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THE EFFECTS OF WORKING MEMORY, PROCESSING SPEED, EXECUTIVE MEMORY, AND PRESENTATION SPEED ON SWEDISH LANGUAGE LEARNING

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Abstract

Individual differences in information processing have been suggested to affect second language (l2) learning. Adult participants with no prior knowledge of the Swedish language were tested for working memory, processing speed, and executive memory capacity. Participants then received 6 instructional sessions with animations of Swedish sentences, with each participant seeing some lessons at High and some at Low rates of presentation. Higher levels of Swedish performance during Instructional Sessions were associated with higher Working Memory levels. In contrast, measures of Swedish language performance at demanding long-term retrieval was more complex and revealed several dynamic relationships between Processing Speed, Working Memory, and Swedish language learning. Implications for theory refinements and adjustments in teaching to individual learner characteristics are discussed.

Table of Contents

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The Effects of Working Memory, Processing Speed, Executive Memory, and Presentation Speed on Swedish Language Learning

Current literature suggests individual differences in information processing may strongly affect second language learning. Yet, there are many gaps in research on patterns of instruction in second language learning based on individual's patterns of information processing. The present study provides an examination of how individual differences in information processing affect progress in second language acquisition. If adjustment in patterns of instruction in a second language to individual information processing profiles can facilitate learning, then there would be widespread applications both for children and adults.

Three important components of information processing are working memory, processing speed, and executive memory. Working memory has become increasingly common in the discussion of second-language acquisition (Baddeley & Hitch, 1994; Nelson, 2006). Working memory is an active short-term space for the storage of information while patterns are abstracted and encoded, and while current information is managed for decisions and actions. Processing speed is the component of information processing pertaining to rate at which information can be stored, accessed, and manipulated within working memory (Leonard, Weismer, Miller, Francis, Tomblin & Kail, 2007). However, processing speed and working memory are two separate components of information processing. Executive memory relates to the integrative and attentional control aspects of memory (Baddeley & Hitch, 1994; Demetriou et al., 2002; Roberts & Pennington, 1996). Executive processes typically coordinate or integrate two or more subprocesses of information processing. These key information processing components have been suggested to have significant influence on language learning.

Information Processing and Second Language (L2) Learning

There are a number of factors which affect an adult individual's second language (L2) learning. Cognitive abilities obviously are worth exploring in research. Skehan (2002) argued that learning mechanisms, different from those used in L1 learning, are what determine success at second language learning. These key differences between second language learning and first language acquisition put increased stress on individual's information processing. MacWhinney (2008) details that second language learning is learning more than acquisition because we actively process information rather than just acquiring it through everyday activity. Furthermore, any language learning after acquiring one's first language is associated with that first language by the individual. Second language learners in part transfer their first language world to acquiring the second language. They treat a word learned in the second language as another way of saying the first language word. This means the newly learned word relies on the first language structure. However, the goal of the second language learner should be to build second language representations that are not based solely on a first language word. This is done by linking the newly learned word to a new representation.

One important theoretical supposition here is that there is a competitive interplay between languages (Hernandez, Li & MacWhinney, 2005). This is in line with the emergentist theory proposed by Elizabeth Bates of first and second languages that emphasizes competition, plasticity and transfer. If two languages are acquired simultaneously early in infancy, then it is predicted that there will be little interaction between the two languages in early childhood. When the two languages are less perfectly balanced, however, then it is expected that there will be intrusions from the stronger language. These intrusions can be overcome by frequent use of the weaker language, which in turn strengthens the interactive connections between the weaker language.

In the case of adult learners of a second language, the young adult learns their L2 against the backdrop of a deeply entrenched L1 (Hernandez et al., 2005). This L1 will be relied upon in a parasitic way to bootstrap to the conceptual representations when learning the L2. Whereas the young preschool child bilingual is able to retain some plasticity and re-organize the lexical space due to lesser L1 entrenchment, the young adult in contrast will rely strongly upon the neural substrate for their L1. "Resonance" in the L2, or the ability to activate interactive connections in the second language, is possible via metacognitive procedures such as rehearsal, recoding and imagery. This can result in the L2 acquiring integrity independent of the L1 without full reorganization of the underlying neural system. However, until proficiency is acquired in the L2, there will be little separation between L1 and L2, and thus second language acquisition will depend heavily on the existing language representations. These theoretical speculations have yet to be integrated with research that also examines individual differences in information processing profiles of adults who are at early stages of second language (L2) acquisition.

