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Individual Differences in Working Memory Capacity and Task Switching Performance

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The present study was designed to examine individual differences in working memory capacity on task switching ability. Eighty-six students whose age ranged from 18 to 30 years voluntarily participated in this study. A 2 (Working memory span group: high vs. low) x 3 (Preparation Time: 200 ms, 600 ms and 1000 ms) x 2 (Trial type: repeat and switch) mixed factorial design was employed. Participants who scored in the upper and lower quartiles on the Operation span working memory task were designated to high and low-working memory span groups respectively. Both groups performed a digit and letter classification task in alternating-runs paradigm of task switching. In this task, participant switched back and forth between digit and letter tasks in which they were required to classify either digits as odd/even or letter as vowel/consonant. Three preparation intervals were also provided between trials to prepare for forthcoming task. Results revealed that high-working memory participants were faster and more accurate in classification of digits and letters on both switch and repeat trials. High-working memory span participants endowed smaller switch cost though they showed lesser improvement with increase in preparation time. Findings of the study provide evidences for executive attention view of working memory capacity.

Keywords: Working memory, Executive attention, Task switching, Preparation

Working memory (WM) is considered as a broader system comprised of storage and processing components. Researchers have differentiated between working memory and working memory capacity (WMC). The concept of WM was established with the multi-component model of Baddeley and Hitch (1974), which argued that WM is a flexible and limited-resource system with storage (phonological loop and visuospatial sketchpad), and processing capabilities (central executive) that are traded off as needed. Phonological loop and visuospatial sketchpad are closer to the traditional concept of short-term memory.

Baddeley and Hitch (1974) considered WM as a replacement of the short-term memory while, other researchers (Cowan, 1999; Engle, 2002) viewed working memory as consisting of memory units (of long-term memory) active above threshold, which can be represented via a variety of different codes (phonological, visuospatial, semantic etc.), and as an executive attention component.

Central executive is the component which differentiates conventional short-term memory with contemporary working memory. The executive attention component primarily deals with maintaining or suppressing activation of long-term memory traces and task goals, conflict monitoring and resolution, and the flexible allocation of attentional resources (Unsworth, Heitz & Engle, 2005). The working memory capacity is different from working memory and reflects primarily the executive attentional component of a broader working memory system (Engle, Kane & Tuholski, 1999).

Most of the initial work of Baddeley and other researchers were concentrated on the two storage systems and attentional component of WM model was ignored. Lately, researchers started to explore the central executive component of WM, which resulted in emergence of two distinct approaches; one approach attempts to understand the breakdown of executive processes following brain damage in the frontal lobe patients or in patients suffering from Alzheimer's disease (Baddeley, 1996). The second approach was influenced by the psychometric tradition with its primary concern for individual differences within the normal adult population (Daneman & Carpenter, 1980; Engle, Tuholski, Laughlin & Conway, 1999; Turner & Engle, 1989). This approach shaped the Executive attention theory of working memory capacity in which performance on different complex span tasks was attempted to relate with higher order cognitive tasks and attentional tasks.

The executive attention view suggests that individuals high in working memory capacity are better at controlling aspects of their attention to actively maintain goal-relevant information to successfully perform a task than individuals low in working memory capacity in the presence of interference and distraction (Engle, 2002). Evidence for executive attention view of working memory capacity comes from many studies termed as macro-analytic and micro-analytic.

Macro-analytic studies proposed relationship between working memory capacity and other hypothetical constructs, such as general fluid intelligence (Gf), using multiple WM span tasks (Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Engle et al. 1999; Redick, Unsworth, Kelly & Engle, 2012) and credited executive attention (tapped by WM span tasks) to be responsible for working memory and Gf relationship.

Micro-analytic studies take a more focused approach in analyzing working memory span-executive attention relations. Micro-analytic studies examined working memory span-related differences by comparing individuals with high working memory span scores to those with low scores in the performance of elementary cognitive tasks such as memory and attention tasks (Kane, Conway, Hambrick & Engle, 2007) by using quasi-experimental designs. The present study tends to focus on micro-analytic studies because they provide close and specific explanations about executive attention view of working memory capacity.

