The Symbolic Working Memory: memory accommodations for schematic processing of symbolic information

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Abstract

This paper describes an evolutionarily plausible description of of a specialized working memory system involved in information management for high-order cognitive tasks through its capability for controlled maintenance and schematic access to symbolic representations. Along a volatile serially accessible symbolic storage that serves a basic maintenance function the system utilizes other accessory volatile memory systems along long-term memory (LTM) and learning systems for execution of schematic access to its content. Accessory systems can help encode the episodic information including the current state of the task and more importantly provide a means for address-based access to the content of symbolic storage. LTM and learning systems help map the current state of the task onto execution programs and thus help render schematic access and process of the retained symbolic information. Implications of this feature of the model are examined for the case if concurrent-counting task.

Keywords: Symbolic Working Memory; Volatile Memory; State Registry System; Working Memory; Selective Access;

The concept of working memory (WM) has emerged from a general interest in understanding the function of memory in the context of goal-oriented behavior. WM is often used to refer to the capability of provisional retention of selective information in a mode which is accessible to running processes. Research on working memory in cognitive science is traditionally concerned with high-order cognitive tasks. In this realm WM is often described as a universal limited capacity pool of information kept in an active state where cognitive processes can bind to their needed information. This universal pool is equipped with a universal set of processes which allow controlled utilization of its storage capacity with respect to the status of the task. This view of a universal pool of information equipped with a universal set of control processes which is deeply embedded in standard models of WM can barely stand up to the challenge of explaining the body of evidence gathered over near half a century. Here I give a brief summary of some of these challenges that have recently motivated proliferation of new WM models.

Involvement of long-term memory A monumental challenge facing standard models of WM is defining the nature of WM storage and its relationship with long-term memory (LTM). Popular models of WM either assume a complete dissociation between WM storage and LTM (Baddeley, 1992, 2000) or assume that WM as an entirely LTM-embedded construct (Cowan, 1999; Ruchkin, Grafman, Cameron, & Berndt, 2003; Oberauer, 2009). However, recent evidence suggests *'selective involvement'* of LTM in storing information for WM tasks which seems to equally challenge both these views. Recent neural evidence suggests that previous assumption about complete dissociation between LTM and STM (Scoville & Milner, 1957; Atkinson & Shiffrin, 1968; Shallice & Warrington, 1970) need to be revised at least with respect to retaining information in novel WM tasks where involvement of the hippocampal area of the human brain –known for encoding LTM – has become evident (Ranganath & Blumenfeld, 2005; Ranganath, Cohen, & Brozinsky, 2005; Olson, Page, Moore, Chatterjee, & Verfaellie, 2006; Jonides et al., 2008). Based on behavioral evidences some researchers have reached to a similar conclusion in assuming non-waiverable role for a primary STM along a secondary LTM component in working memory (Davelaar, Goshen-Gottstein, Ashkenazi, Haarmann, & Usher, 2005; Unsworth & Engle, 2007). There have been some theoretical efforts for explaining a role for both LTM resources and STM resources in WM storage determined by a trade-off between the cost of capacity limitation in STM resources and the cost of learning and interference of memory traces in LTM resources (Ericsson & Kintsch, 1995; O'Reilly, Braver, & Cohen, n.d.). These models although assume a dual nature for storage in WM tasks yet are not specific about where utilizing LTM resources is obligatory (Ranganath & Blumenfeld, 2005; Olson et al., 2006).