Working memory plays a key role in information processing in regards to second language learning. One of the primary components of working memory is the phonological loop (Baddeley, Gathercole & Pagano, 1998). The phonological loop is the functional working memory component which stores information and rehearses it until it can be put into more permanent memory. This component’s primary function is to aid in language learning. Baddeley & Gathercole (1989) found that the capacity of the phonological loop is a strong predictor of both L1 and L2 vocabulary learning. For example, Baddeley et al. (1998) used a digit span and nonword repetition task to measure phonological loop capacity in children ranging from 2 to 13, and compared those scores with vocabulary knowledge. They found that throughout early and middle childhood, vocabulary scores were strongly correlated with the measures for phonological loop capacity. Correlations between a nonword repetition task and vocabulary knowledge ranged from 0.4 to 0.6. For a digit span task, correlation ranged from 0.25 and 0.45. Therefore, vocabulary knowledge could be predicted by phonological loop capacity.

Baddeley (2000) proposed another component of the working memory system, known as the episodic buffer. This is a limited temporary storage system that is distinct from the central executive in that it is primarily concerned with storage of information rather than attentional control. This episodic buffer is considered to be responsible for binding or integrating information from different sources into "chunks" or "episodes." This information could include phonological, visual, and spatial information, and possibly information not covered by the slave systems (e.g., semantic information, musical information).

Gilabert & Munoz (2010) further investigated the role of working memory in second language acquisition. Specifically, the study investigated whether working memory scores were associated with overall second language proficiency. Participants in the study were 59 undergraduate students who were native Spanish speakers and had gone through an English language course. The study then examined individuals' English language proficiency as well as working memory capacity. Using a reading span task along with a film retelling task to measure working memory, and the Oxford Placement Test along with two vocabulary tests to measure English language proficiency, it was determined that a correlation between working memory and overall English language performance existed. More specifically, it was found that higher working memory was associated with increased L2 fluency and variety of vocabulary used. Furthermore, working memory was found to be the strongest predictor of second-language acquisition. However, this study was limited in that it was not prospective; it did not determine working memory levels before tracking progress in English as L2.

Information Processing and First Language (L1) Learning

According to MacWhinney (2008), first language learning is acquisition rather than learning. We pick up our first language as we go more than we are actually “taught” this language. However, there are several in depth processes taking place during first language learning. Furthermore, there are a number of ways in which first language learning can be impaired or assisted, and multiple authors have shown that important variations in language learning rates can be understood by close analyses of variations in child-adult patterns of interaction (e.g., Nelson, 1989, 2001; Nelson et al., 2004).

Information processing is a key factor affecting the ways individuals learn, the pace at which they learn, and their performance of that learned material (Nelson & Arkenberg, 2008). When care is taken to improve the conditions in which learning takes place, learning is fostered. Furthermore, for learning to occur, a positive union of conditions must take place. The acronym LEARN contains 5 components which when united dynamically create a more conducive learning environment. These components are launchers, enhancers, adjustment, readiness, and networks. Any learning requires at least a minimal convergence of components, and as more of these components are optimized the rate of learning is increased. The launching condition consists of the opening in which learning can take place. This learning must be challenging, and the learner must be engaged. The enhancing condition is the aspect of learning where a partner may use strategies that enhance the learner's processing and where a learner's awareness of learning and active strategies to improve learning come into play. Metacognition is one key enhancer. The adjustment component refers to the aspect of learning in which social-emotional adjustment improves or declines, and changes in learning result. The readiness condition is the prior ability set the learner possesses. This can be basic knowledge of what is being learned, or it can be any relevant capacity for learning. Within the readiness component lies an individual's information processing abilities such as working memory, processing speed, and executive memory. The networks component of the LEARN acronym refers to neural networks. Arousal of these networks is necessary for attention to be active and learning to take place. Optimal arousal will help accelerate learning.

Several key components of information processing have been linked specifically to language learning. Executive memory has been linked to phonological awareness (Alloway, Gathercole, Adams, Willis, Eaglen & Lamont, 2005). Alloway et al. (2005) tested the working memory capacity and phonological awareness of 194 children between the ages of 4 to 6 in their first few months of school. Current performance in school was then measured. The study found that working memory, along with phonological awareness, was very important in many of the vital learning areas at the start of schooling, especially language development.