Initial studies on working memory capacity shows that executive attention relations started with anti-saccade task paradigm, dichotic listening task and Stroop task (Colflesh & Conway, 2007; Conway, Cowan, & Bunting, 2001; Kane, Bleckley, Conway, & Engle, 2001; Kane & Engle, 2003; Unsworth, Schrock & Engle, 2004). Despite surface differences among these three attention-control tasks, they equally emphasized on active maintenance of goal related information, ignorance of powerful stimuli for goal-appropriate responding and inhibition of prepotent responses. In these tasks, low spans performed significantly worse than high spans, and low spans were deficient in their ability to prevent attentional distraction and respond in a goal-directed manner.

Later, researches with other attentional tasks such as attention network test (ANT), Egly and Homa's visual selective attention task, Eriksen flanker paradigm (Bleckley, Durso, Crutchfield, Engle & Khanna, 2003; Heitz & Engle, 2007; Redick & Engle, 2006) also validated the enormous attentional capability of high-WM span participants as compared to low-WM span individuals. Thus, findings suggest that individual differences in WMC reflect the ability to keep goal related information active in immediate memory to guide current behavior and this ability is especially important in interference and distraction-rich situations or during concurrent processing (Redick, Calvo, Gay & Engle, 2011).

Working Memory and Task Switching

The ability to switch flexibly between tasks not just allows us to adapt to changing demands in the environment but, it also allows approaching the same situation from different perspectives. Nevertheless, our daily life often requires performing multiple tasks either simultaneously or in rapid alternation, as when a mother prepares a meal while tending her children or when you drive a car while talking on the mobile phone (Rubinstein, Meyer & Evans, 2001). In task switching studies, participants have to perform two or more simple tasks presented by a set of stimuli; each task requires attention to, and classification of, a different element or attribute of the stimulus, or retrieval from memory or computation of a different property of the stimulus (Monsell, 2003). Task switching takes time and produces interference, as is evident in a variety of procedures that compares performance when tasks change with performance when tasks are repeated.

Task switching has recently become a popular paradigm in the study of executive attention. Switching from one task to another requires executive attention and this executive attention is considered as major component of working memory, thus, it can be assumed that working memory may predict switch costs in task switching paradigm. There are many studies which showed association of executive attention with working memory capacity. Such as Lehto (1996) used Wisconsin card sorting sets as a measure of task switching and reported high correlations with performance on complex span tasks such as the reading span task and the operation span task. Brand (2007) examined relationship between operation span performance and task switching while task switching was manipulated in two different tasks, visual search task and flanker task. In her study, span differences on switch cost was apparent only in flanker task, though high operation span group performed better on all performance measures than low span group. She concluded that individuals who had high executive capacity could use their extra capacity to protect them to some extent from the cost of switching tasks. Few studies have found little or bleak relationship between working memory capacity and task switching performance (Kane & Engle, 2000; Miyake et al., 2000; Oberauer, Süß, Schulze, Wilhelm, & Wittmann, 2000; Oberauer, Süß, Wilhelm, & Wittmann, 2003; Unsworth et al., 2004). Kane, Poole, Tuholski and Engle in 2003 (as cited in Kane et al., 2007) with numerical Stroop task and alternating-runs paradigm of task switching found that high- and low- span participants showed almost equivalent performance.

The contradictory findings and growing concern about the role of working memory in task switching provided the concept for this study, which aimed to explore the effect of working memory capacity on task switching performance with extensive focus to individual differences approach.

Present Study

The aim of the present study was to examine the effect of working memory capacity and preparation on task switching performance. Firstly, it was hypothesized that high-WM span individuals would perform better than low-WM span individuals and second hypotheses stated that two groups of working memory would show different trends of preparation effect.

