An investigation of chunking and inhibitory processes in young and older adults using a sequential action paradigm

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Abstract

An investigation of chunking and inhibitory processes in young and older adults using a sequential action paradigm

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The completion of a sequence of actions in a fixed order is necessary to perform everyday activities. One line of research posits that all actions in a sequence are activated simultaneously and inhibited upon completion whereas another viewpoint suggests the successive activation of chunks of to-be-performed actions. Previous work using a sequential monitoring task indicated that chunks of items were retrieved successively from long-term memory and inhibited upon completion, suggesting a hybrid model of serial behaviour. The objective of this thesis was to examine inhibitory and chunking processes in sequential behaviour and how they change with aging. Participants learned an 8-item sequence and subsequently responded to these items in the order learnt while ignoring distractors (items out of sequence). Chunking and inhibitory processes were simulated by training participants to use overt articulation of chunked items, either with or without suppression of completed items: One group of participants continuously recited both items in each chunk in an 8-item sequence (chunking only) whereas another grouped recited both chunk items initially but subsequently updated their recital to the last item of the chunk (chunking plus inhibition). The role of chunking in sequential behaviour was supported as the chunking strategies employed resulted in similar findings as previous research. Further, suppression of previous items from conscious awareness was evident in YA compared to OA, consistent with the inhibition deficit hypothesis, which states that the ability to suppress previous task-relevant information declines with aging. Together, these results support the proposed hybrid model of sequential performance.

Acknowledgements

I wish to thank my supervisor, Dr. Karen Li, for setting the stage for the paradigm used in this study and her guidance, support, and insightful feedback in the course of this project. I also wish to thank Stephanie Torok and Anne Bailey for their help setting up this study and data collection, and current and former members of the Li Lab for their support and advice throughout this project.

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An investigation of chunking and inhibitory processes in young and older adults using a sequential action paradigm

As the population of older individuals grows, more pressure is placed on nursing homes and other care facilities. Along with other factors (increasing age, family support, and the presence of medical conditions such as a stroke and musculoskeletal disorders), cognitive status plays a significant role in deciding an older individual's capacity for independent living (Tomiak, Berthelot, Guimond, & Mustard, 2000). Status of cognitive functioning impacts both high level activities of daily living (ADL), such as shopping and meal preparation, and basic ADLs, including dressing and bathing. Regulating sequential action is necessary to successfully carry out various ADLs. This is defined as the completion of a series of actions, steps or tasks in a specified order. For instance, when making toast, we take the bread out of the bag, put it into the toaster, press down the lever, wait for it to pop, remove our toast, and apply butter or a spread of choice. Even tasks that are less subjected to temporal constraints, such as writing and mailing a letter in which steps can be performed in various sequences, show remarkable consistency in the way they are performed. This observation that various tasks are executed in a fixed order suggests that the regulation of sequential actions is stored in long term memory (Humphreys & Forde, 1998). The goal of this research was to improve our understanding of the mechanisms underlying sequential behaviour over the lifespan by comparing the performance of a group of younger adults (YA) and older adults (OA) on a sequential task.

Executive control processes, which are high-level cognitive processes responsible for planning and coordinating lower level cognitive operations in order to guide behavioural activity (Salthouse, Atkinson, & Berish, 2003), are known to be age sensitive (Salthouse, 2004; Verhaeghen & Cerella, 2002). One of the many theoretical accounts to explain reduced executive control in OA is the Inhibition Deficit Hypothesis (IDH), which states that working memory becomes increasingly "cluttered" in these individuals due to difficulty in removing or preventing the entry of irrelevant information (Hasher, Zacks, & May, 1999). The objective of this research was to examine the underlying executive control mechanisms involved in sequential behaviour, such as inhibitory processes and also hierarchical control processes that are responsible for subdividing action sequences.

In this study, individuals learned a fixed series of stimuli and subsequently performed a sequential monitoring task. To fully understand the nature of the task used and the executive control mechanisms found using this methodology, a number of relevant issues relating to sequential action regulation are reviewed. These include theories of sequential behaviour, aging and sequential performance and lastly, aging and inhibitory control.

Theories of Sequential Action Regulation

Over a half a century ago, Lashley (1951) proposed that similar underlying mechanisms were responsible for integrating serial order in various facets of behaviour including spoken and written language production, typing, musical production, and many other activities. He pointed out the inadequacy of associative chain theories dominant at the time, which state that serial behaviour is accomplished by inherent cues within each sequence element which indicate the next step in sequential tasks. For instance, no particular letter or word consistently follows another; each letter used depends on the nature of the word and each word used depends on the structure of the sentence. He surmised that the activation of future sequence elements, as observed by widespread anticipatory errors in typing and language production (e.g. Spoonerisms such as "our queer old dean" instead of "our dear old queen"), suggest that actions to be carried out are activated in parallel in conscious awareness before they are executed. He postulated that an underlying mechanism existed, independent of sequence elements, which represents the general structure of the order in which actions are produced. However, he noted that "the real problem, however, is the nature of the selective mechanism by which the particular acts are picked out" (Lashley, 1951, p. 130).

Along with the parallel activation of sequence elements theorized by Lashley (1951), Estes (1972) proposed that inhibitory processes also facilitate the execution of serial output. In particular, he suggested that processes of inhibition among sequence elements and inhibition of each element upon execution were integral to serial performance. Following up on ideas proposed by Lashley and Estes, Houghton (1990) introduced a competitive queuing model of sequential behaviour which retained the idea of parallel activation of sequence elements as well as inhibitory processes, particularly due to their ubiquitous effects on the neuronal level (Houghton & Tipper, 1996). In the competitive queuing model, many nodes or representations of actions to be performed are concurrently activated in working memory. Each item node is represented by a filter node by a one to one correspondence in a competitive filter network. In this network, designated as a "winner take all" layer, the most active node inhibits subsequent nodes. This imbalance in activation across the competitive filter sets up a gradient of activation. After reaching a threshold of activation, the most active filter node inhibits its corresponding item node thereby deactivating this node and as a result, makes the action it represents less likely to reoccur. This deactivation of the previously most active node is referred to as self inhibition. This self inhibition of previously completed actions changes the gradient of activation across the competitive filter allowing for the sequence of actions to move forward.

In contrast to models stipulating simultaneous activation of actions to be performed followed by self inhibition, a competing viewpoint posited by Logan (2004) suggests the successive activation of chunks of actions to be performed. Logan arrived at this conclusion in the context of a task switching paradigm, which usually requires individuals to flexibly repeat or switch between performing a series of tasks upon target stimuli (Monsell, 2003). Logan had participants study tasks composed of three types of judgements: magnitude (greater than or less than five), parity (odd or even), and form (number or digit). Mixed blocks comprised of the three tasks studied were subsequently performed on numbers one through nine presented in digit and word formats. Logan found a scalloped pattern of performance for reaction time (RT) at each list position suggesting that participants retrieved the tasks from long term memory in 3-element chunks, consistent with the structure of the string of tasks to be performed, namely, the three kinds of judgements. He concluded that chunks were initially slow to be retrieved from long term memory, but when brought into working memory, remaining chunk elements were subsequently "unpacked", allowing for faster responses.

In a subsequent experiment, Logan (2004) also found that manipulating list length changed the number of elements within chunks. For instance, when list lengths consisted of two, three, six, and nine tasks, a scalloped pattern in RT was again evident with chunks made up of three tasks as shown by slower RT at serial positions one, four, and seven. However, participants exposed to list lengths composed of two, four, six, and eight tasks, chunked the sequence into sets of two or four as indicated by slower RT at positions one, five, and seven. Logan's results suggested that the sequential task structure influenced the way in which chunks were retrieved from long term memory. Together, Logan's results are consistent with retrieval of sequential tasks in chunks from long term memory and are at odds with theories that suggest that all actions or tasks are activated in parallel in working memory, namely, the competitive queuing model of sequential action regulation (Houghton, 1990; Houghton & Tipper, 1996). Notably, Logan's model does not assume that inhibitory processes are involved in sequential action.

Aging and Sequential Performance

Using a new paradigm known as the sequential action (S-ACT) task, recent research by Li and colleagues (Li & Chow, 2006; Li, Lindenberger, Rünger, & Frensch, 2000) has provided evidence for both chunking and inhibitory processes in serial behaviour. In research by Li et al. (2000), younger participants responded to a fixed series of stimuli from arbitrary categories, for instance, Chinese characters and math symbols. They observed evidence for lateral and self inhibition from the type of lag errors observed. Lag errors were defined as engaging in tasks that were ahead of the target (anticipatory errors) or performing actions previously completed (perseverative errors). They found that lag errors were suppressed around the target item and increased laterally at more distant lags, providing support for lateral inhibition. Evidence for self-inhibition was observed by fewer lag errors for items previously responded to (at the n - 1 position) as compared to items one step ahead of the current target (at the n + 1 position).

However, research by Rünger (2002) suggested that the pattern of lateral inhibition observed by Li et al. was due to visual similarity in stimuli used, but self inhibition remained a robust factor underlying the pattern of results obtained.

In a follow up study by Li and Chow (2006), both young and older participants memorized a list of eight animals that were arranged according to size. Sequential items with an increasing order were employed because stimuli with an inherent order are more akin to performing everyday sequential activities as opposed to tasks with arbitrary stimulus sets as used by Li et al. (2000). Participants were presented with trials of 15-17 stimuli and were instructed to respond only to the ordered sequence (bolded: **1**-8-3-**2**-5-**3**...) and not to respond to items out of sequence. Median RT analyzed as a function of serial position revealed a scalloped pattern: participants responded slower to every other item (i.e., $RT_1 > RT_2$; $RT_3 > RT_4$). In line with Logan's (2004) findings, it was inferred from this pattern that participants spontaneously retrieved 2-item chunks from long term memory to facilitate sequence recall. Evidence for self inhibition was found in the type of lag errors observed. Both groups of participants made significantly more anticipatory errors that were one step ahead of the target (Lag + 1 errors) compared to items that were just completed (Lag - 1 errors). This pattern suggested that participants were less likely to produce perseverative errors as previous items were inhibited, supporting an underlying self-inhibition mechanism.

Further, in a subsequent experiment by Li and Chow (2006), a scrambled order of sequential items was compared to a canonical arrangement (i.e., increasing order). They found an exaggerated chunking pattern in the scrambled order that was indicated by longer response latencies within chunks. YA were faster at chunking the canonical sequence as compared to the scrambled sequence, but OA had similar difficulty chunking both sequences. This pattern of results had two main implications: firstly, it indicated that OA have particular difficulty chunking sequential items, likely due to slower retrieval of chunks from long term memory; secondly, this observation suggested that a scrambled sequences is less amenable to chunking, likely due to difficulty finding commonality among items in a sequence with no particular common links or associations among items. Notably, self inhibition was absent for both groups in the scrambled sequence.

Overall, Li and Chow's (2006) results suggested a hybrid model of sequential action regulation that involved chunking and also inhibition, particularly when items were in a canonical order. Based on the scalloped RT pattern observed, both age groups engaged in chunking, but OA showed slower chunk retrieval from long term memory and less benefit to sequential performance. Self inhibition, as operationalized by the asymmetry of anticipatory and perseverative errors, was similar in YA and OA in the canonical sequence, but absent for both groups in the scrambled sequence.