According to Leonard et al. (2007), limitations in processing speed and working memory are directly related since faster processing leads to a greater amount of information being held in working memory. However, the two are not the same. Moreover, attention has been identified as key to functional working memory. In Leonard et al.'s (2007) study, typically developing fourteen year olds as well as those with language impairments performed processing speed and working memory tasks, as well as completed a comprehensive language battery. The study suggested that limitations in these information processing components intensify existing language impairments and may actually be one of the initial causes of these impairments.

Gathercole and Baddeley (1993) have argued explicitly that for L1 learning phonological working memory is a crucial foundation (cf. Case, 1998). In a longitudinal study, 150 four year olds were given tests measuring reading, vocabulary, general intelligence, and a nonword repetition task to test phonological memory six weeks prior to the start of schooling. The children were retested at age 5, 6, and 8. Of the 150 children participating in the study, 70 could not read at the first testing session. At age 8, these children took the British Abilities Scales, Neale Test, and Primary Reading Test in order to test reading ability. The study found that phonological memory scores at age 4, as measured by the nonword repetition task, predicted reading ability scores at age 8 as measured by the Primary Reading Test.

Gathercole (1993) found that phonological working memory plays a serious role in language learning, and language disordered children have severe deficits in short-term retention of new phonological forms. In a study of language disordered 7 to 9 year olds, measures of phonological working memory were taken using a nonword repetition task. Language disordered children were found to perform much poorer on the task than control groups of typically developing children with matched nonverbal ability. Moreover, language disordered children's performance on the working memory task was at the same level as that of a typically developing 4 year old. However, while working memory skills were 4 years behind that of typically developing children, performance on standardized language tests was only 18 months behind typically developing children. These findings are further evidence of the importance of information processing components in language learning.

Potential Adjustments of L2 Software Presentation Patterns

As stated earlier, a key factor in second language learning is not thinking of a second language word as simply another way to say a first language word, but to link it to additional richer representations (Nelson, 2006; MacWhinney, 2008). Furthermore, combining multiple learning conditions as detailed with the LEARN acronym, enhances language learning conditions further (Nelson, 2001; Nelson et al., 2004; Nelson & Arkenberg, 2008). That is, rapid learning occurs when there are real-time, rapid dynamic convergences that bring together the Launching-challenges of L2 along with Enhancer patterns, positive Adjustment (social-emotionally), Readiness (cognitive), and strong Neural activations.

In the current study, this will be sought by using a newly revised version of the Omega-IS software program to link Swedish vocabulary words and sentences to animations rather than an English equivalent. Within the Omega program, learners can take the lead and make their own new mixes of words. The teacher's role for children in studies so far is to facilitate social emotional adjustment, attention and engagement, and follow-up conversation relevant to the challenges in the software. For children along the autism spectrum experiencing little to no gains in language development over preschool and early elementary years, gains of over 5 times baseline rates were achieved through using this instruction (Nelson & Arkenberg, 2008). New dynamic mixes of learning conditions within the program which differ from previous methods of instruction greatly increased learning. Moreover, allowing the learner to dictate the order in which items are learned was found to increase learning. In the present study for adults learning Swedish as L2, all of the above conditions will be similar except that an adult experimenter will mainly encourage and observe rather than actively converse with the learner.

Expectations of Impacts on L2 Learning of Individual Differences in Information Processing

As Gupta and MacWhinney (1997) observe: "Unfortunately, experimental psychology has paid little attention to the investigation of processes involved in learning new words, and virtually nothing is known about the abilities and component processes underlying this fundamental ability (p. 268)".

In line with this observation, literature to date has provided only a few rigorous studies with clear-cut association between individual measures of information processing capacities and L2 learning, and most of these have looked only at working memory. Further, unlike the present study, these studies with rare exceptions (Gathercole & Baddeley, 1989; Gathercole, Willis, Emslie, & Baddeley, 1992) have not been prospective: they have not measured information processing before learning encounters in L2 occur. The present study not only takes that step but also examines experimental contrasts in presentation speeds of learning materials. To do this, the study used specially-constructed software that allows evaluation of whether info-processing profiles interact with fast-versus-slow presentation speeds of multimedia animations that are central to learners building meaningful new representations for the Swedish L2 structures.