Ambiguity in describing control processes The concept of 'control processes' was first introduced to explain the variance in the capacity of a presumed universal structural short-term store (Miller, 1956; Broadbent, 1958) by considering the possibility of controlled and voluntary use of processes that can help optimize encoding and retention of information in this structure (Atkinson & Shiffrin, 1968, 1971). The idea of subject's discretionary control over resources of memory became the most distinctive aspect of WM research agenda and gained a crucial theoretical status when inspired by the architecture of digital computers Baddeley and Hitch assumed a central executive (CE) unit as the embodiment of control functions and in charge of regulating storage components (Baddeley & Hitch, 1974). Yet, after four decades of efforts for describing functions and mechanisms of CE, this 'most important' component of standard WM models is often described as the 'least understood' component of these model (Repovs & Baddeley, 2006; Baddeley, 2012). Baddeley once revised his initial description of CE as a collection of strategic control processes to a unit which exert controls over its subsidiary storage units through controlling limited executive attentional resources. This revision helped relate WM to executive resources of the brain which are believed to be predominantly localized in prefrontal regions of the brain. These resources are particularly necessary for rendering complex and novel responses where automatic responses need to be inhibited as their outcome may conflict with the goal of the task. However, relating control processes of WM to executive resources of the brain has broadened the scope of questions facing WM models. The challenge lies in articulating a relationship between CE and storage components which is consistent with dominant views of functioning executive resources through inhibition of automatic responses or selection through biasing.

Inconsistencies with an evolutionary plausible narrative It is well accepted in perception research communities that working memory and short-term memory should be dissected into functionally specialized faculties each serving a problem of adaptive importance to the function of brain. Functioning of these specialized short-term memory systems in perception-action routines are described in terms of schemas that explain the flow of information with respect to its specific function (Arbib, 1992). This functional modularity fits standards of evolutionary psychologists in describing cognitive systems (Cosmides & Tooby, 1994b; Barrett & Kurzban, 2006). In comparison the dominant narrative of WM in cognitive psychology as a universal, general-purpose, functionally non-modular and centrally controlled cognitive faculty does not integrate well with growing trends in cognitive science for viewing cognitive capabilities in a broader scope and in relationship with low-level functions of the nervous system (Barsalou, 1999) or as a continuation of an evolutionary process (Cosmides & Tooby, 1994a).

This paper gives a description of a working memory system whose functional domain spans high-order cognition by virtue of its speciality in retaining symbolic codes of human language that potentially empower a diverse set of tasks. The proposed system features schematic use of sensorimotor systems for management of information which can be the target of executive control mechanisms. In this sense, the proposed model has necessary elements for integrating executive attentional resources into an information management system. The proposed system also provides a novel explanation of contributions of volatile short-term and long-term memory resources in providing different modes of access to information.

The Symbolic Working Memory

General framework

What is described here is a working memory system which is fundamentally dependent on the evolution of human language. The very systems that are at the core of perception and articulation of communication signals in an open ended communication system provide the capacity of controlled retention of disposable information in the form of code segment with symbolic representation function that feed to cognitive processes. This system is far from description of a universal and general purpose WM system which can serve cognition in any form or facet. In this sense storage capacity of such a system should not be viewed as an instance of a universal store or pool of information (Broadbent, 1958; Atkinson & Shiffrin, 1968). The symbolic working memory system however, appears as a ubiquitous system with a crucial role in many high-order cognitive tasks that in some form rely on processing abstract representation of specialized sensory and motor codes that belong to human symbolic system for communication.

The system is a composite system with different functional modes with a a variable configuration depending on the functional mode. Even for its most basic function in simple controlled retention of symbolic codes the system relies concerted operation of a sensory and a motor system. The system relies on a distributed control system when collaboration of several subsystems is required. Functioning of the system at different level are described in terms of schema language a control theoretic representation of functions and mechanisms in neural systems (Arbib, 1992; Noori & Itti, 2013).

In a more complicated functional mode which supports selective access to content of SWM the system utilizes different sources of volatile memory in addition to learning system to employ a data structure that allows selection of a particular segment symbolic code. It is in this latter functional mode that involvement of hippocampal regions of the brain will become necessary and LTM practically plays a role in executive functions and rendering complex access to the content of volatile components of SWM which is required for schematic processing of information.