Inhibition and Aging

Decline in cognitive functioning over the lifespan, documented in areas such as speed of processing, reasoning, and memory (Salthouse, 2004; Verhaeghen & Cerella, 2002), has been attributed to reduced efficiency in a number of executive control processes. Recent research indicates that executive control processes – the ability to coordinate one's attention between multiple tasks, update working memory as environmental demands change, and maintain inhibitory control – mediate the relationship between age and decline in cognitive functioning in old age (Salthouse et al. 2003). One of the most investigated theoretical accounts of reduced executive control in the area of aging and inhibitory control is the Inhibition Deficit Hypothesis (IDH; Hasher et al., 1999). According to the IDH, three aspects of inhibitory control that are age sensitive include the *access* function of inhibitory control which prevents irrelevant information from entering working memory; the *deletion* function which clears working memory of information that is no longer relevant to the present task; and the *restraint* function which precludes the activation and performance of prepotent responses, leaving open the possibility for unlikely but appropriate behaviours to be carried out. With efficiently operating inhibitory mechanisms, only information relevant to the task at hand is activated in working memory. However, because inhibitory mechanisms decline with aging, working memory is often imbued with additional irrelevant information that impairs cognitive functioning in areas such as memory recall and retrieval (Zacks, Hasher, & Li, 2000).

In regards to the deletion function, Zacks, Radvansky, and Hasher (1996) observed reduced inhibitory control in OA using a directed forgetting paradigm. In this task, individuals were exposed to items that are designated as to-be-remembered or – forgotten, however, all list items were tested for later recall. Consistent with an inefficient deletion mechanism, when surprisingly asked for all items seen, OA showed more intrusion errors in recall from items that were to-be-forgotten and evidenced less of a difference between to-be-remembered and -forgotten items than YA. These results were in accordance with reduced inhibitory control in OA.

Recently, the IDH has been called into question due to mixed findings in the literature, particularly in regards to the deletion function (Maylor, Schlaghecken, & Watson, 2005). For instance, repetition inhibition in serial recall known as the

Ranschburg effect was greater in OA compared to YA (Maylor & Henson, 2000). In serial recall studies, the Ranschburg effect is the general finding of poorer recall for nonadjacent repeated items in a list compared to nonrepeated items at the same serial position in a different list. Poor recall for repeated items is attributed to inhibitory processes, which suppress further activation of an item already recalled. Contrary to the IDH, Maylor and Henson (2000) found that recall for repeated items was more suppressed in OA compared to YA; thus, self inhibition or response suppression which makes recall or repetition of a previous response less likely was greater in OA. Further, in a task switching paradigm, decline in backward inhibition was not observed in OA as compared to YA (Mayr, 2001). For example, the effects of backward inhibition were observed when participants were slower to make a colour judgement on trial *n* if a similar judgment as opposed to a different judgement (such as a shape judgement) was made on trial *n* - 2. Therefore, no age difference was found in persisting inhibition, which resulted in slowed responding on the present task if the task set was engaged recently.

Mixed results have also been found in the context of visual marking (Watson & Maylor, 2002), which also relates to the deletion function of inhibition. In their first experiment, Watson and Maylor (2002) examined the time to search for visual targets in three conditions: a single feature condition in which the target was presented simultaneously with distractors of the same colour; the conjunction condition in which the target, and distractors of similar and dissimilar colours to that of the target were presented simultaneously; and a preview condition in which dissimilar coloured distractors to that of the target were first presented and remained on a display in which the target and distractors of the same colour were subsequently added. Similar search rates in the preview condition as the single feature condition indicated that an individual could successfully ignore old items in the preview condition and search for the target among the new set of stimuli, resulting in a preview benefit. They observed that the time to find the target was similarly faster in the single feature and preview condition compared to the conjunction condition for both YA and OA. Thus, successfully ignoring old items in the preview condition allowed for faster responding to the target for both YA and OA compared to the conjunction condition, suggesting no age difference in the ability to inhibit previewed stimuli. However, in subsequent experiments, age effects in visual marking consistent with the IDH were observed with moving stimuli: when distractors and target stimuli moved down the screen and also when presented in a rotated format, which allowed for the previewed items to be grouped as a single virtual object. Thus, the preview benefit disappeared for the older group with moving stimuli: response latency in the conjunction condition was similar to that of the preview condition in OA; however, the same pattern of results was obtained for YA as was found with stationary stimuli.

There are a number of ways to reconcile these conflicting findings on the deletion function, as well as mixed research on inhibitory mechanisms as a whole (Maylor et al., 2005). It is possible that the deletion function may not represent a unitary inhibitory mechanism or may differ depending on the type of paradigm used. Along these same lines is the possibility that inhibitory mechanisms in general are subserved by different areas of the brain that are differentially affected by the effects of aging (Maylor et al., 2005). A more drastic alternative is the suggestion that studies presumably examining measures of inhibition may be looking at entirely different mechanisms, such as conflict resolution between distracting and target stimuli (MacLeod, Dodd, Sheard, Wilson, & Bibi, 2003). Despite conflicting results regarding the deletion function of the IDH mentioned above as it relates to the suppression or inhibition of no longer relevant information, it remains one of many global explanations of declining cognitive functioning in OA.

Present Study

The present study follows up on recent research by Li and colleagues (Li & Chow, 2006; Li et al., 2000) in using the S-ACT paradigm to further aid our understanding of various mechanisms, including inhibitory processes, in sequential action. Participants memorized an 8-item sequence in a specific order and subsequently monitored for these items as they were presented on a computer screen. They responded when presented with the item they were looking for according to its position within the sequence while ignoring distractors mixed within (items out of sequence). We examined two theories of sequential action regulation, namely the chunking model (Logan, 2004) and competitive queuing model (Houghton, 1990; Houghton & Tipper, 1996) of sequential action regulation. The primary goal of this research was to assess the utility of chunking, and also mechanisms of self inhibition in coordinating serial behaviour. The self inhibition function was examined in this study in the context of the deletion function of IDH (Hasher et al., 1999), as it pertains to the suppression or removal of item information to which a response was recently made.

To date, research supporting the chunking theory in a sequential action task is based on the assumption that participants spontaneously chunked without being trained to do so. We aimed to extend the findings of Li and Chow (2006) with a direct manipulation of chunking strategy to examine the effects of training a chunking strategy in younger and older groups. Rather than inferring that chunking occurred, participants were trained to chunk the same 8-item animal list in 2-element chunks. Further, we explored facilitatory effects of overtly articulating the items, which is posited to keep target items in an active state in working memory, thereby reducing interference from irrelevant information (Bryck & Mayr, 2003; Kray, Eber, & Lindenberger, 2004). Optimally maintaining target items in working memory by means of item rehearsal harkens back to Baddeley's (1986) model of working memory in which subvocal rehearsal maintains items in the phonological loop, and hence, readily available in conscious awareness. In fact, Bryck and Mayr (2003) showed that disruption of inner speech by means of task irrelevant verbalization (articulatory suppression) increased switch costs in a task switching paradigm; however, in a follow up experiment, the impact of articulatory suppression was reduced when external cues were added to reduce the need for rehearsal of task sequences. Furthermore, in a highly demanding task switching setting (i.e., no external cueing specifying switch versus no-switch trials) in which tasks repeated and switched in the same block, they found similar effects of articulatory suppression when participants switched tasks compared to when they repeated the prior task. This result led Bryck and Mayr to conclude that verbalization may play a crucial role in maintaining and updating task relevant information during sequential tasks. The role of overt articulation of task goals was also examined by Goschke (2000). He found that when participants had a long time (1500ms) to prepare for upcoming tasks in a task switching setting, switch costs were reduced when they engaged in task relevant as opposed to task irrelevant overt verbalizations.

Given that verbalization is important for keeping task relevant information readily available in task switching paradigms and the fundamental role of language for self guidance and regulation as posited by Vygotsky (1988), we used two articulation methods to simulate two possible models of sequential action regulation in this study. The two articulation strategies used in the current study were designed to simulate chunking only (full articulation) and chunking plus self inhibition (updated articulation): half of the participants in each age group fully recited the two items in each chunk until they responded to the respective chunks throughout the list (full articulation condition) whereas the other half recited the two items initially but subsequently updated their recital to the last item in each 2-item chunk after responding to the first item (updated articulation condition). Because both strategies involve grouping the items into 2-item chunks, for the first hypothesis it was expected that chunking would be evident across both articulation strategies for both age groups. If the RT pattern shown previously (Li & Chow, 2006) reflects chunking, both articulation conditions should show long RTs for every other item (see Figure 1).

For the second hypothesis, it was predicted that Lag - 1 and Lag + 1 errors should be elevated within a chunk in the full articulation condition because both items in each chunk were kept currently active until a response was made; in the updated articulation condition, only the Lag + 1 errors were expected to be elevated within a chunk whereas the Lag - 1 errors were expected to be suppressed. The latter prediction is consistent with self inhibition of previously completed actions (Houghton & Tipper, 1996; Li & Chow, 2006) as participants no longer rehearsed the first item in each chunk in the updated condition when a response was made (see Figure 2). Therefore, the updated condition should replicate findings by Li and Chow (2006) if both chunking and inhibition led to the pattern obtained. However, if the previous findings reflected chunking only, then the full articulation strategy should yield a similar pattern of results.

In accordance with the IDH (Hasher et al., 1999), for the third hypothesis, it was predicted that self inhibition of prior responses would be more evident in YA as compared to OA. In other words, self inhibition was expected to be intact in YA as compared to OA, consistent with a decline in inhibitory control that specifically relates to the deletion function of the IDH.