Although it might seem straightforward to assume that higher measures of working memory, processing speed, and executive memory will correlate with higher measures of Swedish language learning, there are other highly plausible relationships that might be expected in some learning contexts. First, no prior prospective study has ever examined all these together, so no firm empirical base can be relied upon. Second, a variety of models that discuss complex dynamics of converging information processing components in real-time while new sentences are being processed and related to nonverbal representations point toward other distinct possibilities. For example, under certain circumstances less rapid shuttling of verbal information into and out of working memory space for some individuals could support deeper processing of that verbal information and stronger, more complete encoding of word-sentence/meaning relationships into long-term memory (Nelson, 1998, 2000, 2006; Nelson et al., 2001; Pennington & Roberts, 1996; Thelen & Smith, 1996). The circumstances in the present study that most directly relate to those dynamic complexities are that half of the learning encounters for each participant incorporate fast presentation rates and half slow presentation rates.

Design of the Present Study

Prior literature has largely neglected how much processing speed, executive memory, and working memory contribute to the earliest stages of second language (L2) learning. Therefore, the present study is designed to fill that gap, by looking at how these factors affect Swedish language acquisition by English-speaking adults from the very first words and sentences they encounter. The central hypothesis of this study is that individual differences in these processes will contribute both to differences in initial learning during learning sessions and to differences in long-term retrieval of Swedish language at the end of the study. The study also tests whether in any respect higher versus lower pre-instruction abilities in working memory, processing speed, or executive memory interact with presentation speeds during software instruction in affecting Swedish L2 performance.

Method

Participants

Participants were 25 adults, ages 19 to 30 (mean = 21.1). Flyers for the study were posted in various buildings around the Penn State University campus. Participants in this study were required to have no previous exposure to the Swedish language. Of the 24 participants completing the study, 18 were female and 6 were male. Participants were compensated monetarily for their time.

Measures

This study included measures of processing speed, working memory, executive memory, and Swedish language ability at pretest. Multiple measures of progress in Swedish during the Instructional Sessions were also obtained. At posttest, the performance of participants in Swedish as a second language based upon longterm memory retrieval was assessed.

Pretest measures of information processing.

Processing speed. Subtests from the CTOPP were used to test participants processing speed (Wagner, Torgesen & Rashotte, 1999). A rapid color naming subtest asked the participant to name the color of each in a series of colored squares as rapidly as possible. The rapid object naming subtest asked the participant to recite the name of the object in a series of pictured objects as rapidly as possible. Fish, key, and house are examples of objects used in this subtest. The number of seconds to complete each task was recorded using a stopwatch.

Working memory. The digit span task asked participants to successfully repeat increasingly long series of numbers (Gathercole, Service, Hitch, Adams & Martin, 1999; Arkenberg, 2005). The numbers were spoken by the examiner at a rate of one per second. Immediately after the string of numbers was spoken, the participant repeated the series of numbers at his or her own rate. Points were awarded for each correct series of numbers from 2 to 9 number digits, with a maximum score of 24. The word span task asked participants to successfully repeat increasingly long series of words (Lonigan, Wagner, Torgesen & Rashotte, 2002). The words were spoken by the examiner at a rate of two per second. Immediately after the series of words was spoken, the participant repeated the string of words at his or her own rate. Points were awarded for number of correct series of words from 2 to 7 words, for a maximum score of 21.

Executive memory. The OSpan operational memory task measured participants' executive memory (Turner & Engle, 1989). This task required participants to correctly identify a series of mathematical equations as either correct or incorrect while memorizing English words that showed up in between each equation. After a series of equations the words were to be recalled. The words did not have to be recalled in order. However, the last word seen in the series could not be recalled first. After each set, the number of equations and English words seen was increased. Equal points were given for correctly answering the mathematical equation and recalling the word for a maximum score of 60.

Pretest checks on initial Swedish skills before instruction.

Swedish word & phrase pretest. In order to measure individual's Swedish language ability, a paper pre-test was given, consisting of a list of Swedish words and phrases next to which the participant was asked to write the correct English translation. Participants were awarded points for each correct English translation for a maximum score of 35. Pretest scores on Swedish were initially low (mean = 0.48).

Omega pretest. As another measure of Swedish language ability, the participants went through a pretest in the Omega-IS software program where they viewed an animation and then had to form the correct phrase from a list of Swedish vocabulary. Participants were awarded points for each correct phrase for a maximum score of 12.

Measures of progress in Swedish during 6 instructional sessions.