Components of the system

1. Volatile Serial Symbolic Storage The core component of every SWM system which provides its basic functionality of retention of symbolic codes is a volatile serial symbolic storage. The crucial role of this system stems from the functional versatility of symbolic codes of human language in cognitive functions. The most ubiquitous implementation of such a system is the phonological loop (PL) (Baddeley, Lewis, & Vallar, 1984) however, PL is not the only possible implementation of such system. Sign language as another alternative form of human language features a a system similar to PL which is capable of retention of symbolic codes of sign language (Wilson & Emmorey, 1997). This system is indeed a necessary arrangement between perception and production systems of every form of language which features open-ended set of lexemes. This component can be described in a more generic form and as a result of coupling of sensory and motor systems which are responsible for perception and articulation of symbolic signal of the language. The evolutionary purpose for forming a loop between the a sensory/perceptual system and a motor/articulatory system is learning motor representations for automatic articulation of signals which are similar to sample signals provided by a mentor. Both perceptual and production subsystems are equipped with a volatile memory whose content is subject to a relatively rapid decay. Without refreshing the content of these volatile buffers in a loop by constant exchanging segment codes between buffers their content will vanish.

A critical feature of such a system is preserving the order of segments in buffers and therefore, it stores information in the form sequential arrangement of segment codes from subject's repertoire of lexemes. Capacity limitation in this system is rather determined by the ability of the subject for reliable rehearsing or robust exchanges between articulatory and perceptual subsystems before information in traces of activations in sensory or motor buffer fade away. As a result the length of symbolic codes– determines the time needed for their articulation– affects the number of symbolic segments that can be retained reliably (Baddeley et al., 1984; Wilson & Emmorey, 1998). A sever limitation of this system which affects its functionality is related to the fact that stored segments do not have address and thus the system has no internal mechanism for granting selective access to a symbolic segment based on its position in the store. This feature is restricting for supporting those tasks that at each stage need to have access to only a subset of symbolic codes for processing. Without a random access functionality this system can support very well trained cognitive functions which rely on serially stored symbolic segment. Integration with two other components which are explained in next the two sections is a remedy for this handicap.

2. Volatile State Registry System An add-on mechanism that gives the symbolic serial storage the needed capability of selective access to particular retained segments is provided by coupling with an accessory system that first, is capable of encoding addressable states that are subject to selective access and second, operationally can be coordinated with the process of rehearsing or serial monitoring symbolic segments in the serial symbolic storage. Such an arrangement provides a proxy state for the content of serial symbolic storage by synchronizing the iteration through the content of serial segment and a schema for changing in the state of the coupled system. In this paper this accessory system is referred to as State Registry System or (SRS).

State registry system is defined functionally which means that unlike VSSS it does not refer to a particular system. There are a number of systems with built-in location-based representation and mechanisms for controlled shift between those states which fulfil above descriptions and thus can function as SRS in the SWM system. These systems may have routine primary function in other primitive and basic functions yet are capable of being coupled with rehearsing process of VSSS. Recruitment of same brain regions in tasks that feature spatial/motor functions and WM tasks with no immediate spatial/motor feature (Knops, Thirion, Hubbard, Michel, & Dehaene, 2009; Tamber-Rosenau, Esterman, Chiu, & Yantis, 2011) along with reports of systematic use of limbs (Noori, 2015) and occulomotor system in WM tasks (Noori & Itti, 2011) provide supporting evidence for this hypothesis. Moreover, this hypothesis can help explain abundant evidence of extensive engagement of the posterior parietal cortex (PPC) with conspicuous spatial tuning characteristics and a critical role in wide range of sensorimotor functions in WM tasks that involve manipulation of information (Olson & Berryhill, 2009).

Combining this added registry features with a system that can learn and retain association between these proxy states and processing programs creates a full fledged symbolic working memory system with capability of schematic processing.

3. Symbolic Schema Learning System SWM system utilizes learning and LTM systems in a role other than retaining episodic information across individual trials of the task and in a way which is more balanced in terms of cost of learning and in the meantime less susceptible to effects of interference. In the proposed role, associative learning and associative memory help learn and retain a mapping between internal state of the system reflected in current state of SRS and the content of those volatile memories that retain the task status onto processing programs which take in symbolic codes. This role is drastically different from functioning as a storage for episodic information. The cost of using LTM for retention of episodic information rises with the rate of updating episodic information (as a result of interference and relatively slow encoding process) and interference between traces of stored information across different episodes of the task is inevitable. In contrast, the information about structure of the task reflected in the mapping between possible states onto processing programs remain stable across different episodes of the task and reusable across different episodes. In this schema VSSS and SRS as volatile memory resources which are subject to control and are protected against interference. These resources play the role of storing episodic information. In contrast LTM resources retain data structures that reflect programs for tasks execution. In this role LTM is in fact a part of executive system rather than storage of information in each trial. In a sense, LTM practically becomes an essential part of memory management in those tasks that draw on random or selective access to the information retained in the symbolic serial buffer. This assumption has non-trivial implications for understanding deficit in function of WM in AD[1] patient which was previously attributed to a dysfunction in central executive system (Baddeley, 1996; Baddeley & Wilson, 2002).