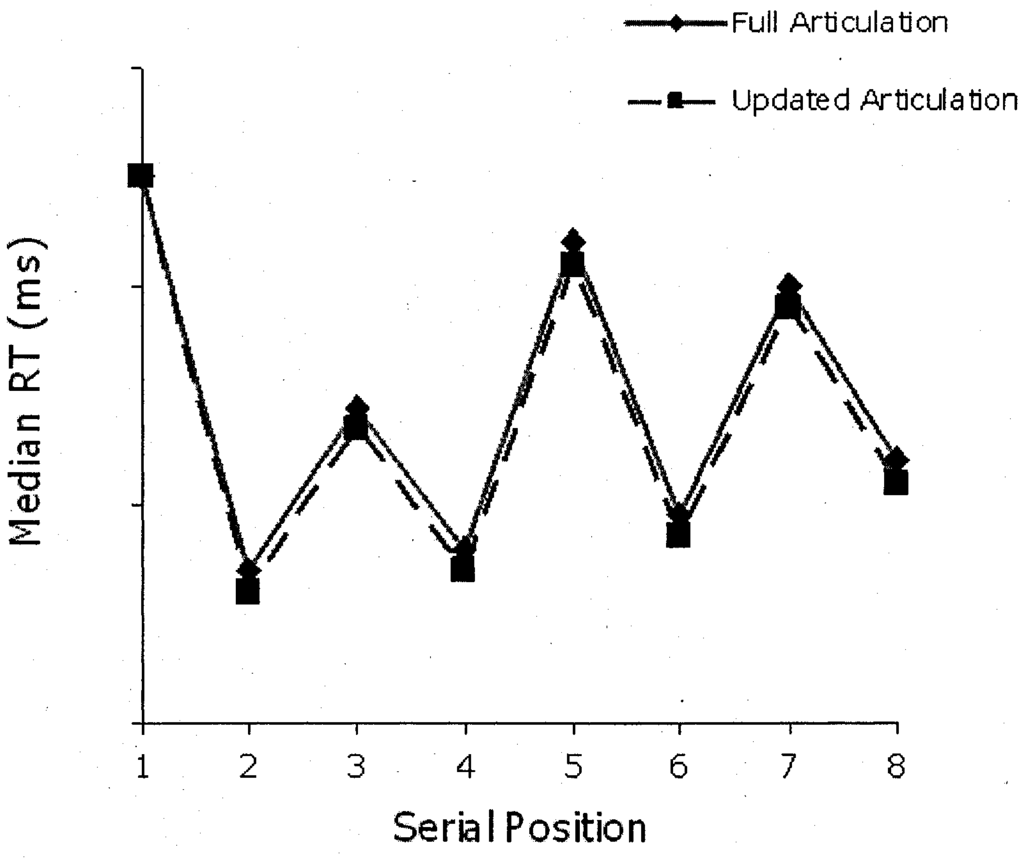

Figure1. Expected results for RTs as a function of list position and articulation strategy.

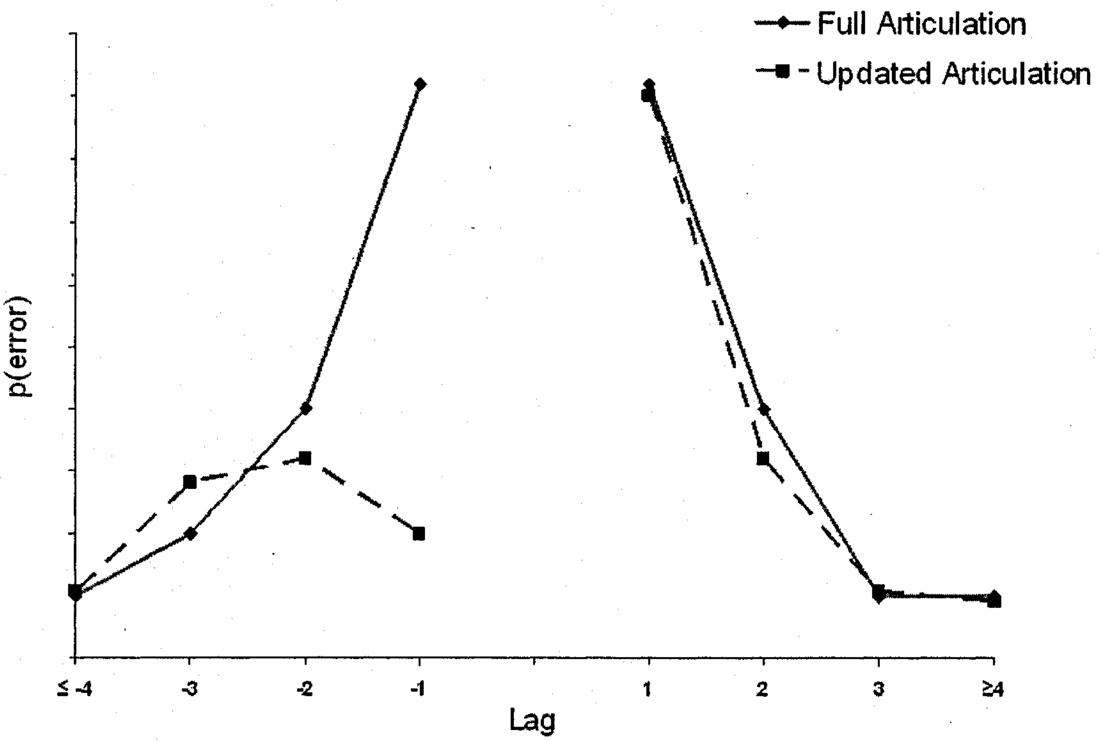

Figure 2. Expected results for intrusion error rates as a function of lag position and articulation strategy.

Method

Participants

Thirty YA (age range: 18 - 30) and thirty OA (age range: 60-75) participated in this study. Younger participants were recruited from introductory Psychology classes at Concordia University and through classified ads. Course credits were assigned to younger participants recruited from the undergraduate participant pool whereas participants recruited through ads received $10 CAD. Older participants were recruited from a subject pool common to aging laboratories at Concordia University and received $15 CAD compensation for their time. Inclusion criteria for both YA and OA included fluency in English, and participants were excluded if they had neurological disorders, colour blindness, stroke, other medical conditions or were taking medications that cause alertness problems, drowsiness, dizziness, motor slowing or impaired thinking.

Apparatus and Materials

In a demographic questionnaire, participants reported background information such as age, gender, handedness, marital status, language, education, medical history, medication use, and health status (see Appendix A). A series of cognitive tests were employed to assess level of cognitive functioning. These included a measure of verbal ability, namely the Extended Range Vocabulary Test (ERVT, Form V2; Educational Testing Service, 1976) (see Appendix B), and a measure of cognitive speed, namely the WAIS-R Digit Symbol test (Wechsler, 1981) (see Appendix C). Table 1 shows demographic information and cognitive test results for each age group.

Table 1

Means (standard deviation) for demographic characteristic and cognitive test results by age group.

	Younger Adults ($n = 30$)	Older Adults ($n = 30$)	*p*-value
Gender (F:M)	25:5	14:16	.003
Age (years)	21.63 (2.46)	67.60 (5.08)	<.001
Years of education	14.97 (1.40)	14.90 (2.96)	.914
Digit Symbol (maximum = 133)	68.00 (15.44)	52.20 (9.89)	<.001
ERVT (maximum = 24)	7.60 (3.86)	14.01 (5.34)	<.001

Note. YA = Younger Adults, OA = Older Adults, ERVT = Extended Range Vocabulary Test.

The sequential action regulation stimuli used in this study were the same as used in Li and Chow (2006). The stimuli consisted of a fixed series of eight coloured animal drawings ordered according to increasing size that included a ladybug, butterfly, bird, cat, wolf, zebra, camel, and elephant (see Figure 3). All drawings appeared in the centre of the computer screen and occupied a dimension of 11 x 11 cm. Participants sat in front of a Macintosh G4 computer with a 17-inch screen and responded using a one-button Apple Pro M5769 mouse.

In a total of 105 trials, participants saw the eight target animals and distractor items that included items out of sequence. The first nine trials were practice ones and the remaining 96 were test trials. Participants saw a feedback screen when they made an intrusion error or failed to click on the mouse when appropriate. The feedback screen indicated the next animal participants should click on within the sequence. The sequence restarted after participants clicked anywhere on the screen.

In a single trial, participants saw anywhere from 15 to 17 items that included the eight target items and between seven to nine distractor items. Trials with nine distractors included a random distractor that appeared twice. Furthermore, between any two target items within a trial, the number of possible distractors varied from zero to three. Stimulus duration was 350 ms with a 1000 ms interstimulus interval.

Procedure

Participants first read and signed the consent form (see Appendix D). Subsequently they were administered the demographic questionnaire. Next, they memorized the animal sequence in 2-item chunks (see Figure 4). The experiment continued when participants were able to successfully name all animals. Depending on

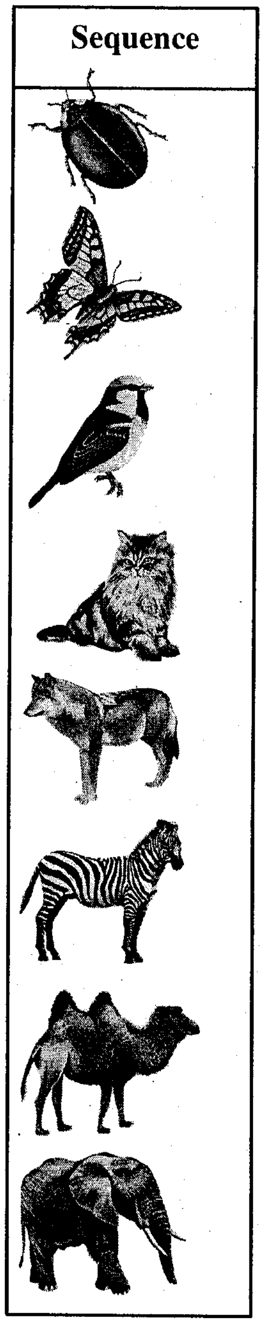

Figure 3. Animal sequence

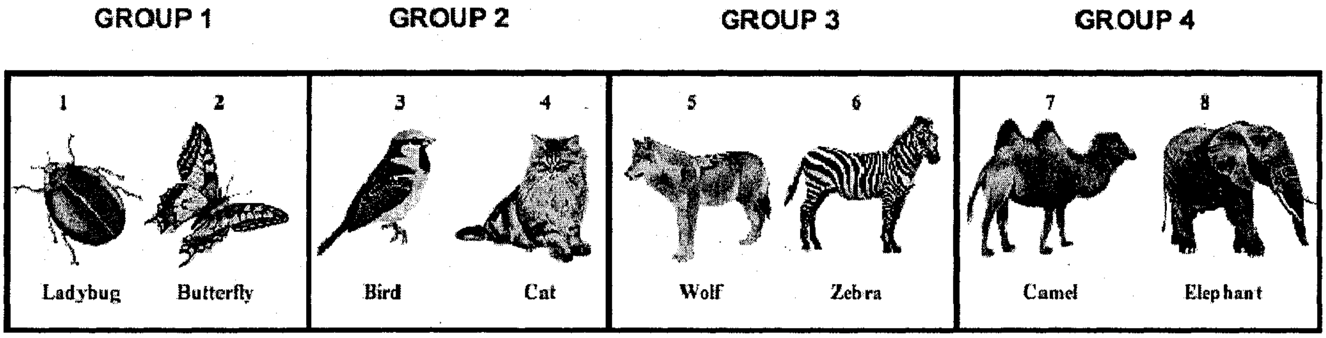

Figure 4. Memory aid depicting animals in chunked format

the articulation strategy they were assigned, they were instructed to either fully recite out loud both chunk items until they were responded to as they progressed throughout the sequence (full articulation) or rehearse only the last item within the chunk after responding to the first item (updated articulation). For instance, in the full articulation strategy when participants were looking for the first group, i.e., the ladybug-butterfly group, they recited "ladybug-butterfly" until they clicked on the last item, at which point they started to recite the next group, namely the "bird-cat" group, and so on; thus the full articulation strategy simulated chunking items into groups of two. In the updated articulation condition, they similarly recited "ladybug-butterfly" initially; however, after having responded to "ladybug", they recited only "butterfly" until they clicked on this item and then they started to recite the "bird-cat" group and so on; thus the updated articulation strategy simulated chunking items into groups of two and subsequently inhibiting one's response to the first item in the chunk when a response was made.