Omega lesson tests. For sessions 2 through 7, participants used the Omega-IS software program to learn Swedish words and phrases. Within the software program, participants were asked to take a number of tests following the learning phase for that lesson. The tests consisted of a simple animation being shown, following which the participant had to form the correct phrase from the bank of Swedish vocabulary. No feedback was given following each entry. Following the series of animations, scores for number of correct and incorrect words and sentences were given.

Long-term retrieval post-testing.

Session 8 consisted of 3 written post-tests being administered.

Familiar Swedish post-test. The first post-test was the same Swedish word and phrase test administered in the pre-testing session. These words and phrases taught during the instructional sessions. Points were awarded for number of correct English translations given for a maximum score of 35.

Recalling from fast-presentation lessons compared with slow-presentation lessons. The second of the post-tests consisted of words and phrases taken together from each lesson in the study. Each participant saw 20 words and phrases from lessons viewed in the fast speed and 20 from lessons viewed in the slow speed. Points were awarded for number of correct English translations given for a maximum score of 40.

New combination post-test. The third posttest consisted of new combinations of words that had been learned during the study but had never been seen together. Points were awarded for number of correct English translations given for a maximum score of 18.

Total Old and New combinations at post-test. An average of Z-scores for the New Combinations post-test and the Familiar Swedish post-test served as a composite measure of Swedish Learning.

Procedures

During session 1 of the study, participant demographic information was collected, consent forms were signed, and participants were then taken through each of the processing speed, working memory, and executive memory pretest measures.

Following the initial session, participants were randomly assigned to either group A or group B. Participants in each group saw half of the Omega lessons and tests at the fast rate of presentation and half at the slow rate of presentation. Speed was counterbalanced such that those animations that group A saw at the fast presentation rate were seen at the slow rate of presentation speed by group B. The animations seen by group A at slow rates of presentation were seen by group B at the fast rate.

Starting at session 2 and continuing through session 7, participants used the Omega-IS interactive sentence program to learn Swedish words and phrases. During session 2, participants were directed to choose individual nouns from a list of Swedish words. The selection of each word resulted in a voice pronouncing that word, and that word was displayed in an animation on the screen. Starting in session 3, participants created phrases (2 words per phrase in session 3 and up to 8 words per phrase in session 7). Each word selected resulted in the Swedish pronunciation of that word. Following the creation of a phrase/sentence, the voice repeated the entire phrase, following which an animation displayed the meaning of that phrase. After the instructed number of phrase/sentences was created, encompassing each new word possibility for that lesson, the participant either moved onto the next lesson or took the Omega lesson test, if one was required. In the Omega lesson tests, the animation was displayed first, and then the correct phrase/sentence was to be created from the bank of possible Swedish words. Difficulty of Swedish phrases and sentences increased by advancing session. For example, among the sentences to be learned in Session was “fageln jagar moroten”, and in Session 7, sentences to be learned included “den sjungande pingvinen seglar over sjon och pekar pa bjornen”.

Session 8 consisted of post-testing, at least 48 hours after session 7. The Swedish words and phrase post-test, the old combination (fast versus slow presentation) post-test, and the new combinations post-test were administered.

Results

As hypothesized, individual differences at pretest on information processing measures were predictive of differences in acquisition of Swedish as a second language. This overall outcome will be seen in each of the following three sections of results.

Performance on Swedish Lessons during Instructional Sessions

The earliest of the 6 instructional sessions with Omega-IS software built the learners' confidence and established an initial foundation of Swedish words and simple Swedish sentences. Learners were so consistently close to 100% performance that these early lessons were not further analyzed. The remaining data in this section are for the final 3, most complex lessons that each participant encountered.

Swedish performance on sentences in these last 3 lessons per participant was scored in percentage correct terms. Average performance on sentences for the final 3 lessons was significantly higher for learners with High or Medium Working Memory/Digit-Span abilities at pretest as compared with those with Low Working Memory/Digit-Span abilities at pretest, $F(2,18) = 5.02$, $p < .02$, partial eta square = *.358, very large effect size.* Mean proportions correct respectively for High (n = 6), Medium (n = 11), and Low (n = 7) Working Memory were 95.1 (SD = .039), 93.8 (SD = .048), and 85.4 (SD = .105). This result is one confirmation of the key hypothesis of the study.