It is important to note that above description of SWM does not preclude the use of LTM resources for directly retaining episodic information. If the cost of learning and interference allows then subject may opt for using these resources for storage of episodic information.

SWM in its fully integrated mode

This section gives an example of functioning of SWM in its *'integrated mode'* where all components of the system collaborate toward supporting schematic processing of WM items. For this purpose functioning of SWM in a self-paced concurrent-counting task is discussed in detail. The discussion here is then used for developing a model and computer simulation of triple concurrent counting tasks which allows quantitative evaluation of the model and its distinctive prediction against real data.

Imagine you are handed a number of cards; randomly chosen from a deck of cards and you are allowed to see each card once and one card each time. Your task is counting and then reporting the number of cards belonging to each of four suits after drawing the last card. The task is self-paced which allows allocating enough time for updating working memory content before drawing the next card. The task in practice needs concurrent counting of cards of each suit and retention of four numbers ($n_\spadesuit, n_\heartsuit, n_\diamondsuit$ and $n_\clubsuit$) in some form at each moment. Ideally, every time a card is drawn from the hand one of these four numbers which represents the running count of the matching suit should be increased by one leaving the sum of counts equal to the number of cards in the end. Relying only on LTM for retaining these four numbers requires creating an association between available cues and current values (e.g. $\{n_\spadesuit \leftarrow \spadesuit, n_\heartsuit \leftarrow \heartsuit, n_\diamondsuit \leftarrow \diamondsuit, n_\clubsuit \leftarrow \clubsuit\}$). Since the associated running counts are subject to change every time a card is drawn, these cues will become overloaded which make the counting process susceptible to interference especially when the subject is forced to perform the task as fast as possible.

The phonological loop as a volatile memory resource is well protected against effects of interference and provides a better means for keeping up with the fast pace of the task and frequent changes of values. Retaining four word numbers by subvocal rehearsing very well falls in the range of PL capacity in normal subjects (Baddeley et al., 1984). Let's denote rehearsing

[1] Alzheimer's Disease

process as follow: $\langle \mathcal{W}_1 \rhd \mathcal{W}_2 \rhd \mathcal{W}_3 \rhd \mathcal{W}_4 \rhd \cdots \rangle$ where $\mathcal{W}_i$ denotes the ith segment from the head of the rehearsal loop (e.g. the first segment after a long pause). However, what renders the difficulty of relying only on PL is that it has no internal mechanism for distinguishing absolute order of these segments and as a result locating a particular segment in the loop which is associated to a particular type of suit is not possible. An additional registry system equipped with enough number of addressable states can help if the process of shifting between states is synchronized with the rehearsing process. A potential registry system needs to allocate four distinguishable states, say $\mathcal{S}_1, \mathcal{S}_2$, $\mathcal{S}_3$ and $\mathcal{S}_4$ for performing this task. Let's denote the process of shifting from state $\mathcal{S}_x$ to $\mathcal{S}_y$ by $\mathcal{S}_x \rightsquigarrow \mathcal{S}_y$. Then synchronizing a shift between states of SRS with rehearsing process is denoted as follow:

$$\begin{array}{l} \langle \mathcal{W}_1 \rhd \mathcal{W}_2 \rhd \mathcal{W}_3 \rhd \mathcal{W}_4 \rhd \cdots \rangle \\ \langle\ \mathcal{S}_1 \rightsquigarrow \mathcal{S}_2 \rightsquigarrow \mathcal{S}_3 \rightsquigarrow \mathcal{S}_4 \rightsquigarrow \cdots \rangle \end{array}$$