Participants were then given a paper practice trial that simulated the computer trials. As they verbally rehearsed chunk items, they were instructed to tap on the desk once when they saw the item they were looking for in the sequence and not to tap when they saw a distractor item. Following a minimum of two paper practice trials or however many trials were necessary for perfect performance, participants were seated in front of the computer and were administered nine practice trials. They were instructed to respond as quickly and as accurately as possible and to click on the mouse button anywhere on the screen when they saw the animal they were looking for according to the specified sequence (see Figure 3). They did this until they clicked on all the animals in the sequence, at which point a screen indicated that the trial had been completed and they must start over again from the smallest to the largest animal. During practice trials only, participants were free to refer to a memory aid depicting the animals in the specified order. After completing the practice trials, the first of two blocks of 48 trials began.

At the end of the first block, participants were administered the WAIS-R Digit Symbol test to complete within 90 seconds. Upon completing the second block of the computer task, they were asked about any particular strategies used to aid performance and whether the increasing size of the items within the sequence helped in executing the task. Finally, they were administered the ERVT, debriefed on the purpose of the experiment, and assigned course credits or financial compensation. The experiment lasted approximately 90 minutes for both younger and older participants. The experimenter (a research assistant, graduate student, or undergraduate student) remained in the room throughout the experiment and reminded participants to continue reciting if they forgot to do so. Participants were randomly assigned to either the full or updated articulation conditions.

Statistical Analyses

Between subjects factors included age group (YA, OA) and articulation strategy (full, updated) whereas within subjects factors consisted of list position (1, 2, 3, 4, 5, 6, 7, 8) and lag errors (≤ -4, -3, -2, -1, 1, 2, 3, ≥4) with median correct RT and proportion of intrusion errors as dependent measures. Median RTs were computed for correct responses at each list position. Lag errors were defined as clicking on an item that was either ahead of the target (anticipatory error) or responding to an item that was previously completed (perseverative error). Thus, participants could make anywhere between Lag + 7 and Lag - 7 errors. For instance, if a participant was looking for ladybug but clicked on elephant, an item seven steps ahead of the target, this was classified as a Lag + 7 error. Given the low base rates (maximum number of opportunities) to commit lag errors from + 4 to + 7 and - 4 to - 7, these more extreme lag errors (± 4 - 7) were pooled to make their base rates more comparable to lags ± 1-3. This resulted in eight possible kinds of lag errors (≤ -4, -3, -2, -1, 1, 2, 3, ≥ 4). Intrusion error rates were computed by dividing the number of each type of lag errors committed by a participant by the maximum number of opportunities to make that error, resulting in a proportion error score for each type of lag error.

To test Hypothesis 1, namely that chunking would be evident across both age groups and articulation strategies, a group (YA, OA) x articulation strategy (full, updated) x serial position (1, 2, 3, 4, 5, 6, 7, 8) mixed factorial ANOVA was performed using the RT data. Hypothesis 1 would be supported if results showed a scalloped pattern as found in previous research (Li & Chow, 2006; Logan, 2004), namely that odd positions had longer RTs than even positions across groups and articulation conditions. Further evidence for chunking was sought by analyzing lag errors using a group (YA, OA) x articulation strategy (full, updated) x lag error (≤ -4, -3, -2, -1, 1, 2, 3, ≥ 4) mixed factorial ANOVA. More Lag + 1 errors over all other lag errors would be consistent with this first hypothesis, suggesting that participants were holding *n* and *n* + 1 items in working memory. However, based on results at this stage, it would not be clear whether the two items participants were holding in working memory are within chunks or between chunks. Therefore, more Lag + 1 errors within chunks as opposed to between chunks would provide further evidence for chunking. In other words, such a result would suggest that participants were holding *n* and *n* + 1 items within a chunk in working memory. Together, a scalloped RT pattern and elevated Lag + 1 errors within chunks would be consistent with the retrieval of serial items in chunks from long term memory as postulated by prior research (Li & Chow, 2006; Logan, 2004)

Lag - 1 and Lag + 1 errors within chunks were compared across articulation conditions for all participants with independent samples *t*-tests. This was done to examine Hypothesis 2, which posited that dropping recital of the first item within a chunk after responding to this item in the updated articulation strategy (i.e., chunking plus inhibition strategy) simulated self inhibition of the previous response. Results showing suppressed Lag - 1 errors within a chunk in the updated condition compared to the full articulation condition (i.e., chunking only strategy) but similar Lag + 1 errors would be consistent with this hypothesis. However, to strengthen such a result, it was initially necessary to ascertain that items within a chunk were more active in working memory than items between chunks. To perform this analysis, mean proportion of Lag - 1 and Lag + 1 errors within chunk were compared to mean lag errors (-4....+4) between chunks.

To test Hypothesis 3 which stipulated that self inhibition would be intact in YA but not in OA as predicted by the IDH, a group (YA, OA) x articulation (full, updated) x negative lag errors (-4, -3, -2, -1) mixed factorial ANOVA was carried out. In considering only negative lag errors, we can more confidently assess the inhibition of previously completed responses as opposed to earlier studies (Li et al., 2000; Li & Chow, 2006) in which self inhibition was operationalized as a higher proportion of positive (anticipatory) over negative (perseverative) lag errors, possibly confounding inhibitory and anticipatory effects. Results showing significantly fewer immediate negative lag errors, specifically Lag - 1 errors, in YA as compared to OA and similar negative lag errors for more distal items, namely Lag - 2, -3 and -4, would be consistent with Hypothesis 3.

Results

Chunking Analysis

Evidence for chunking in both age groups was examined by comparing response latencies across serial positions. The group (YA, OA) x articulation (full, updated) x serial position (1, 2, 3, 4, 5, 6, 7, 8) mixed factorial ANOVA showed a significant main effect of group, $F(1, 56) = 17.31, p < .001, \eta_p^2 = .24$, such that YA ($M = 482$ ms, $SE = 8.93$) had faster RTs than OA ($M = 540$ ms , $SE = 10.21$). A significant main effect of serial position was also observed, $F(7, 50) = 15.33$, $p < .001$, $\eta_p^2 = .68$, such that odd positions when grouped together ($M = 523$ ms, $SE = 8.40$) were significantly longer than even positions ($M = 499$ ms, $SE = 7.72$), $t(59) = 5.05, p < .001$. These significant main effects were qualified by a significant group x serial position interaction, $F(7, 50) = 2.41$, $p = .03, \eta_p^2 = .25$.

Following up on the group x serial position interaction, Bonferroni corrected (analyzed at alpha level of .025) paired *t*-tests were done to analyze differences in RTs at odd and even positions for YA and OA separately. For OA, odd positions ($M = 560$ ms, $SE = 11.45$) were significantly longer than even positions ($M = 520$ ms, $SE = 10.20$), $t(29) = 5.53, p < .001$, indicating a more exaggerated scalloped pattern across both articulation strategies consistent with 2-item chunks (see Figure 5). A trend for longer RTs for odd positions ($M = 487$ ms, $SE = 7.99$) compared to even positions ($M = 478$ ms, $SE = 10.44$) was found for YA across both articulation strategies, $t(29) = 1.74, p = .093$. This result appeared more evident from the third position in the full articulation strategy and the fifth position in the updated articulation strategy as shown in Figure 5.

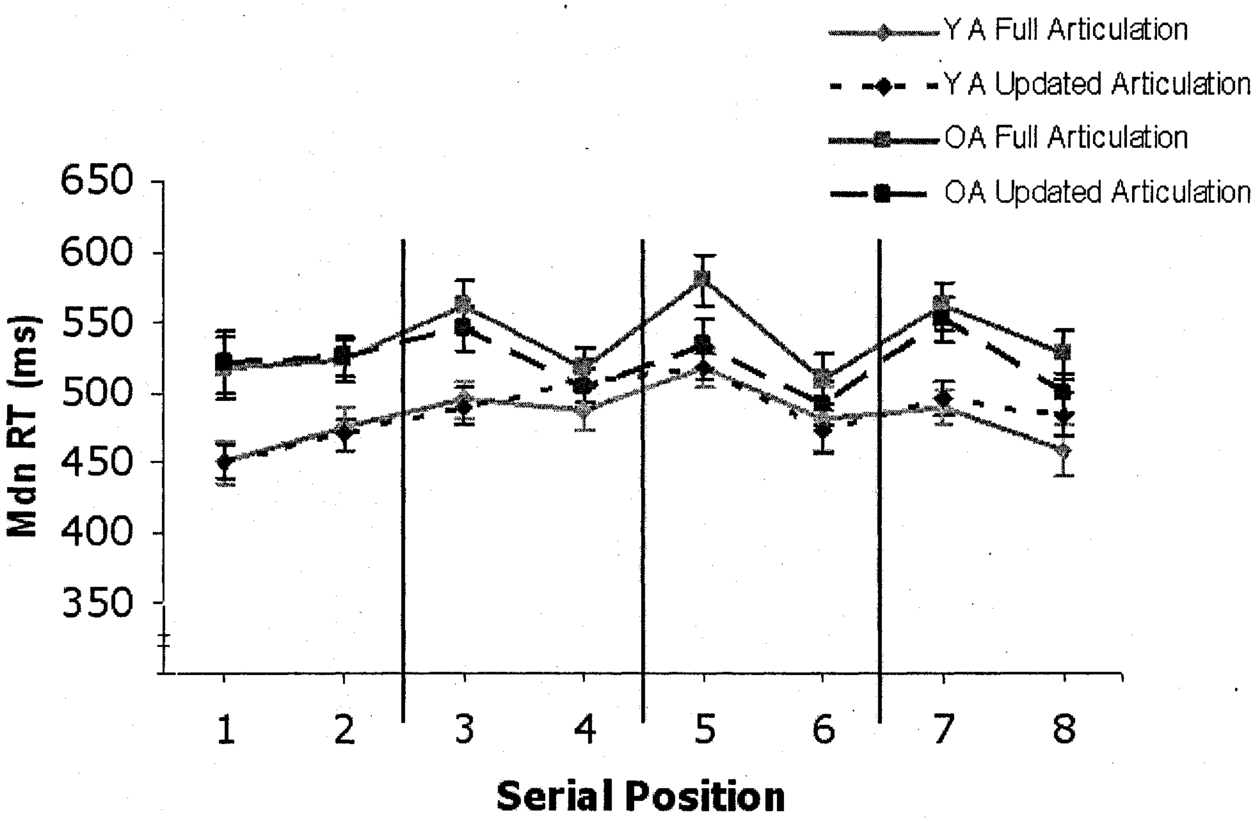

Figure 5. Median target RTs as a function of list position, age group, and articulation strategy. Error bars represent one standard error of the mean.

Further evidence for chunking was sought by analyzing the pattern of lag errors with a group (YA, OA) x articulation (full, updated) x lag error ($\leq$ -4, -3, -2, -1, 1, 2, 3, $\geq$ 4) mixed factorial ANOVA (see Figure 6). Results showed a main effect of group, $F(1,56) = 8.46, p = .005, \eta_p^2 = .131$, such that OA ($M = .02$, $SE = .002$) made more lag errors than YA ($M = .01$, $SE = .002$); and a main effect of lag errors, $F(7, 50) = 17.25, p < .001, \eta_p^2 = .71$. Post hoc analyses with a series of paired *t*-tests with a Bonferroni adjustment for multiple comparisons showed elevated Lag + 1 errors over all other lags, *p*s < .007.