Method

Experimental Design

A 2 (Working memory span group: high vs. low) x 3 (Preparation Time: 200 ms, 600 ms and 1000 ms) x 2 (Trial type: repeat and switch) mixed factorial design was used with repeated measure on the last two factors. Working memory span group was the only between-subjects factor, while preparation time was manipulated between block and trial type was manipulated on trial-by-trial basis within a block.

Participants

Eighty-six students of the Banaras Hindu University whose age ranged from 18 to 30 years with mean age of 22.46 years (SD = ± 2.89) participated in this study. All participants had either normal or corrected to normal (20/20) visual acuity at Snellen chart test.

Experimental Tasks

Operation Span Task for Working Memory

Automated operation span task (OSpan; Unsworth, Heitz, Schrock, & Engle, 2005) was used to measure working memory capacity in which participants performed a memory task simultaneously verifying simple mathematical equations. This automated operation span task was used in slightly modified way and the automated part of the task was performed manually. In this task, participants were required to attend one operation (equation) at a time, appearing in the centre of computer monitor, and they had to respond whether the math equation was correct or incorrect by pressing an appropriate designated key. Immediately after the response, a letter appeared in the centre of computer screen to be memorized. This sequence continued until three question marks (???) appeared on the monitor screen as cue to recall all the letters in order of their presentation in that set on an answer sheet provided to them. The trials consisted of 3 sets of each set size, which ranged from 2-7 thus, making a total of

81 letters and 81 math equations. Letters were sampled from the set of F, H, J, K, L, N, P, Q, R, S, T, and Y. Eighty percent accuracy was required for mathematical portion of the task, for each participant to be included in the task switching session.

Task Switching Paradigms

Alternating-runs paradigm was used for task switching in which participants were required to classify either digit as odd/even or letter as vowel/consonant. An 8-cm square divided into four quadrants was displayed on the computer screen. In each trial, a character pair (e. g. 3M) was displayed in one of the quadrants. On successive trials, the position moved to the next square in clockwise manner. Target stimuli were a character pair (bivalent stimuli) consisting of both a letter and a digit. The relevant character (target stimuli) was either a letter or a digit depending on the task. The letters for vowel/consonant task were chosen from a set A, E, G, M, R, and U. The digits for odd/even task were selected from a set 3, 4, 5, 6, 8 and 9. The orders of stimuli were randomly displayed in such a way that the same character could not appear on two successive trials. Half of the participants were assigned left key to indicate "odd" or "vowel" and remaining half participants received left key to indicate "even' or "consonant" and vice-versa to counterbalance the spatial error, if any.

Procedure

Before starting the experiment, written consent and biographical information were taken from the participants then they were tested on Snellen test for their visual acuity. At first, the participants performed operation span task (Ospan), which was divided in two sections: practice session and experimental session. Participants solved 15 equations in practice session. There was no time limit for solving math operation in practice session. However, math operations were presented for a limited period of time in the main session and this time limit was calculated for each participant depending on their performance in practice session, accounting for individual differences.

After completing practice session, participants performed main experimental session, which consisted of performing three sets of each set size, which ranged from 2-7 thus, making a total of 81 letters and 81 math equations. After completion of operation span task participants were rested for 10 minutes before giving task switching session. In task switching, participants were given practice task comprising of four blocks. First two practice blocks were pure blocks having 32 trials for each task (letter and digit task respectively) and last two blocks were mixed-trial blocks consisting of 72 trials in which participants performed both tasks alternately. Participants who secured at least 75% accuracy in practice session were selected to participate in the final session. In each block, a trial started with fixation (+) at the centre of the screen followed by a target i.e. a character pair appearing in the rightmost quadrant of the square and the target remained on screen until the participant responded or 2,500 ms, whichever was earlier.

After variable response stimulus interval (RSI; 200, 600 or 1000 ms) the next target appeared in the adjoining quadrant in a clockwise pattern. Sequence of task was predictable i.e. AABB, therefore position of trials in run and spatial location of target served as a cue for an impending task. In each block, half of trials were repeat trials, in which next task is like the previous one and half were switch trials in which the task changed from the previous trial. Three RSIs were kept constant within a block. Participants were instructed to use available time (RSI) to prepare for the next stimulus.