Performance in Swedish Overall Based Upon Longterm Retrieval at Posttest

A first measure of Swedish performance at posttest was a composite of some sentences "new" at posttest (not ever presented during Instruction) and sampled sentences and words that were encountered during the instructional sessions. Learner performance again varied by pretest cognitive abilities. In this instance, learner performance was an interaction between Working Memory/Digit-Span and Processing Speed/Object Naming, $F\ (2, 18) = 3.56$, $p < .05$, partial eta squared = .284, *very large effect size.* Learners with Low Processing Speed showed variation according to levels of Working Memory: 29.0 (SD = 5.57) for those with High Working Memory, 32.3 (SD = 4.68) for those with Medium Working Memory and 22.0 (SD = 7.57) for those with Low Working Memory. In contrast, Learners with High Processing Speed showed increasing performance as levels of Working Memory *declined*: 24.0 (SD = 3.00) for those with High Working Memory, 28.8 (SD = 8.04) for those with Medium Working Memory, and 32.3 (SD = 3.21) for those with Low Working Memory. As part of this interaction, it is thus apparent that the very highest Swedish performance based upon longterm retrieval was for participants either with a combination of High Processing Speed and Low Working Memory or a combination of Low Processing Speed and Medium Working Memory, whereas the very lowest Swedish performance based upon longterm retrieval was for participants with a combination of Low Processing Speed and Low Working Memory.

These results indicate that by longterm retrieval of new Swedish skills after all Instruction was completed, there are dynamic interactions of information-processing components that contributed during Instruction to the deepest and fullest levels of processing achieved.

Performance in Swedish Based Upon Longterm Retrieval at Posttest from Software Lessons Presented at High versus Low Presentation Rates

Performance was first examined here for a set of 20 sentences that had been presented at Fast Presentation Rates during the Instructional sessions. Learner performance was predicted significantly both by Working Memory/Word-Span, $F(2, 18) = 5.60$, $p < .03$, partial eta squared = .237, *very large effect size*, and by Processing Speed/Color-Naming, $F(2, 18) = 4.80$, $p < .02$, partial eta squared = .348, *very large effect size*. Swedish longterm performance was higher for *lower* cognitive levels at pretest for Working Memory. Swedish mean performance was 12.76 (SD = 4.60) for learners with Low Working Memory (n = 11) versus 9.16 (SD = 3.82) for those with High Working Memory (n = 13). Similarly, Swedish mean performance was higher at 14.13 (SD = 3.37) for learners with Low Processing Speed (n = 8) than for those with either Medium (n = 10, mean = 8.90, SD = 4.20) or High (n = 6, mean =9.83, SD = 3.97) levels of Processing Speed. As compared for results on Swedish performance during the Instructional sessions, these findings on Swedish performance at posttest where longterm retrieval was required again implicate interesting dynamic interactions of information-processing components contributing to deep processing and highly successful encoding of new L2 knowledge into longterm memory.

For a matched-difficulty set of sentences that had been presented at Slow Presentation Rates, performance on the long-term testing showed no systematic relation to any of the pretest measures of Information Processing. It would seem that learners of all levels of information processing abilities were able to establish similarly successful longterm memory representations of the Swedish material presented during Instruction *if* material was presented at the (relatively) slow rate.

Discussion

Multiple findings confirm the central hypothesis of this study that individual differences in these processes would contribute both to differences in initial learning during learning sessions and to differences in long-term retrieval of Swedish language at the end of the study. These outcomes will be examined in the next two sections and then final sections will consider implications of the findings.

L2 Performance during Instruction

Working memory did predict Swedish language learning. First, performance on the final three Omega lessons was directly related to level of working memory as measured by the digit span task. The high and medium working memory groups performed significantly better on the Omega lesson tests than did the low working memory group. This finding of higher levels of WM predicting better L2 language gains carries a very large effect size but otherwise matches the one most similar prior prospective study conducted for children and their longitudinal first language progress by Gathercole & Baddeley (1989).

L2 Performance Based Upon Long-term Retrieval

Working Memory as measured by the digit span task together with Processing Speed as measured by the rapid object naming task affected performance on a posttest composite of new word combinations previously unseen, plus some phrases seen during instruction. Those with low processing speed and medium or high working memory capacity performed better than those with low processing speed and low working memory. However, participants with high processing speed and low working memory performed better than those with high processing speed and medium or high working memory. As part of this significant interaction, longterm retrieval of Swedish was highest for two contrasting subgroups: those with high processing speed and low working memory, and those with low processing speed and medium working memory. Dynamic interactions of information processing components existed and likely affected levels of longterm encoding during Instruction and the subsequent performance on longterm retrieval of Swedish at post-testing.