Where $\underset{\rightsquigarrow}{\overset{\rhd}{\vdots}}$ denotes synchronization between iterating through SRS and rehearsing in PL. Additionally, learning an arbitrary association between these states and cards suits is necessary. Let's assume that $\mathcal{A}_1$ represents a learned association:

$$\mathcal{A}_1 = \{\mathcal{S}_1 \leftarrow \spadesuit, \mathcal{S}_2 \leftarrow \heartsuit, \mathcal{S}_3 \leftarrow \diamondsuit, \mathcal{S}_4 \leftarrow \clubsuit\}$$

This association will help throughout an episode of the task identify the state and its synchronized segment in the PL to be accessed after a particular type of card is identified. The target segment then is processed for running the addition process which yields a new value whose symbolic representation in the form of phonological code should replace the previous one. With respect to a specific order between states of SRS the symbolic phonological segments in the loop are arranged in the order which their associated states in SRS are associated to the card suits. So, in an episode of the task which uses $\mathcal{A}_1$ as the association schema four segments in the loop (from the head of the loop) will respectively correspond to $n_\spadesuit, n_\heartsuit, n_\diamondsuit$ and $n_\clubsuit$. If instead $\mathcal{A}_2 = \{\mathcal{S}_1 \leftarrow \heartsuit, \mathcal{S}_2 \leftarrow \spadesuit, \mathcal{S}_3 \leftarrow \clubsuit, \mathcal{S}_4 \leftarrow \diamondsuit\}$ is learned the segments in PL will respectively correspond to $n_\heartsuit, n_\spadesuit, n_\clubsuit$ and $n_\diamondsuit$.

A significant difference between a schema for associating card suits to changing values and a schema for associating card suits to the states of SRS is that the latter one stays unchanged throughout an episode and can be learned in the beginning of the episode while for the former schema associations should be relearned each time counter values change which in turn creates overloading cues and a within-episode interference effect. Even more importantly, once an association between card suits and states of SRS is learned it can be used for different episodes of the task which offers an opportunity to avoid overloading associations and a between-episodes interference. This situation provides an opportunity to test the model. Since the order of association matches the order of rehearsing if subjects use a fixed order of rehearsing (i.e. a fixed association schema is used) then they are less likely to make error in retrieving or replacing the correct segment from PL. Thus this model predicts that by changing the order of rehearsing between different episodes subjects are more prone to error in counting as a result of between-episodes interference. Noori has tested this prediction in a series of experiments involving a triple concurrent-counting (TCC) task (Noori, 2015). In summary his studies show the advantage of adopting a fixed rehearsing strategy (FRS) compared with mixed rehearsing strategy (MRS) and choosing different orders for rehearsing in different episodes. This advantage can be observed even when the sum of reported counts are compared with the sum of real values. He also reports overt forms of body movement including hand movement, finger movement, finger tapping or foot movement which despite their variability in manifestation follow a specific patterns in pointing to three locations in an order which is synchronized with rehearsing process. His description of patterns of body movement matches with specifications of iteration of states in SRS. The footnote here includes a link to sample video recording of his experiment [2].

Simulation of the triple concurrent-counting task

The above model for TCC task was used for implementing a computer simulation for a qualitative evaluation. The focus of analyses is on errors in performing the counting task. The sequence of events and parameters for stimulus presentation was similar to what is described in (Noori, 2015). The model includes a registry system with three states in addition to an array of three running numbers which simulates the symbolic storage (VSSS). In this model iteration of items in VSSS and states in SRS are completely synchronized. However, possible effects of slipping in synchronized iteration of VSSS and SRS which leads to incorrect retrieval of running counts is considered via a perturbation effect which is independent of the rehearsing strategy. For MRS blocks the association between states of SRS and targets of counting is learned in the initial phase of the trial where initial counters (0 or 1) are assigned to each counter. During FRS blocks the order of registry is learned once in the initial phase of the block's first trial. Updating counters after each target identification invokes retrieval process twice: once for retrieving the associated counter to be increased by one and once for retrieving the position in which the updated value should be inserted or replaced with the old value. When a target appears repeatedly and sequentially the retrieval phase is skipped and instead the previous updated number is selected for the addition process. This will save on retrieval operation for targets that are processed in immediately last operation. This aspect of the model is consistent with this observation that reaction time in counting is faster when the target was presented immediately before the current operation (Garavan, 1998; Oberauer, 2002; Noori, 2015). The retrieval process can return a wrong target with a small chance represented by the coefficient of perturbation , C_p. The effect of perturbation which is strategy independent can account for slipping in synchronized iterations of VSSS and SRS. This effect is different from the effect of interference where a registry state can be bound to its binding target of the previous trial with additional probability of p_i. In this simulation the effect of interference is only limited to two consecutive trials.