Moreover, a trend towards significance was observed for the group x lag error interaction, $F(7, 50) = 1.86, p = .096, \eta_p^2 = .21$. Follow-up one way within subjects ANOVAs for each group separately revealed main effects of lag errors for YA, $F(7, 203) = 13.95, p < .001, \eta_p^2 = .33$, and OA, $F(7, 203) = 15.09, p < .001, \eta_p^2 = .34$, with Lag + 1 errors elevated over most other lags in each group (more Lag + 1 errors than Lag - 4, - 3, - 1, 3, 4 errors in YA and Lag - 4, - 3, - 2, 2, 3, 4 in OA, *ps* < .007) based on subsequent paired *t*-tests with a Bonferroni adjustment.

At this stage, however, elevated Lag + 1 errors over most other lag errors only indicated that two items, *n* and *n* + 1, were activated in working memory at any given time; this result did not indicate if activated *n* and *n* + 1 items were within a chunk, between a chunk or both. Therefore, a group (YA, OA) x articulation strategy (full, updated) x Lag + 1 errors (within chunk, between chunk) mixed factorial ANOVA was conducted. The finding of a significant main effect of Lag + 1 errors, $F(1, 56) = 4.92, p = .031, \eta_p^2 = .08$, such that more errors were found within a chunk ($M = .05$, $SE = .01$) than between a chunk ($M = .03$, $SE = .01$), was qualified by a marginally significant group x

Lag + 1 error interaction, *F*(1, 56) = 3.78, $p = .057$, $\eta_p^2 = .06$. For the older group, a paired *t*-test revealed significantly more within chunk Lag + 1 errors (*M* = .06, *SE* = .01) than between chunk Lag + 1 errors (*M* = .03 , *SE* = .01), *t*(29) = 2.54, $p = .02$; thus, this detailed analysis demonstrating more Lag + 1 errors within chunks rather than between chunks indicated that the two items activated in working memory at any given time belonged to the same chunk. No significant difference between Lag + 1 errors within a chunk and between a chunk was found in the younger group, *t*(29) = .25, $p = .81$, although the within chunk error rate was numerically higher than the between chunk errors, as expected (within chunk Lag + 1 errors: *M* = .031, *SE* = .006; between chunk Lag + 1 errors: *M* = .029; *SE* = .008).

Self-Inhibition Analyses

In this section, analyses were performed to examine the effect of self inhibition across articulation strategies as posited in Hypothesis 2 and age groups as predicted in Hypothesis 3. Results from paired *t*-test show significantly more within chunk errors (*M* = .03, *SE* = .004) compared to between chunk errors (*M* = .01, *SE* = .002), *t*(59) = 5.93, $p < .001$, confirming that items within chunks were more active in working memory than items between chunks. Subsequently, the proportion of Lag - 1 errors within chunks across articulation strategies for each group was examined with independent samples *t*-tests. This was done to assess whether Lag - 1 errors were more suppressed within chunks in the updated as compared to the full articulation condition as predicted in Hypothesis 2. Contrary to this hypothesis, more Lag - 1 errors within chunks were found in the updated (*M* = .02, *SE* = .02) than the full articulation strategy (*M* = .005, *SE* = .01), *t*(28) = 2.38, $p = .024$ in the younger group; whereas no difference in Lag - 1 errors within chunks were

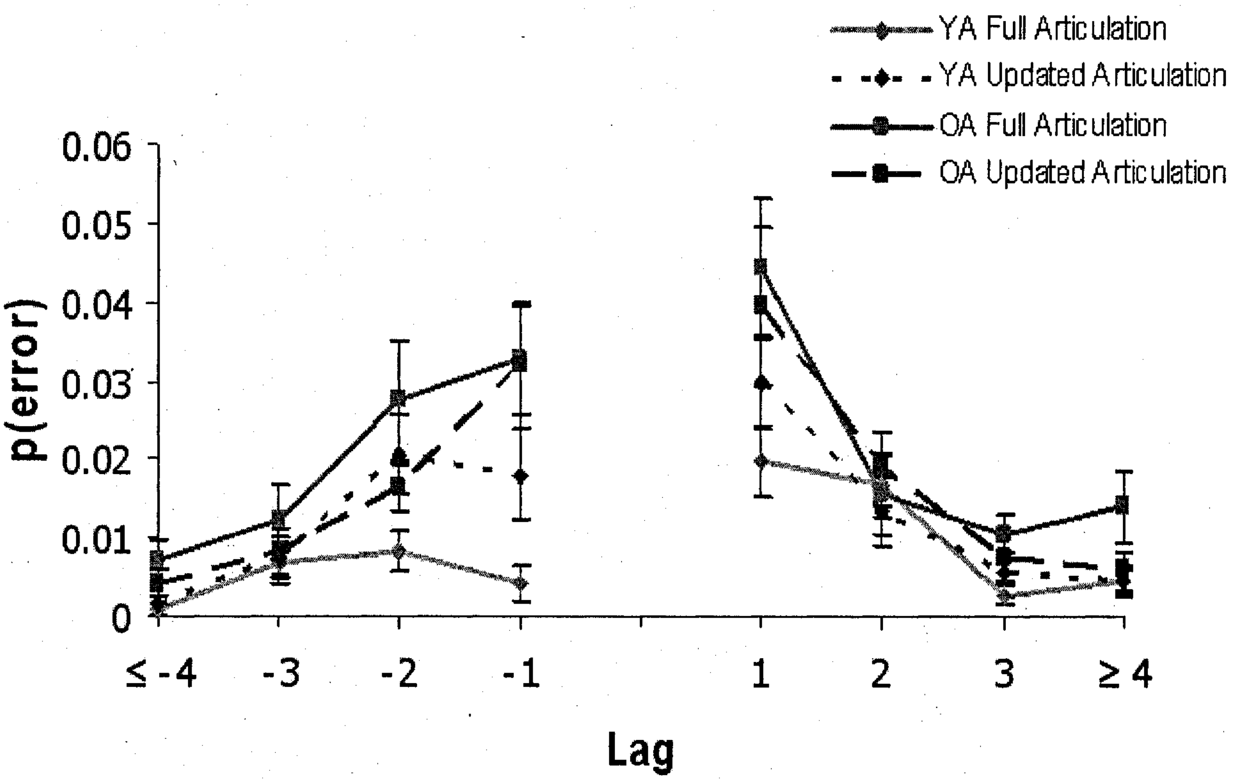

Figure 6. Intrusion error rates as a function of lag position, age group, and articulation strategy. Error bars represent one standard error of the mean.

observed across articulation strategies in the older group (full articulation: *M* = .029, *SE* = .01; updated articulation: *M* = .029, *SE* = .01), *t*(28) = .06, *p* = .952. No difference was found in Lag + 1 errors within chunks in the updated as compared to the full articulation strategy in either groups, *p* > .05.

Differences in self inhibition across age groups as predicted by the IDH and outlined in Hypothesis 3 was examined with a group (YA, OA) x articulation (full, updated) X negative lag errors (-4, -3, -2, -1) mixed factorial ANOVA. Results showed a significant main effect of group, *F*(1,56) = 10.30, *p* = .002, $\eta_p^2 = .16$, such that OA (*M* = .02, *SE* = .002) made more negative lag errors than YA (*M* = .01, *SE* = .002). A significant main effect of negative lag errors was also observed, *F*(3, 54) = 23.37, *p* < .001, $\eta_p^2 = .57$ such that there were more Lag - 1, -2, and -3 errors compared to Lag - 4 errors and more Lag -1 and -2 errors compared to Lag - 3 errors, *p* < .001. Furthermore, a significant group x articulation interaction was found, *F*(1, 56) = 4.17, *p* = .046, $\eta_p^2 = .07$, such that OA (*M* = .02, *SE* = .003) made significantly more negative lag errors in the full articulation strategy than YA (*M* = .01, *SE* = .01), *t*(28) = 3.67, *p* < .001, whereas no difference in negative lag errors was observed between the groups in the updated strategy (OA: *M* = .015, *SE* = .01; YA: *M* = .01, *SE* = .01), *t*(28) = .84, *p* = .411.

More importantly for the purpose of this study, a significant group x negative lag interaction was observed, *F*(3, 54) = 4.08, *p* = .01, $\eta_p^2 = .19$. Post hoc analysis using independent samples *t*-test with a Bonferroni correction (alpha level of .01) showed that YA had fewer Lag - 1 errors compared to the OA, *t* (58) = 3.46, *p* = .001, but similar Lag - 2, *t*(58) = 1.47, *p* = .147, Lag - 3, *t*(58) = .98, *p* = .333, and Lag - 4 errors, *t*(58) = 2.60, *p* = .012. This result indicates that immediate lag errors, namely Lag - 1 were suppressed to a greater extent in YA than in OA, but later lag errors, namely Lag - 2, - 3, and - 4 errors, were similar between the groups (see Figure 6).

Discussion

This study is an extension of earlier work by Li and Chow (2006). There, both younger and older participants performed the S-ACT paradigm with a logically ordered sequence of items, which is more akin to sequential action in everyday life. From the pattern of results obtained, they inferred chunking and self inhibition were integral to sequential action regulation in both groups. To directly examine this inference made by Li and Chow, the present study employs differing articulatory rehearsal strategies that are meant to simulate chunking (full articulation) and chunking plus self inhibition (updated articulation) of sequence elements. In doing so, it furthers our understanding of the chunking model of sequential action put forth by Logan (2004) and the nature of inhibition as stipulated by the competitive queuing model (Houghton, 1990; Houghton & Tipper, 1996). In addition, the IDH (Hasher et al., 1999) was examined by comparing performance by YA and OA. According to this hypothesis, inhibitory processes of sequential action should be reduced in OA. Results provide evidence for both theories of sequential action regulation, and in line with the IDH, self inhibition of previously completed actions is weakened in OA as compared to YA.

Chunking

Methodological induction of chunking was evident in the RT pattern obtained in both articulation strategies: odd serial positions had significantly longer response latencies than even positions. Consistent with the rehearsal of two items at a time in both articulation strategies, the scalloped pattern evident in the RT curves suggests that 2-item chunks are activated in working memory in both groups. However, this scalloped pattern was more accentuated in the older group across both articulation strategies, indicating that they were slower at retrieving chunks from long term memory (Figure 5) as expected from prior research (Zacks et al., 2000). This pattern was further supported by the observation that the *t*-value comparing RT for odd versus even positions was larger in the older group. These results are consistent with longer response latencies in chunk retrieval for the older group as found in Li and Chow (2006).