Performance on the posttest of sentences specifically seen at the Fast Presentation Rate during instruction were predicted by working memory as measured by the word span task and processing speed as measured by the rapid color naming task. It is interesting that for encoding into longterm memory during Instruction and then delayed longterm retrieval at posttest, that it is a *verbal* span measure of working memory that was predictive. Performance on the posttest was higher for those with lower working memory scores than for those with medium or high working memory scores. Scores were also higher for those with low processing speed than medium or high processing speed. Material presented during Instruction at the slow rate was learned equally well by all participants regardless of individual information processing abilities.

Some of the dynamic interactions of information processing components appear to be similar to parts of Newport's (1990) "Less is More" Hypothesis. This hypothesis states that as individual's age and development increases, certain aspects of their language learning potential declines because, paradoxically, cognitive abilities increase. Children at ages 1 1/2 to 3 years of age may more easily perceive and store component sentence parts rather than complex wholes like adults. Consequently, under the actual dynamic conditions of encountering new syntactic challenges, children are better at isolating parts required for recombination. Lower information processing capacity, such as that in young children, could then lead to better progress in the earliest stages of syntax learning.

This hypothesis may fit well with other dynamic systems accounts of why in this study at longterm retrieval lower information processing capacities sometimes were associated with higher Swedish retention and performance. Dynamic interaction of information processing components (cf. Demetriou et al., 2002;Elman et al., 1996; Gupta & MacWhinney, 1997; Nelson, 1989, 2000; 2006; Nelson et al., 2001; Nelson et al., 2004; Nelson & Arkenberg, 2008; Peltzer -Karpf & Zangl, 2001; Roberts & Pennington, 1996; Thelen & Smith, 1996) appears to be a plausible explanation of why those with high processing speed and low working memory performed better than those with high processing speed and high working memory on the composite Overall Swedish (both old and new sentences) posttest. Those with lower working memory may have been more capable of learning Swedish component parts during Instruction to a deep level of longterm memory encoding, and could therefore demonstrate longterm retention and employ the learned Swedish at posttest in both previously-seen and new combinations. Furthermore, this same dynamic account of some paradoxically higher levels of encoding during Instruction, depending upon not-too-high processing speed and not-too-high working memory, could explain why performance on the posttest of sentences presented at the fast pace during Instruction was better for participants with low working memory and for participants with low processing speed. When each part of a sentence is processed a bit slower and in the presence of a smaller "span" of items simultaneously in working memory, then each part may receive fuller, deeper encoding into longterm memory. For the tests during Instructional sessions that relied upon relatively shorter-term memory, these dynamic interactions were not apparent, but were visible only when Swedish L2 performance was examined at the longer-term post-testing.

The current study had a number of limitations. First, if a sample size larger than 24 could have been used, other significant results may have been seen. Nevertheless, theoretically-predicted and conceptually important differences did reach significance, with very large effect sizes in each case. Information-processing profiles of beginning L2 learners as well as

Presentation Speed of lessons do indeed help to account for differences in performance, both during Instruction and in demanding long-term retrieval tests. Future research could build upon these findings by investigating how particular syntactic structures can best be taught to individuals with varying information processing profiles, by experimentally varying other features of lesson presentation in addition to animation speeds, and by experimentally establishing "best fits" between lesson design and individuals' characteristics.

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Appendix A: Tables and Figures

Table 1

Mean (with standard deviation) long-term retrieval in session 8 on a composite of Old (previously seen) and New (new phrases) Swedish sentence meanings, as related to working memory and processing speed. Working Memory from the Digit Span task was divided into groups with low, medium, and high performance. Processing speed, as measured by performance on the Rapid Object Naming measure was divided between low and high processing speed.

	Low Working Memory	Medium Working Memory	High Working Memory
High processing speed	32.3 (3.21)	28.8 (8.04)	24.0 (3.00)
Low Processing Speed	22.0 (7.57)	32.3 (4.68)	29.0 (5.57)

Figure 1. Mean Percent correct (with standard error) on the last three Omega Swedish Instructional Sessions at each of three working memory levels (low, medium, or high) based on performance on a digit span task.

