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Role of Rehearsal Language in Working Memory

Introduction

Working Memory (WM) refers to the temporary storage and manipulation of sensory information, as required for various cognitive tasks (Baddeley, 2003, 2010). Various models and approaches have attempted to explain the dynamics of WM from different points of view. These include, among many others, the ‘Processing Efficiency Hypothesis’ by Daneman and Carpenter (1980), ‘Embedded-Process model’ by Cowan (1999), the ‘Executive Attention model’ by Kane and Engle (2000).

However, the most commonly referred model of the WM system is Baddeley’s Multi-component model (Baddeley, 1992, 2000a). This model postulates four main components of WM – the Central executive, the Phonological loop, the Visuo-spatial sketchpad, and the Episodic buffer (added later). The central executive assesses the different incoming information and regulates the distribution of a ‘finite’ amount of attention to the most relevant cognitive task. The central executive is mainly responsible for inhibiting irrelevant information, shifting attention between concurrent tasks, as well as updating information (Blom, Küntay, Messer, Verhagen, & Leseman, 2014). The phonological loop and the visuo-spatial sketchpad store domain-specific information. The phonological loop temporarily holds verbal and auditory information. Regular rehearsals, help in maintaining the information for a longer time. The visuo-spatial sketch pad, on the other hand, stores visual information such as the location of objects in space. The episodic buffer acts as a ‘binding agent’ for the multimodal information within the WM system, such as integrating information about a talker who is also moving. The buffer is also responsible for creating meaningful and usable ‘chunks’ from the received information.

Typically, the WM system works by first directing attention towards the target stimuli (central executive). The phonological loop, then, temporarily stores the attended stimuli, followed by chunking into meaningful units by the episodic buffer. However, the WM system is limited in its capacity, and therefore, the 'memory trace' that is generated in the phonological store fades within a few seconds (Baddeley, 2003; Campoy & Baddeley, 2008; Henry, 2012). Participants, therefore, need to use different 'rehearsal strategies' such as subvocal or overt articulation of the target signals to overcome the effect of decaying memory trace. According to Baddeley, two components constitute the phonological loop – the phonological store and the articulatory rehearsal (Baddeley, 1992, 2000a, 2003). In this paper, we discuss a specific aspect of rehearsal – the language of rehearsal – in bilinguals on backward digit (BD) span.

Over the last few decades, many researchers have investigated the role of articulatory rehearsal strategies on the WM spans. Rehearsal strategies are techniques (internal/mental) that an individual employs to facilitate the processing and/or storage (Turley-Ames & Whitfield, 2003) of sensory information. These strategies can include overt or covert (subvocal) vocalisation (Baddeley, Buchanan, & Thomson, 1975; Neath & Nairne, 1995), verbalising and/or visualising (Rayner & Riding, 1997), intonation-based grouping (Glanzer, 1976) etc. Dunn, Gaudia, Lowenherz, and Barnes (1990) reported that listeners use highly individualistic and amorphous rehearsal strategies during BD span task. The interested reader is referred to Dunn, Gaudia, Lowenherz, and Barnes (1990) for an excellent review of rehearsal strategies used by individuals during digit span tasks. It is suggested that choice of rehearsal strategies may be responsible for the individual variations seen in WM span (Baddeley, 2000b; Bailey, Dunlosky, & Hertzog, 2009; Hilbert, Nakagawa, Puci, Zech, & Buhner, 2015; McNamara & Scott, 2001).

In WM tasks involving digit or word recall, it is shown that words which take longer time to articulate are recalled less accurately (Baddeley et al., 1975). For example, the Arabic language has two variations - long and short versions - of digits. This means that each digit can be pronounced in two different ways, both differing in length (number of syllables) but are conceptually identical. Shebani, Van De Vijver, and Poortinga, (2005) reported that BD spans were significantly smaller for longer version of the digits compared to shorter version. Similar results are also reported in other languages such as Chinese versus English (Stigler, Lee, & Stevenson, 1986), Mandarin versus English (Mattys, Baddeley, & Trenkic, 2017)and English, Spanish, Hebrew and Arabic (Naveh-Benjamin & Ayres, 1986). These studies show that syllable length and duration of the digits vary across languages, and these differences in the duration affect the BD span (Van De Vijver, 2015). While the digits are often monosyllabic in English, they are often bisyllabic (occasionally trisyllabic) in some south Indian Dravidian languages such as Kannada, Malayalam, Tamil, and Telugu. For example, in the Dravidian language Kannada, digits 'zero', 'one', and 'three' are produced as /sonne/, /ondu/, and /mooru/ respectively which are all bisyllabic. Therefore, the characteristics of the language used for the working memory tasks must be considered while designing and interpreting working memory tasks.