Younger participants showed a scalloped pattern later in the task in both articulation strategies (from the third item forwards in the full articulation condition and the fifth item forwards in the updated articulation condition) which may suggest memory facilitation for earlier items in this group; in other words, facilitation effects from rehearsal of items may have allowed for multiple items in two different chunks to be represented in one chunk, allowing for a larger number of items to be activated in working memory at the same time. This presumed activation of multiple items in one chunk is similar to findings of sequential actions in the area of motor preparation. For instance, in research by Klapp (1995), participants typed simple 1-element Morse codes, namely responses of a short duration known as *dit* or a long duration known as *dah*. In addition, participants also made entries of 4-element sequences mixed with *dit* and *dah* codes. Initially, the time taken before entering the 1-element codes were much shorter than simple RT to enter the first code in the 4-element sequences, suggesting increased motor planning before entering longer sequences compared to single entries. More importantly, with extended practice, the difference in simple RT for 1-element and 4-element sequences disappeared. Further, the inter-element RT in the 4-element chunk decreased significantly and became less variable with extended practice. Klapp and colleagues concluded that initially, each code in the 4-element sequence was represented as an individual unit or chunk; however, with extended practice, the 4-element sequence came to represent one chunk, similar to single codes.

Akin to Klapp's (1995) findings, which show longer sequence elements combining into one chunk, it is possible that for YA in this study, items at the beginning of the list may have come to be represented as one chunk. In other words, articulatory rehearsal may have facilitated YA performance in the early part of the list by allowing for these items to combine into one chunk. Given this possibility, one may ask why the first few items do not follow the typical pattern of a longer response latency for the first item and shorter latencies for the remaining items as they are subsequently unpacked. However, during the course of the experiment, participants were noticeably rehearsing the first set of items before the trial sequences started. This rehearsal strategy may have led to early activation of the first item in working memory, resulting in a similarly short RT for the first item as other items in the early part of the list. However it is not clear why a similar facilitatory effect was not present for OA.

Another possibility for the delayed scalloped pattern for YA is that despite the 2-item verbalization instruction, younger participants may have initially retrieved four sequence elements into working memory, which is at the upper limits of working memory capacity according to Cowan (2001); he suggested after an extensive review of the literature that three to five items are more representative of the limits of working memory and not seven plus or minus two as suggested earlier by Miller (1956). Hence, in this design, participants may have retrieved four items initially but were unable to maintain this strategy and resorted to activating 2-item chunks for the rest of the sequence. This change in chunk activation pattern may be due to stimulus characteristics, verbalization instructions, or the quick pace of the task; specifically, a more efficient approach in light of the pace of the task may be to use a 2-item chunk retrieval strategy as the task goes on, given that the time cost may be less when retrieving fewer number of chunk items as opposed to a larger number. OA may have used a similar strategy in the early part of the sequence, at least up until the third item in the list.

In previous work (Li and Chow, 2006; Logan, 2004), evidence in favour of chunking was restricted to RT analysis; however, in this study, analysis of the different types of errors individuals made also provided support for chunking. Lag error analyses showed that both groups had elevated Lag + 1 errors over most other lags, suggesting that they were holding two items, *n* and *n* + 1, in working memory at any given time. However, this result did not indicate whether items *n* and *n* + 1 were within chunk items or between chunk items. Thus, follow up analysis of within versus between chunks errors revealed that Lag + 1 errors were higher within chunks than between chunks; therefore, this result suggested that not only were participants holding two items at any given time in working memory, but that the items belonged to the same chunk.

Given the scalloped pattern observed in the RT curve, particularly for the older group throughout the sequence, and elevated within chunk Lag + 1 errors , these results provide converging evidence for the inference made by Li and Chow (2006) for the critical role of chunking in performing sequential actions. These results support Logan's (2004) chunking model of sequential action and are incompatible with the simultaneous activation of all action sequences to be performed as posited by the competitive queuing model (Houghton & Tipper, 1996). Consistent with Logan's (2004) chunking model, this research shows that individual chunks of items are readily brought into working memory from long term memory and subsequently "unpacked' as evidenced by the scalloped RT pattern. However, determining the precise number of elements within a chunk is less straightforward and appears to depend on the structure of the list or tasks being employed. Logan founded that there were three items within a chunk consistent with the three task sets used in his procedure. Further, when he manipulated list length, the number of within chunk elements changed accordingly. In Li and Chow (2006), participants appeared to group items into 2-element chunks. This makes intuitive sense on the basis of stimulus characteristics as the first two animals, ladybug-butterfly, are fairly small animals; the next two animals, bird-cat, are medium sized and also known to be semantically related; and the last two animals, camel-elephant, are the largest animals in the list. Admittedly, the third group of animals, wolf-zebra, is somewhat harder to associate. Nevertheless, the inference of 2-element chunks based on the scalloped RT pattern in Li and Chow are somewhat consistent with stimulus characteristics (size and salient semantic grouping) of the animals within the list. A future study using groups of items with similar features to manipulate chunking of items into groups of varying sizes would help provide evidence for the effect of stimulus characteristics on the number of elements within a chunk. For instance, one might conduct a study using the S-ACT paradigm with different categories of animals (such as groups of birds, fish, and dogs) that can be easily associated into chunks of varying sizes.

Self Inhibition

We aimed to simulate self inhibition in this study by using a chunking plus inhibition articulation strategy, namely the updated articulation strategy; half of the participants were instructed to recite both items in the chunk initially and subsequently update their recital to the last item of the chunk. We hypothesized that fewer Lag - 1 errors would be observed in the updated condition compared to the full articulation strategy (chunking only condition). This prediction was made because the updated articulation condition was designed to simulate self inhibition of previous responses by dropping rehearsal of previously responded to items within chunks. However, results obtained were opposite to what was predicted, particularly for YA. Instead of fewer Lag - 1 errors within chunk in the updated articulation strategy, more Lag - 1 errors within chunks were observed in this condition for YA whereas no difference in Lag - 1 errors was observed in the older group. Therefore, it appears that for YA, instructions to drop recital of a previously responded to item within a chunk resulted in increased activation of that item and as a result, led to more Lag - 1 errors in the updated articulation condition than expected.

The enhancement effect that results when individuals engage in thought suppression (Wenzlaff & Wegner, 2000) is a possible explanation for this finding of increased activation for *n* - 1 items within a chunk in the updated articulation condition over and above its overt rehearsal in the full articulation condition. A paradoxical increase in to-be-suppressed thoughts (enhancement and rebound effects) is typically observed when individuals are instructed to suppress a thought (Abramowitz, Tolin, & Street, 2001; Wenzlaff & Wegner, 2000). An enhancement effect is usually observed when participants are under thought suppression conditions whereas a rebound effect is primarily observed when participants are no longer under a thought suppression condition and are allowed to think of anything (Wegner, 1994; Wenzlaff & Wegner, 2000). Research in this area started with the seminal "white bear" study by Wegner, Schneider, Carter, and White (1987). In this study, one group of participants were initially placed in the suppression condition in which they were instructed not to think of a white bear over a 5-minute period; subsequently, they were placed in an expression condition in which they were told to think of a white bear. Another group of participants were initially placed in the expression condition and then the suppression condition. They observed that both groups of participants were unable to suppress the thought of a white bear as instructed over the 5-minute period. Further, when they compared "white bear" thoughts in both groups during the expression condition, they found that those initially placed in a suppression condition thought about a white bear more during the expression condition as compared to participants who were initially in the expression condition; thus, a rebound effect was observed after participants were "released" from suppression as indicated by the increase in "white bear" thoughts when in the expression condition.

In contrast to the rebound effect observed when participants are no longer instructed to suppress a thought, the enhancement effect observed under thought suppression conditions is typically found when cognitive demands are high as in divided attention settings or when time constraints are imposed (Wegner, 1994; Wenzlaff & Wegner, 2000). It is plausible that the enhancement effect is responsible for increased activation of *n* - 1 items in the updated articulation condition for the younger group in this study due to the highly demanding conditions of the S-ACT task employed. However, to further explore this possibility, we would need to conduct a study in which the cognitive load in the S-ACT task is increased by using shorter stimulus duration or inter-stimulus intervals. In this situation, there should be increased activation of *n* - 1 items as task demands increased.

A similar enhancement interpretation cannot be made for the OA group due to the finding of similar Lag - 1 errors within a chunk for both updated and full articulation conditions. One of the more dominant explanations of the increased preoccupation with a thought that is to be suppressed is the ironic process theory (Wegner, 1994), which assumes that when one engages in thought suppression, an effortful internal operating process and an unintentional or ironic monitoring processes are engaged. The intentional process searches conscious awareness for thoughts other than the to-be-suppressed thought, whereas the less effortful unconsciously triggered ironic monitoring process searches for the to-be-suppressed thought. Instances of the to-be-suppressed thought observed by ironic monitoring process serve as a feedback mechanism to reinforce conscious efforts of the intentional operating process to focus on other thoughts. Discontinuity of the intentional operating process, distraction, or increased cognitive load allows for the less cognitively demanding ironic process to continue to seek out and increase instances of the to-be-suppressed thought. It is possible that the automatic ironic monitoring mechanism advanced by Wegner's (1994), which assesses the efficiency of thought suppression, is weakened in old age. However, there is a dearth of research on enhancement and rebound effects in OA and studies so far have primarily utilized self report measures to assess the tendency to engage in thought suppression instead of experimental methodologies. For instance, Erskine, Kvavilashvili, and Kornbrot (2007) found equivalent rates of thought suppression in YA and OA using the White Bear Suppression Inventory; this measure assesses the frequency of thought suppression strategies based on the premise that individuals who are more likely to engage in this behaviour are also likely to activate the to-be-suppressed thought in conscious awareness (Wegner & Zanakos, 1994).

However, for the purposes of the present study using an experimental paradigm (albeit not designed to examine the enhancement effect), if it is assumed that the ability to suppress or inhibit an item (by dropping its recital as in the updated articulation condition) and the enhancement effect (increased activation of the to-be-suppressed item/thought) are proportional, then the lack of an enhancement effect in the older group is consistent with weakened inhibitory processes. Therefore, by looking at the results from this perspective, the lack of an enhancement effect in OA in the updated articulation condition may be another indication of reduced self inhibition.

The other aspect of inhibition examined in this study is the presumed age effect of the deletion function of the IDH (Hasher et al., 1999) assessed in the context of self inhibition of completed actions (Houghton & Tipper, 1996). The younger group made fewer immediate prior responses, *n* - 1, as opposed to earlier responses, such as *n* - 2, -3 and -4, compared to OA as evidenced by fewer Lag - 1 errors but similar Lag - 2, - 3, and -4 errors. Consistent with the IDH, this pattern of results suggests that immediate prior responses are less active in working memory in YA compared to OA, indicating weakened self inhibition of previous responses with age. The operationalization of inhibition was restricted to completed responses which removed the possible confound of anticipatory effects when conceptualizing inhibition as the asymmetry between upcoming and prior responses as used previously (Li & Chow, 2006; Li et al., 2000).

