoni, 2004) but more research looking at this issue in natural language learning is required. In general, whilst the involvement of WM in explicit learning seems to be becoming established, the bases for variation in implicit learning remain largely open for further research.

Models of working memory provide frameworks for helping us carry out detailed analyses of the cognitive processes underlying language learning and performance. WM tests provide a means of empirically testing these analyses through individual variation in the cognitive components that have been identified. As we progress, our analyses will suggest further aspects of WM that should be differentiated and measured, such as memory for order information, semantic STM, or attention switching. We can also look for interactions between WM and other, independently measurable, cognitive factors such as the extent of relevant first and second language knowledge, the automaticity of the targeted cognitive operations, and the implicitness or explicitness of the learning process. Interactions with age and proficiency will become reduced to underlying cognitive factors. In this way the study of WM provides real opportunities for deepening our understanding of the language learning process. As this volume amply illustrates, we are moving beyond the study of WM as a basis for aptitude, and towards using tests of WM, like tests of individual differences more generally, to inform theory building. If WM is a "language learning device" (Baddeley, Gathercole, & Papagno, 1998) then WM tests are tools for prising apart the device's components.

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