In bilinguals, digit recall spans are better in the language where the digit lengths are shorter. Ellis and Hennelly (1980) reported shorter digit span in Welsh language compared to English in Welsh-English bilinguals. They attributed these findings to significantly longer duration of Welsh digits compared to English. Several investigators have reported similar results in other bilingual participants (Brown & Hulme, 1995; Cheung & Kemper, 1994; Chincotta, Hyönä, & Underwood, 1997; Hoosain, 1979). In summary, these studies demonstrate that the digit span is influenced by the recall language in bilingual participants.

In a digit recall task, bilingual participants can choose to rehearse the stimuli in either of the languages they know. We hypothesise that the participants' selection of language may depend on the stimulus-related properties such as word length and in turn, may influence the WM spans. We propose that in bilingual participants, rehearsing in the language with the shorter digit length results in better digit spans than in the language with longer digit length. If this is true, then, while testing a bilingual participant, explicit instruction regarding the rehearsal language is necessary as rehearsal language could be a potential variable and may influence the BD span scores. Therefore, we measured BD spans in bilingual individuals, where they were explicitly instructed to engage in overt rehearsal in both their proficient languages. Specifically, we aimed at observing the differences in BD span scores with rehearsal in Kannada versus English. Because Kannada digits are always bisyllabic or trisyllabic (Malda et al., 2008), they also have longer syllable lengths than English digits. Therefore we hypothesise that the BD spans would be longer when rehearsed in English compared to Kannada.

Methods

Participants

We recruited 24 participants (10 males, 14 females), with a mean age of 21.15 years (range = 18 to 25 years). Hearing thresholds of all participants were within 15 dB HL at the octave frequencies between 250 Hz and 8000 Hz. All participants were native speakers of the Kannada language. All participants had a minimum of 12 years of formal education, with the medium of instruction being English. Additionally, all participants signed an informed consent according to the Bio-behavioral ethics guidelines.

Further, all participants rated their proficiency in both Kannada and English languages using the Language Experience and Proficiency Questionnaire (LEAP-Q) (Marian, Blumfield, & Kaushanskaya, 2007). All participants were sequential bilinguals with English as the second language. All participants self-rated their proficiency in Kannada with a minimum score of '8' (rated as 'Very Good') for the 'Speaking', 'Understanding of Spoken Language' and 'Reading' sections. They also rated themselves with a minimum score of '7' (rated as 'good') for English proficiency for the same three sections. Additionally, we included an additional question into the questionnaire to rate the frequency with which they use English or Kannada language digits in regular conversation. A rating of 1 was given for using 'only Kannada' digits in daily conversation while a rating of 10 was given for using 'only English' digits in conversation. Most participants (20 out of 24) used the digits in both languages equivalently in regular conversation. Table 1 gives further details of the LEAP-Q for all the participants.

Table 1.

Mean responses for the different relevant sections/questions of the LEAP-Q

Parameter	Kannada	English
Exposure to language (%)	65.20	34.8
Choice of language to read (%)	29.37	70.63
Choice of language to speak (%)	67.5	32.5
Age of acquisition (in years)	Since birth	5.0
Age of fluency of speaking (in years)	4.62	12.16
Age of fluency of reading (in years)	10.66	11.16
Proficiency (mean of three sections)	9.15	8.15
Language of using digits (%)	5.62	4.38

NOTE: Comparisons are made across Kannada (Native language) and English (Second language). The parameter 'language of using digits' was not a part of the LEAP-Q but was additionally included especially for this study.

Stimuli

All digits for the experiment were presented in the Kannada language. According to the 2011 Census of India, Kannada is spoken by approximately 43 million people, predominantly in the South Indian state of Karnataka, India. It is a verb-final (predominantly subject-object-verb) language with a predominant CVCV syllable structure, with words ending with open syllables (Nag & Snowling, 2011). Kannada mostly has bi- and tri-syllabic words with few words containing up to six syllables. Monosyllabic words are sporadic and can only be observed in some dialects (Nag, Treiman, & Snowling, 2010). More details regarding the phonemic and phonotactic characteristics of the Kannada language can be found in Rupela, Manjula, and Velleman, (2010).