Although the results of this study support a weaker functioning deletion mechanism in OA, conflicting findings regarding the deletion function (Maylor &

Henson, 2000; Mayr, 2001; Watson & Maylor, 2002) as mentioned earlier have led to strong criticism of the IDH. In their review of the literature on inhibition, MacLeod et al. (2003) noted that other mechanisms and strategies such as selective rehearsal and conflict resolution provided a better explanation of findings in studies presumably assessing inhibitory mechanisms. For instance, they suggested that selective rehearsal accounts negate an inhibitory explanation in the directed forgetting paradigm in which it has been assumed that similar recall of to-be-remembered and -forgotten items represents reduced inhibitory control (Zacks et al., 1996). MacLeod et al. suggest that selective rehearsal of to-be-remembered items provides a more parsimonious account of the directed forgetting effect (i.e., inefficient recall of to-be-forgotten words as compared to to-be-remembered words). Further, MacLeod et al. suggested that other findings in the literature traditionally associated with difficulty in inhibitory control, such as the negative priming effect (finding of longer RTs when responding to an item that was previously ignored as opposed to the responding to the same item when it was not ignored prior) are more consistent with memory retrieval of past stimulus elements conflicting with the present one.

Despite the controversy, the results of the current study are as predicted by the IDH, namely reduced functioning of the deletion mechanism in OA. Alternatively, in the area of aging, MacLeod et al. (2003) suggests that supposed inhibitory deficits in OA may be due to failure to prioritize task relevant goals. The results of this study do not settle the debate on aging and inhibitory control; they do however provide supporting evidence for enhanced information in working memory that relates to actions that were previously completed in OA as compared to YA, possibly suggesting the lack of inhibitory effects in old age. More generally, these results show that OA experience more difficulty from the influences of items to which a response was already made, which is consistent with decline in executive control over the aging process (Salthouse, 2004; Salthouse et al., 2003; Verhaeghen & Cerella, 2002).

As a future study, it would be interesting to examine whether self inhibition differences in YA and OA are reduced or eliminated with groups of items that can be readily chunked; in particular, using items that have stronger associations among them, such as using a fixed sequence of items in which two or three sub-items belong to specific groups of animals or other categories. Support for such an interaction of chunking and inhibition comes from research on task switching by Koch, Philipp, and Gade (2006) which showed that another inhibitory process, namely backward inhibition, was reduced when participants chunked task sequences. In their study a group of participants who were made aware of repeating sequences embedded in task sequences used these repeating sequences as chunk points to facilitate performance. Backward inhibition, which tends to slow down responses to current tasks that are identical to those completed two steps prior (i.e. performance is slowed when performing task *A* in AB*A* compared to task C in ABC), was reduced in the group made aware of the repeating task sequences as compared to the unaware group. Additionally, in Li and Chow's (2006) second experiment in which they compared scrambled and canonical animal sequences, self inhibition was observed in the canonical condition as opposed to the scrambled condition, with more suppression of prior items in the canonical condition for YA (although this finding was not significantly different from OA). Serial performance was also more efficient for YA in the canonical condition compared to the scrambled condition, whereas no difference was observed for OA. It is likely that chunking may have led to more efficient serial performance, evidenced by faster serial recall, and self inhibition for YA in the canonical sequence. The canonical sequence may have activated semantic attributes or a deeper level of processing of list items, which may have given participants a performance advantage in the canonical condition as compared to the scrambled condition. Thus it is plausible that using sequential items with stronger associations among them may improve chunking efficiency and likely influence self inhibition. A future study with the S-ACT paradigm comparing a scrambled list of items with a list more amenable to chunking, which includes distinct categories embedded within, may result in improved OA performance in the embedded categories condition, and possibly reduce the age effect in self inhibition.

Item Activation in Working Memory

A fundamental assumption of this research is that overtly rehearsed items are kept active in working memory; as a result, participants are more likely to make intrusion errors for items that are activated in working memory. Participants were more likely to make within chunk lag errors as opposed to between chunk lag errors. This result confirms the hypothesis that verbally rehearsed items within a chunk are more active in working memory than items outside that chunk. Consequently, participants are more likely to make errors by responding to items that are activated in working memory as opposed to items that are not (presumably items between chunks that were not recited at that point). This finding is consistent with other research showing that rehearsing target items helps to keep these items in an active state in working memory (Bryck & Mayr, 2005).

Given this facilitation effect of overt verbal rehearsal, mean RT and lag errors from this study for both age groups was compared with data from Li and Chow (2006) where articulation was not used. Although RT was equivalent for older groups across studies, as well as younger groups, we found reduced mean lag errors for OA in this study as compared to the older participants in Li and Chow's study ($p = .012$). Because participants in this study not only articulated list elements, but were also explicitly trained to chunk items, it is not possible to tease apart whether rehearsal or chunking is responsible for the facilitation observed for OA. However, support for the utility of verbalization in older populations comes from research by Kray et al. (2004), which showed that overt articulation was generally beneficial to OA in a task switching setting. Nevertheless, routinely chunking and verbalizing sequence elements is an easy strategy for OA to adapt in their everyday lives when dealing with sequential activities that are particularly demanding.

Hierarchical Representation in Sequential Behaviour

Hierarchical representation of sequence elements (as shown by chunking strategies in this study) appears to be a general strategy in sequential performance that crosses various domains of research. The influence of hierarchical representation in performing sequential actions is evident when the pattern of results is consistent with the structure of the tasks being performed. Hierarchical organization or representation within a sequence of actions has been shown to be present at the level of motor programming (Collard & Povel, 1982; Kornbrot, 1989) and higher levels within the cognitive system when performing tasks which minimize the effect of motor preparation (Koch et al., 2006; Schneider & Logan, 2006).

Research in the area of motor preparation suggests that hierarchical representation of a sequence is influenced by inherent organization within the sequence and the way in which it is executed. For instance, Collard and Povel (1982) demonstrated that participants represented different parts of a tapping sequence as a group depending on patterns within the sequence, such as repetitions and symmetry. For example, when participants tapped a sequence (with one to one mapping between fingers and responses) such as 1-2-3-3-2-1, response latencies suggested that 1-2-3 was represented as one unit and 3-2-1 as another as the two halves were mirrored images of each other. Similarly, Kornbrot (1989) had participants respond as quickly as possible under conditions that employed three different motor patterns: first, they required participants to type sequences that ran sequentially through all fingers except the thumb from the left hand to the right hand; in another condition, participants alternated in typing keys from the left and right hands with the added stipulation that homologue fingers on the right hand followed those on the left (e.g. right index finger followed left index finger); and in a third condition, keystrokes were alternated between hands but without homologue fingers following each other. As expected, the RT pattern in the first condition suggested that sequences were represented in groups of two corresponding to keystrokes in the left hand and right hand separately. Groups corresponding to pairs of alternating homologue keypresses were found in the second condition whereas each keystroke in the third condition was represented as single unit. Hence, research by Collard and Povel and also Kornbrot show that hierarchical organization is influenced by patterns within a tapping sequence and the motor pattern in which the keystrokes are made, respectively.

Hierarchical organization extends from research on motor programming to research in the area of task switching. Research on task switching in which motor programming or motor preparation are minimized by randomization of stimuli also provides evidence for the imposition of hierarchical organization in task sequences (Schneider & Logan, 2006). In other words, participants cannot program motor responses in advance particularly if the target stimuli randomly vary on a specific stimulus dimension in a task switching setting when participants are asked to perform a series of task judgements, such as colour or shape repeatedly, across a trial. This is because when engaging in a colour judgement for instance, the stimulus presented at any given moment may be red or blue, and each response is matched to a separate response key, which makes motor programming of series of responses unlikely as the stimuli randomly changes over the trial.

Schneider and Logan (2006) showed that cognitive processing at the task sequence level interacted with processing at the level of individual tasks, suggesting that hierarchical representation of task sequences influences performance at the level of tasks. In particular, they showed that switch costs at the level of tasks were influenced by task sequences. In a series of experiments, participants performed memorized task sequences that were immediately performed on target stimuli. Task sequences of the form AABB or ABBA were repeated separately within blocks. The sequences were similar in that, task A and B were performed twice and both sequences resulted in similar frequencies of task repetitions and switches over the course of a block of trials (i.e., AABBAABB…). Participants formed a hierarchical representation of task sets based on the differing structure of task sequences. Analysis of both RT and error rates showed that local switch costs (operationalized as the difference in response latency when the task set switched from when it was repeated in a mixed block of trials) were different between the two task sequences despite similarity in number of task sets and task sequences repetitions performed. More importantly, shifting at the sequence level resulted in the absence of switch costs at the first serial position of the sequence, suggesting that sequence level processing modulates task level processes.

Similar to Schneider and Logan's results, Koch et al. (2006) (described above) inferred that the observed persisting effect of backward inhibition in their task switching study was reduced when participants hierarchically represented a series of tasks by chunking repeating sequences. This inference that the reduced *n* - 2 repetition cost (primarily used as a marker of backward inhibition) was due to chunking was confirmed recently by Schneider (2007) when he directly taught participants to chunk task sequences. In addition, similar to the present study, Schneider observed a scalloped RT pattern across task sequences, which was supportive of the use of chunking strategies in the context of his task switching procedure. However, it should be noted that task switching and the sequential action paradigm differ in important ways; in particular, in the sequential action paradigm used in this study, individuals hold sequence items in working memory and respond only when the appropriate target item in the sequence is presented, whereas task switching can be conceptualized as a process in which task goals and the appropriate stimulus category necessary to engage the appropriate response is performed on every stimulus presented (Schneider, 2007).

Overall, hierarchical representation of action sequences is evident from motor preparation in motor programming research and sequential tasks that stipulate task goals to perform on specific targets in task switching. Instances of hierarchical control in motor programming, task switching research, and also the S-ACT paradigm used in this study suggest that hierarchical representation of action sequences is a general cognitive strategy (Rosenbaum, Carlson, & Gilmore, 2001; Schneider & Logan, 2006, 2007).

Conclusion

The current study extends research by Li and Chow (2006) by directly assessing chunking with two articulation strategies. Results provide converging evidence for the role of chunking in sequential action regulation as inferred by Li and Chow, particularly in the older group. However, the self inhibitory manipulation in the updated articulation condition resulted in inadvertent activation of previously completed items in the younger group, possibly representing an enhancement effect (Wegner, 1994; Wenzlaff & Wegner, 2000). Similar to Li and Chow, the results of this study also provide support for both theories of sequential action regulation: the chunking theory by Logan (2004) and the self inhibitory mechanism in the competitive queuing model (Houghton, 1990; Houghton & Tipper, 1996). Consistent with the IDH hypothesis, OA showed less self inhibition of immediately completed responses compared to YA.

Understanding sequential action in OA is an essential endeavor. As activities of daily living represent an important criterion for deciding older individuals' capacity for independent living (Sahyoun et al., 2001), it is helpful to understand and facilitate sequential actions in everyday activities, particularly those that are cognitively demanding. Given that chunking and articulation play critical roles in sequential behaviour, this research suggests that hierarchical representation of action sequences by breaking up the activity into chunks, as well as verbalization of various steps, may be an important strategy to aid sequential performance. This research may also extend to individuals with action disorganization difficulties (Humphreys & Forde, 1998) and also pathological aging groups (e.g., Alzheimer's disease) in which the planning and organizational skills required to carry out sequences of actions are compromised over the course of the disease.