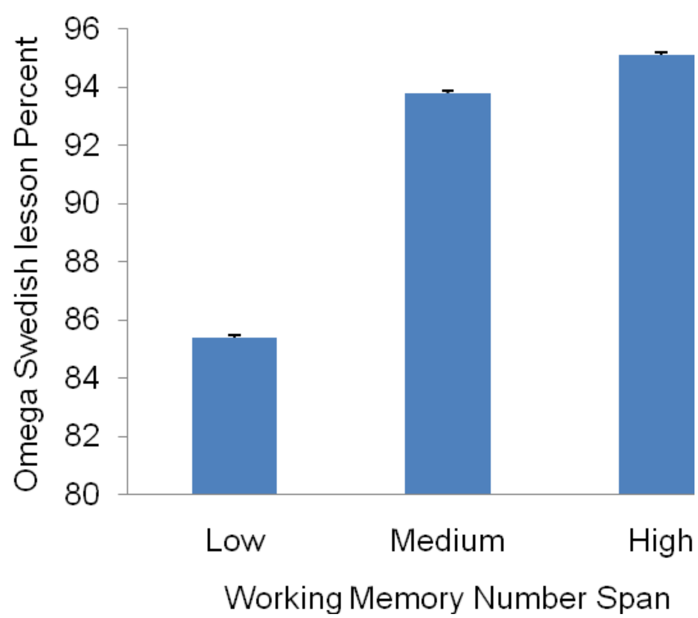


Figure 2. Mean performance (with standard error bars) for performance on long-term retrieval of meanings for sentences previously presented at fast speeds, during the lesson 8 long-term retrieval post-test. Performance on Swedish for participants with high versus low scores on working memory as measured by Word Span.

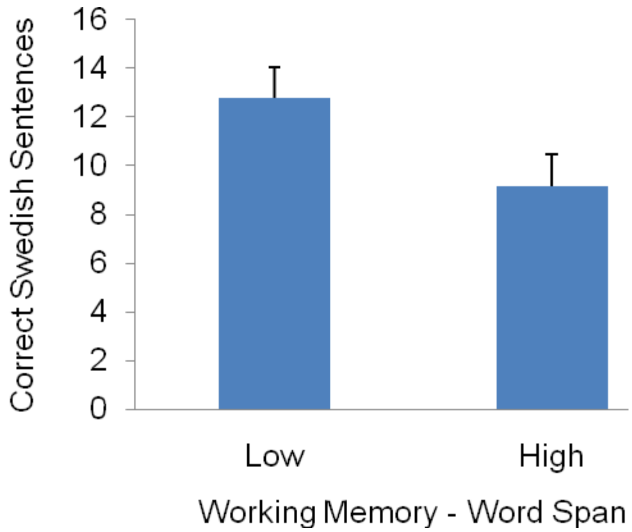
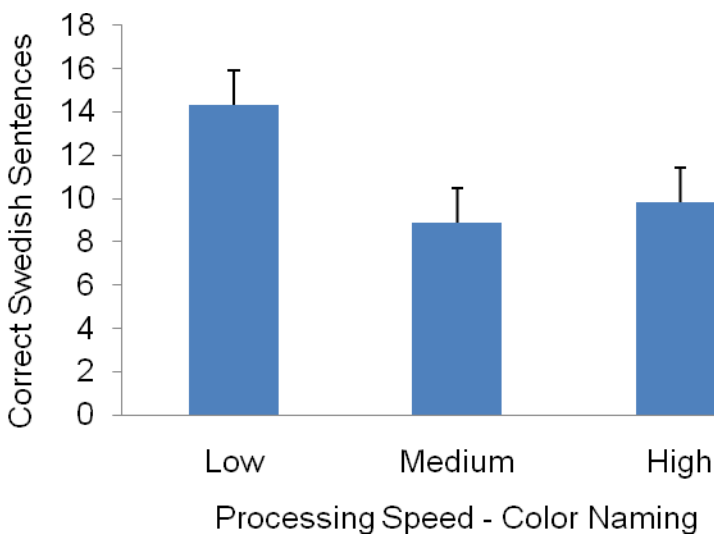


Figure 3. Mean performance (with standard error bars) for performance on long-term retrieval of meanings for sentences previously presented at fast speeds, during the Session 8 long-term retrieval post-test. Performance on Swedish for participants with low, medium, or high processing speeds based on Color Naming.



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