Eight digits in Kannada language, spoken by a native female speaker, formed the stimuli for the BD span task. Digits between zero and eight, except two, were chosen. All digits chosen were bisyllabic in nature (e.g. /naaku/, /aidu/, /aaru/ for the digits four, five and six respectively). The digit 'two' was not chosen because it was trisyllabic (pronounced /eradu/ in Kannada). The mean duration of the digits was 560 ms.

Procedure

BD spans were measured on all participants in a sound-treated room with acceptable noise levels (ANSI, 2003). The stimuli were presented at 75 dB SPL using a Lenovo-Z50 personal computer connected with Sennheiser HD 380 pro (Wedemark, Germany)headphones. The BD task was carried out using the 'Audio-Backward Span' module of the custom-designed in-house software called Smriti-Shravan. The participants were instructed to listen to a sequence of digits, rehearse verbally, and type-in the sequence in the reverse order. To gain familiarity with the task, all participants were first given a practice trial with sequences of three and four digits. Feedbacks regarding the correctness of the responses during the practice trials were also provided. The practice trial was not included for calculating the span scores. Once familiar with the task, an adaptive one-up-one-down technique, as used in Basavanahalli Jagadeesh and Kumar (2019), was used to obtain the BD spans. The software was set to commence the task with a series of three digits. A sequence of random digits was presented with an inter-stimulus-interval of 1 second. At the end of the last digit in the sequence, a new window appeared wherein the participant used the number pad of the computer to type-in the sequence in the reverse order. Participants were also instructed to fill in the sequence with the digit 9 in case they forgot a digit in the sequence. With each correct response/sequence, the number of digits in the next sequence (span length) was increased by one, whereas with a wrong response the span length in the following sequence was reduced by one. This adaptive procedure was carried out for a total of six reversals (from correct to wrong and vice-versa). The first two reversals were discarded, and the mean of the last four reversals was considered for the calculation of the BD spans.

As mentioned earlier, the participants were instructed to verbalise their rehearsal. The BD spans were measured under three rehearsal instructions – (i) No instruction regarding the language of rehearsal (NI), (ii) Instructed to rehearse in Kannada (RK), and (iii) Instructed to rehearse in English (RE). The NI condition was always the first condition to be tested for all participants. Here, no instructions were given regarding the language of rehearsal during this condition. However, all participants were explicitly instructed to rehearse overtly. It should be noted, here, that for all the three rehearsal conditions, the stimuli were presented only in the Kannada language. This ensured that the language of stimulus presentation did not act as an additional variable and the only difference between the three conditions was the language of rehearsal.

It was observed that, in the NI condition, a significant proportion of the participants (16 out of 24) rehearsed in Kannada – the language in which the stimuli were presented. For the RK and RE conditions, specific instructions were given to rehearse in Kannada and

English, respectively. The order of testing the second and third conditions was randomised to avoid any bias or order effects.

Results

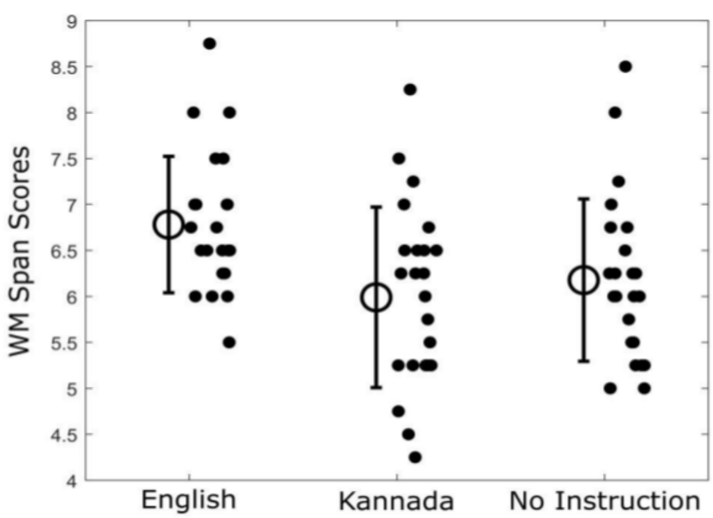
We used the JASP (Version 0.8.6) software package to perform all statistical analyses (JASP Team, 2018). The results of both the LEAP-Q and the BD span scores were analysed. We first examined the results from the LEAP-Q. Table 1 shows detailed information about the different relevant sections of the questionnaire. From the table, it can be observed that the mean proficiency scores (mean of speaking, understanding and reading sections) for Kannada ($M = 9.15$, $SD = 0.62$) are higher than English ($M = 8.15$, $SD = 0.61$). A paired t-test confirmed that proficiency in Kannada was significantly higher than English [$t=5.39$, $p<0.001$, $d=1.1$]. Further, we performed correlational analyses between some of the parameters obtained from the questionnaire – mean proficiency scores in Kannada and English languages, percentage of English usage while speaking, and the percentage of usage of English or Kannada digits in conversation (rows seven, three and eight respectively in table 1). Analyses revealed no significant correlation between any of the four parameters. This indicates that proficiency in either Kannada or English had no significant bearing on the usage of digits in either language.