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Appendix A: Demographics/Medical Questionnaire

ID#______________

Demographics Questionnaire

We are interested in your personal history because it may help us to better understand the results of our study. Your answers to a few short questions will aid us in this effort. All answers will be kept strictly confidential. Thank you for your help.

Demographics

Date of Birth (D/M/Y):______________ 2. Age:____________

3. Gender: *(circle response)* (1) Male (2) Female

4. Handedness: *(circle response)* (1) LEFT (2) RIGHT (3) BOTH

5. Present marital status: *(circle response)* (1) Single – never married
   (2) Married
   (3) Separated
   (4) Divorced
   (5) Widowed
   (6) Cohabit

Language

6. Place of Birth:____

7. Languages Spoken (in order of fluency):_________________________________

8. Primary Language/Language of choice:_________________________________

9. Language at home:______________________ 8. At Work (if applicable):_____________

10. Language of Education:_________________________________

11. At what age did you first learn English? ______________________

12. At what age did you become fluent in it?______________________

13. How many years of education do you have at this time? (i.e., your highest level achieved?)

1 2 3 4 5 6	7 8 9 10 11	12 13	14 15 16	17 18 19 20 21 22 23 24 25	
Elementary	Secondary	Cegep	Undergrad	Graduate	Professional

14. What is or was your main occupation?

____

Medical History

15. Do you have now, or have you had in the past -*(please circle your response)*

Vision:				
A	(i) **Nearsighted**	NO / YES	(ii) **Farsighted**	NO / YES
B	(i) **Glasses**	NO / YES	(ii) **Contact lenses**	NO / YES
C	**Cataract**	LEFT / RIGHT / BOTH / NEITHER		
D	**Colour blind**	NO / YES		
Hearing:				
E	**Hearing Trouble**	NO / YES		
F	**Hearing Aid**	LEFT / RIGHT		

16. Have you ever been unconscious, had a head injury or had blackouts?
   A) NO / YES
   B) Cause:____________________________________
   C) Duration:__________________________________
   D) Treatment:_________________________________
   E) Outcome:__________________________________

17. Have you been seriously ill or hospitalized in the past 6 months?
   A) NO / YES
   B) Cause:____________________________________
   C) Duration:__________________________________

Do you have now, or have you had in the past:

18	a) a stroke	No / Yes	When?
	b) transient ischemic attack	No / Yes	
19	Heart disease	No / Yes	Nature (MI, angina, narrowing of arteries):
20	High blood pressure	No / Yes	If yes, is it controlled?
21	High cholesterol	No / Yes	
22	Bypass surgery	No / Yes	
23	Other surgery	No / Yes	Nature:
24	Seizures	No / Yes	Age Onset_____, Frequency__ Cause______, Treatment_____
25	Epilepsy	No / Yes	
26	a) Diabetes	No / Yes	Type 1/ Type 2 Age Onset______ Treatment________________
	b) Insulin Dependent	No / Yes	
27	Thyroid disease	No / Yes	
28	Frequent headaches	No / Yes	Tension / Migraine
29	Dizziness	No / Yes	
30	Trouble Walking (unsteadiness)	No / Yes	
31	Arthritis	No / Yes	
32	Any injuries to the lower limb (e.g., hip, knee, ankle)	No / Yes	
33	Serious illness (e.g., liver disease)	No / Yes	
34	Neurological Disorders	No / Yes	
35	Exposure to toxic chemicals	No / Yes	
36	Depression	No / Yes	
37	Anxiety	No / Yes	
38	(Other) psychological difficulties	No / Yes	
39	Hormone Replacement	No / Yes	
40	Steroids	No / Yes	

Continued...

37. <u>Medication</u>: Please list the medication you are currently taking and any other medication that you have taken in the past year

	Type of Medication	Reason for Consumption	Duration of Consumption and Dose
A			
B			
C			
D			
E			
F			

38. Approximately how many drinks of alcohol do you have per week?
(1 drink = 1 beer, 1 glass of wine, 1 oz of liquor)

____

39. Do you use non-prescription drugs for recreational purposes? NO / YES
If YES, How many times per week: (A) 1 - 3 (B) 4 - 6 (C) more than 6

40. Do you smoke? NO / YES
If YES, How many packs a day? ____________________

41. Present Problems - Are you currently troubled by any of the following?

A	Concentration / Attention Problems	No / Yes	Nature:
B	Memory Problems	No / Yes	Nature:
C	Difficulties finding words	No / Yes	Nature:

42) How would you rate your health? 1) poor 2) fair 3) good 4) very good 5) excellent

Appendix B: Extended Range Vocabulary Test

EXTENDED RANGE VOCABULARY TEST INSTRUCTIONS

This is a test of your knowledge of word meanings. Look at the sample below. One of the five lettered words has the same meaning or nearly the same meaning as the word above the lettered words. Mark your answer by putting an X through the letter in front of the word that you select.

jovial

1. refreshing
2. scare
3. thickset
4. wise
5. jolly

The answer to the sample item is alternative e); therefore, an X has been put through alternative e).

Your score will be the number marked correctly minus a fraction of the number marked incorrectly. Therefore, it will <u>not</u> be to your advantage to guess unless you are able to eliminate one or more of the answer choices as wrong.

Extended Range vocabulary Test V3 Part I: ID # ________

1. cottontail a) squirrel b) poplar c) boa d) marshy plant e) rabbit	**7. evoke** a) wake up b) surrender c) reconnoiter d) transcend e) call forth	**13. placate** a) rehabilitate b) plagiarize c) depredate d) apprise e) conciliate	**19. curtailment** a) expenditure b) abandonment c) abridgment d) improvement e) forgery
2. marketable 1. partisan 2. jocular 3. marriageable 4. salable 5. essential	**8. unobtrusive** a) unintelligent b) epileptic c) illogical d) lineal e) modest	**14. surcease** a) enlightenment b) cessation c) inattention d) censor e) substitution	**20. perversity** a) adversity b) perviousness c) travesty d) waywardness e) gentility
3. boggy a) afraid b) false c) marshy d) dense e) black	**9. terrain** a) ice cream b) final test c) tractor d) area of ground e) weight	**15. apathetic** a) wandering b) impassive c) hateful d) prophetic e) overflowing	**21. calumnious** a) complimentary b) analogous c) slanderous d) tempestuous e) magnanimous
4. gruesomeness a) blackness b) falseness c) vindictiveness d) drunkenness e) ghastliness	**10. capriciousness** a) stubbornness b) courage c) whimsicality d) amazement e) greediness	**16. paternoster** a) paternalism b) patricide c) malediction d) benediction e) prayer	**22. illiberality** a) bigotry b) imbecility c) illegibility d) cautery e) immaturity
5. loathing a) diffidence b) laziness c) abhorrence d) cleverness e) comfort	**11. maelstrom** a) slander b) whirlpool c) enmity d) armor e) majolica	**17. opalescence** a) opulence b) senescence c) bankruptcy d) iridescence e) assiduity	**23. clabber** a) rejoice b) gossip c) curdle d) crow e) hobble
6. bantam a) fowl b) ridicule c) cripple d) vegetable e) ensign	**12. tentative** a) critical b) conclusive c) authentic d) provisional e) apprehensive	**18. lush** a) stupid b) luxurious c) hazy d) putrid e) languishing	**24. sedulousness** a) diligence b) credulousness c) seduction d) perilousness e) frankness

Appendix C: WAIS-R Digit Symbol test

WAIS-R Digit Symbol Test Instructions

Materials:
Digit-symbol Test sheet.
Pencil.

This next test involves numbers and symbols.
Look here *(point to the digit-symbol key).*
On the top row are the numbers one to nine.
On the bottom row are symbols that go with each number .
Down below *(point to the "samples" portion)*, notice that there are numbers, but below, the boxes are empty.
Your job is to fill in the empty boxes with the corresponding symbols.
You may consult the key *(point)* as often as needed.
You must work from left to right without skipping any of the boxes.
Do not go back to correct your work.
When you are finished with one row, move to the next row below and continue.
Work as quickly and accurately as possible.

To give you some practice, I'd like you to complete the first few sample items now. Stop when you reach the darkened line *(point).*

Experimenter should check that the subject understands and has completed the sample items correctly.

Now you are ready for the actual test. You will have exactly **90 seconds** to complete as many items as possible, working from left to right without skipping items.

Are you ready?
Prepare stopwatch.
Go.
....
Please Stop.

If subject does not stop immediately, record item that was just completed when you said stop.

Score this test after test session is complete. Total score = number correct , minus number incorrect.

Digit Symbol—Coding

1	2	3	4	5	6	7	8	9
—	⊥	⊐	∟	⊔	○	∧	×	=

Sample Items

2	1	3	7	2	4	8	2	1	3	2	1	4	2	3	5	2	3	1	4

5	6	3	1	4	1	5	4	2	7	6	3	5	7	2	8	5	4	6	3

7	2	8	1	9	5	8	4	7	3	6	2	5	1	9	2	8	3	7	4

6	5	9	4	8	3	7	2	6	1	5	4	6	3	7	9	2	8	1	7

9	4	6	8	5	9	7	1	8	5	2	9	4	8	6	3	7	9	8	6

2	7	3	6	5	1	9	8	4	5	7	3	1	4	8	7	9	1	4	5

7	1	8	2	9	3	6	7	2	8	5	2	3	1	4	8	4	2	7	6

Appendix D: Consent Form

ID#________

CONSENT TO PARTICIPATE IN MEMORY ZOO

This is to state that I agree to participate in a research study being conducted by Mervin Blair (514-848-2424, ext. 7567 or me_blair@alcor.concordia.ca) under the supervision of Dr. Karen Li (514-848-2424, ext. 7542 or karen.li@concordia.ca) in the Psychology Department of Concordia University.

A. PURPOSE

I have been informed that the purpose of the research is to understand the effects of aging on the ability to regulate a sequence of actions.

B. PROCEDURES

The research will be conducted on the Loyola campus at Concordia University in the laboratory PY-017. Each participant will be asked to fill out questionnaires, to execute one computer task, and neuropsychological tests. The computer task will involve responding to visual images of animals in a particular order. The testing will last approximately 60 to 90 minutes. Each participant will receive participant pool credits as compensation.

C. RISKS AND BENEFITS

The risks for this study are very low. The benefits of this study are to gain knowledge about the effects of aging on the ability to regulate a sequence of actions.

D. CONDITIONS OF PARTICIPATION

- I understand that I am free to withdraw my consent and discontinue my participation at anytime without negative consequences.
- I understand that my participation in this study is CONFIDENTIAL.
- I understand that the results from this study may be published.

I HAVE CAREFULLY STUDIED THE ABOVE AND UNDERSTAND THIS AGREEMENT. I FREELY CONSENT AND VOLUNTARILY AGREE TO PARTICIPATE IN THIS STUDY.

NAME (please print):

____

SIGNATURE:

____

Please call me again for participation in other research YES ☐ No ☐

If at any time you have questions about your rights as a research participant, please contact Adela Reid, Compliance Officer, Concordia University, at (514) 848-2424 ext. 7481 or by e-mail at areid@alcor.concordia.ca.