Following the analyses of (Noori, 2015) two measures for counting error were calculated: 1. $SumError$ which is the distance between sum of counted values and sum of true values. 2. $SoError$ which is the average of distances between counted values and true values after sorting reported and true values in order. These two measures are sensitive to different sources of error and the relationship between them is determined by the model of counting process and possible sources of error.

[2] http://tiny.cc/tc-motor

For example in a process model where retrieval of target items and updating them is carried out in one stage (updated number replaces the retrieved number) $SumError$ will be equal to zero and $SoError$ will depend on any factor which might affect incorrect retrieval (e.g. error in target identification).

With the process model described here the simulation of MRS blocks showed that for small values of C_p the behavior of both $SumError$ and $SoError$ can be described as an exponentially decaying function of p_i with increasing value (see Figure 1):

$$SumError_{MRS} = \alpha_{Sum} - \beta_{Sum} \times e^{-\gamma_{Sum} \times p_i}$$
$$SoError_{MRS} = \alpha_{So} - \beta_{So} \times e^{-\gamma_{So} \times p_i}$$

Examining different values of these function reveals that for small values of C_p these functions can be estimated as follow: $\alpha_{Sum} \simeq 4.2 \times C_p + 1.2$; $\beta_{Sum} \simeq -8.5 \times C_p + 1.2$; $\gamma_{Sum} \simeq 6.05$
$\alpha_{So} \simeq 1.9 \times C_p + 0.56$; $\beta_{So} \simeq -3.6 \times C_p + 0.56$; $\gamma_{So} \simeq 5.41$

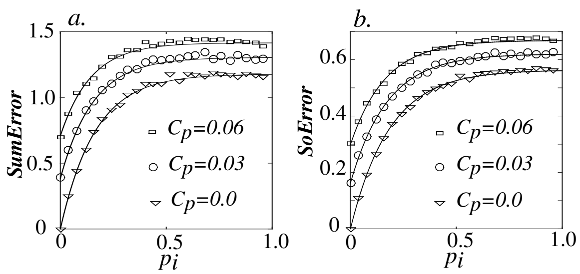

Figure 1: Simulated error measures for MRS condition.

In FRS blocks the interference is practically ineffective and the error value is described with the same function when $p_i = 0$. So, in practice, $SumError_{FRS} \simeq SumError_{MRS}(0) = \alpha_{Sum} - \beta_{Sum} \simeq k_{Sum} \times C_p$. A similar relationship holds for $SoError$: $SoError_{FRS} \simeq SoError_{MRS}(0) = \alpha_{So} - \beta_{So} \simeq k_{So} \times C_p$.

These relationships quantitatively describe the model's prediction. In particular, they show for each subject with a given C_p how both $SumError$ and $SoError$ are expected to be higher for MRS condition compared to FRS condition. The difference is attributed to the effect of between-episodes interference which is represented by p_i in this model.