Subsequently, we analysed the results of the BD span under the different rehearsal conditions. Figure 1 shows the means and (one) standard deviation of the BD span scores across the three instruction conditions. Figure 1 shows that the mean BD span for the RE condition ($M = 6.78$, $SD = 0.74$) was higher than both the RK ($M = 5.99$, $SD = 0.92$) and NI ($M = 6.17$, $SD = 0.88$) rehearsal conditions. We used a one-way Repeated Measures Analysis of Variance (RM-ANOVA) to explore the statistical significance of these mean differences further. RM-ANOVA revealed a significant main effect of rehearsal condition [F(2, 46)=14.233, $p<0.001$, $\eta_p^2=0.382$]. Post-hoc pairwise comparisons (adjusted for multiple comparisons using Bonferroni's correction) showed that the RE condition resulted in significantly higher BD span scores than both RK [t=-5.56, p<0.001, d=-1.131] and NI [t=-3.52, p=0.005, d=-0.719] conditions. There were no statistically significant differences between the RK and NI conditions [t=1.25, p=0.67, d=-1.25].

It is often suggested that proficiency in a language can be a crucial variable in several linguistic and cognitive tasks, particularly in the Indian context (Rao, 2014; Singh & Mishra, 2013). Therefore, we also performed correlational analyses between the mean proficiency scores for both Kannada as well as English languages and the BD span scores across the three conditions. It was observed that there were no significant correlations between any of the conditions considered. This indicates that the proficiency in Kannada or English language did not influence the performance on BD span scores across any of the rehearsal conditions.

Figure 1.

Means and (One) Standard Deviations of the Backward Digit Span scores across the three Instruction conditions.



NOTE: The filled circles, next to the error bars, indicate the individual data points of the participants.

Discussion

In this study, we studied if rehearsal in a language with shorter digit lengths results in improved BD span scores. We measured BD spans on bilingual participants who were explicitly instructed to rehearse (overtly) in either Kannada (longer digit lengths) or English language (shorter digit lengths). As hypothesised, we observed that rehearsal in English resulted in significantly higher BD spans than rehearsal in Kannada. Furthermore, there was no association between the BD spans and the participants' proficiency in either Kannada or English languages.

Previous studies have shown that languages with shorter word-durations result in greater WM spans (Mattys et al., 2017; Shebani et al., 2005; Stigler et al., 1986; Van De Vijver, 2015). Studies have also shown bilinguals gain an advantage when the stimuli are presented in the language with the shorter word duration (Brown & Hulme, 1995; Cheung & Kemper, 1994; Ellis & Hennelly, 1980; Hoosain, 1979). These studies have shown that in bilingual participants, the language of stimulus presentation influences the WM span. Our study extends these findings and shows that even rehearsal in the language with the shorter word length leads to improvement in the WM scores.

The cognitive processes used in the rehearsal strategies are suggested to influence the WM task performance and result in large individual variations seen in the WM task performance (Baddeley, 2000b; Hilbert, Nakagawa, Puci, Zech, & Buhner, 2015; McNamara & Scott, 2001). The results of our studies provide further evidence that different rehearsal strategies can influence WM task performance. Additionally, we observed that, when no instructions were given regarding the language of rehearsal (NI condition), 16 out of 24 participants rehearsed in Kannada (the language of stimulus presentation). This is in spite of the observation that both Kannada and English digits were used equally in regular communication by the participants (self-rated). They also rated themselves to have at least ‘good’ proficiency in English, on average. However, the statistical analyses showed no correlation between the proficiencies in the two languages and BD span scores in any of the three rehearsal conditions. This indicates that it is the rehearsal strategy, and by extension, the word-length effect, that drives the result and not the proficiency and/or frequency of usage of a particular language.

In previously reported studies, typically, word-length effect reflects the effect of stimulus duration (both in terms of the number of syllables and time) on WM performance (Neath & Nairne, 1995). That is, word-length effects are driven by stimulus-related properties (Ellis & Hennelly, 1980). However, we hypothesised that word-length effects could also be related to internal cognitive strategies adopted by the participants. Our finding that rehearsal in English results in significantly better BD spans score, as compared with Kannada, demonstrates that the word-length effect is observed even in the selection of the most appropriate rehearsal strategy.

Furthermore, it has been suggested that, in bilinguals, irrespective of the language of stimulus presentation, the lexical representations in both languages are automatically activated (Dijkstra & van Heuven, 2002). Since it is not possible to produce the sounds in both languages, the speaker selects the most appropriate language (Ratiu & Azuma, 2015). This selection involves an adaptive selection of task-relevant language for processing and further comprehension, along with the inhibition of the task-irrelevant language (Green & Abutalebi, 2013). We presume it is during this selection and inhibition of the two languages that the role of strategy comes in. We believe that, over the duration of the task, a listener fine-tunes and updates his strategy to what suits best to that context. As mentioned earlier, these strategies could include grouping/chunking, verbalisation, or even internal visualisation. Individuals who use the most efficient strategies for the context can often recall more items than those who cannot (Turley-Ames & Whitfield, 2003). Additionally, cross-modal rehearsal strategies have also been reported (Rayner & Riding, 1997). Therefore, it is possible that some of the participants can use an across-language rehearsal strategy when the situation is appropriate. Although it has been suggested that language-switching comes at a cost (Olson, 2017), the results of our experiment provide evidence that language-switching can be beneficial when used as a rehearsal strategy due to the word length effects.

The utilisation of such across-language rehearsal strategies could also partially explain the bilingual benefits in working memory. Inhibitory actions and working memory spans are often better in bilingual individuals compared with monolinguals (Blom et al., 2014; Morrison, Kamal, & Taler, 2018). This is because bilinguals can consistently ignore the task-irrelevant lexical information better than monolinguals (Adesope, Lavin, Thompson, & Ungerleider, 2010; Hilchey & Klein, 2011; Jared & Kroll, 2001; Poarch & van Hell, 2012). This is analogous to constantly and permanently training the executive control mechanisms of the two language systems. Working memory performances depend on the total amount of available mental resources (Just & Carpenter, 1992). The bilinguals, compared to monolinguals, have an additional resource (the ability to process information in a different language) which could help them in identifying a useful strategy faster and more efficiently than monolinguals. Indeed, Bialystok (2017) as well as Yoshida (2008), do hypothesise that long-term bilinguals are better adapted to the demands of a bilingual scenario, in that, the processes associated with executive attention is uniquely trained to find the best strategy for language comprehension. An extension of this premise can also be applied to our results. Because the bilinguals continuously train themselves to choose the best context-relevant-language, they may perform better in English rehearsal than Kannada. However, on what basis the participants make this judgment needs to be explored further in future.

We do note, however, that recent studies have shown that bilinguals do not always have the advantage in working memory task performances (Calvo, Ibáñez, & García, 2016; Lukasik et al., 2018; Yang, 2017). Because bilinguals have to contend with greater lexical competition (Alsaigh & Kennison, 2017; Boukadi, Davies, & Wilson, 2015) between their two languages, there will be conditions where being a bilingual is not necessarily an advantage. Additionally, in the current study, we have measured a very linguistically simple task – the backward digit span. Because of their simplistic nature, BD spans are likely to underestimate the linguistic component of working memory. The main focus of this paper was to highlight the possibility of an across-language rehearsal strategy and not directly to claim the 'bilingual advantage' in working memory tasks. It is, however, also a fact that such across-language rehearsal strategy is unique to bilinguals and multilinguals.

Conclusions

In this study, we provide evidence that the word length effects can also be observed during the choice of rehearsal strategy. Rehearsal in a language with shorter word lengths leads to better WM scores, as measured on a BD span task. The higher WM performance could also be associated with the enhanced inhibitory and executive mechanisms in bilinguals, which could be a result of years of experience in choosing the most context-appropriate language. It is, therefore, essential to consider the bilingual effects on WM while using backward span tasks in the bilingual research. It is recommended, consequently, to have different normative values for bilingual/multilingual populations (like India). It is also recommended to use clear instructions regarding the language of rehearsal while measuring BD spans on bilingual participants. This will likely ensure homogeneity of data in such populations. Also, further studies are warranted to understand the use of such across-language rehearsal strategies while using other, more complex, tests of working memory such as listening span, operation span, etc. Understanding such strategies in more difficult-to-listen scenarios is also warranted. This would help generalise the across-language rehearsal strategies to a more ecological and realistic scenario than the simple backward span task.

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