Evaluation of the model

The model was tested against experimental data from a recent study of triple counting (Noori, 2015). Sixteen subjects had performed the TCC task both under MRS and FRS conditions. To test the model, for each subject both parameters of the model were calculated using the data of $SoError$ as follow: $SoError_{FRS} \simeq SoError_{MRS}(0) = \alpha_{So} - \beta_{So} \simeq 5.5 \times C_p$
or : $C_p \simeq SoError_{FRS} \div 5.5$. With the estimated C_p in hand p_i can be estimated as $\frac{1}{\gamma_{So}} \times ln(\frac{\alpha_{So} - SoError_{FRS}}{\alpha_{So} - SoError_{MRS}})$. With these estimation of C_p and p_i values of $SumError$ for FRS condition can be estimated as follow: $SumError_{FRS} \simeq SumError_{MRS}(0) = \alpha_{Sum} - \beta_{Sum} \simeq 12.7 \times C_p$
And finally the value of $SumError$ for MRS condition can be calculated using estimations in the previous sections by considering C_p and p_i for every individual subject.

The graph on the left panel of Figure 2 compares the predicted values for $SumError$ for both conditions against the real data. To see how data points are scattered around the ideal model ($y = x$) the coefficient of determination (r^2) was calculated for sampled and predicted values. For FRS condition calculated r^2 equals to 0.66 and for MRS condition calculated r^2 equals 0.86, indicating even a better prediction of $SumError$ for this condition.

On the right panel the mean value of $SumError$ for MRS and FRS conditions for predicted values and real data are shown. Error bars in this graph indicate the standard error of mean above and below the average values.

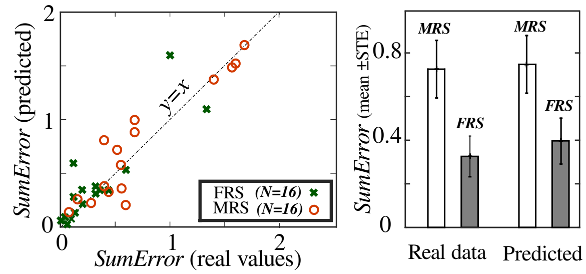

Figure 2: Predicted $SumError$ vs. real data of subjects (N=16).

The mean value of $SumError$ for the case of MRS for real data was 0.726 (SEM=0.132) the mean value for $SumError$ for the same condition for predicted data is 0.747 (SEM=0.132). The mean value for $SumError$ for the case of FRS for real data was 0.326 (SEM=0.093) and for predicted data this value is 0.396 (SEM=0.105).

Conclusion

This paper presented an account for a working memory system specialized in management of symbolic information. The proposed system serves those cognitive tasks that in some form rely on symbolic features of human language. These tasks make up a substantial body of evidence in working memory literature in cognitive psychology (CP) often referenced as cognitive WM tasks. These tasks have been extensively used to speculate about a general-purpose, universal storage with a centralized executive regime. The proposed model is different from previous models of WM in CP in many fundamental ways while it borrows some of its key elements from standard models.

From a broad perspective the goal of the present work is explaining a specialized working memory system along other working memory systems. This system is probably one of most recently evolved working memory systems along with evolution of human language. Many fundamental functions of the brain which we have inherited from our non-human primate ancestors still rely on their specialized WM systems for retention and flow of information. This work is not even an attempt for a universal description of working as multi-component model of WM (MC-WM) tries to achieve. SWM in its fully integrated mode employs different components, however, these components all collaborate for serving the task in hand. This view is different from MC-WM which includes modal storage units for storing information in different modes of cognition function.

Similar to MC-WM the role of storing episodic information is given to volatile (or short-term) resources. However, the difference is that the episodic information in SWM is distributed in different components with the symbolic storage system always present and engaged. These volatile working memory systems are indeed embedded in sensorimotor systems with ability of retaining information in stable and protected neural activities. SWM is different from other models in assuming a crucial and active role for associative learning and associative memory in providing the capability of schematic access to the content of symbolic storage. Schematic access is a crucial feature of many working memory tasks that are used for evaluating specifications of cognitive control.

Another distinctive feature of the model is the emphasis on schematic access to the content of working memory which allows schematic processing of information. Symbolic schematic processing is a characteristics of computational cognitive models which is generally attributed to cognitive processes as the consumers of information rather than the WM system. In the presented paradigm a part of schematic process is given to the WM system. This part is concerned with representation of limitations and constraints imposed by the very specific mechanisms underlying retention and access to information in the Symbolic Working Memory.

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