Results

Working Memory Pre-screening

Partial storage score method was used to calculate working memory span scores and to screen participants as high-and low-WM span groups. Partial storage score is a sum of items recalled at a correct position in each set size. High-WM span group was defined as a membership in the top quartile of all the participants, while low-WM span group was defined as a membership in the bottom quartile. Average score of high-WM span group (n = 21) and Low-WM span group (n =22) were 67.10 (ranging from 59-74) and 17.14 (ranging from 11-21) respectively.

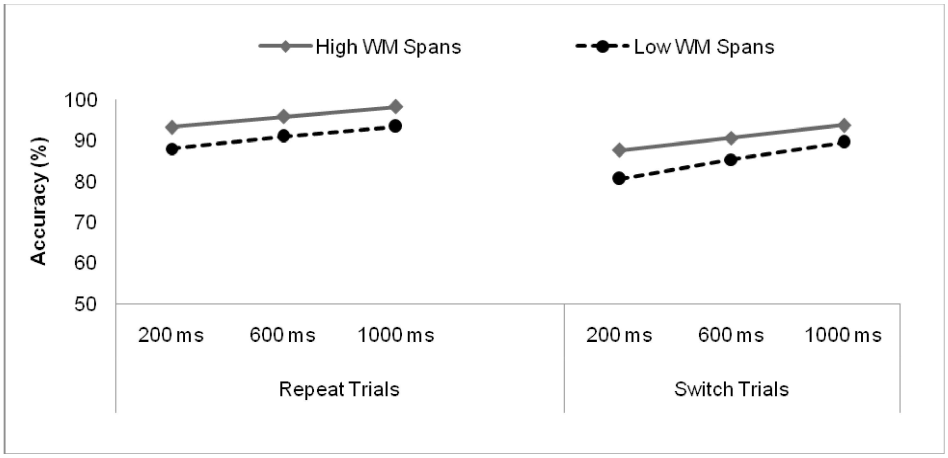

Fig. 1. Accuracy as a function of WM span group, prepartion time and trial type

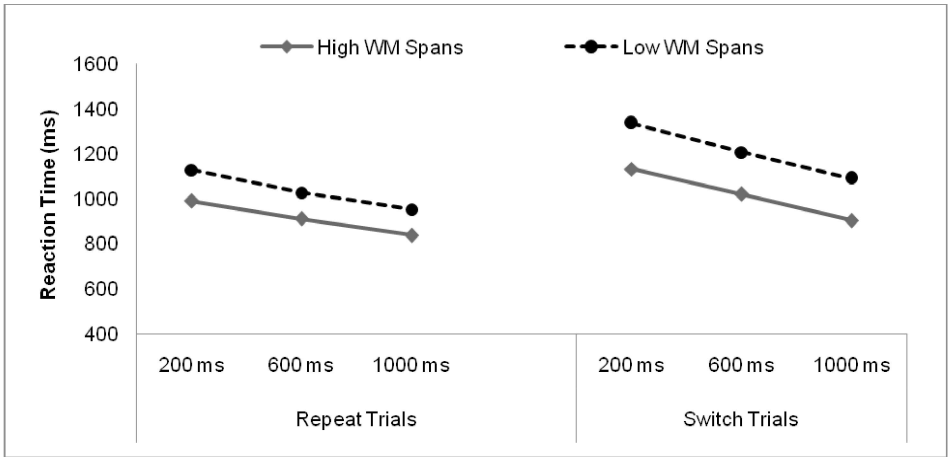

Fig. 2. Reaction time as a function of WM span group, prepartion time and trial type

Task-Switching Performance Measures

Reaction time and accuracy were taken as performance measures. Time switch cost was computed by subtracting the mean RT on repeat trials from corresponding values on switch trials (Switch trials RT – Repeat trials RT). Accuracy switch cost was calculated by subtracting the mean accuracy on switch trials from corresponding repeat trials (Repeat trials – Switch trials).

Accuracy Performance

The obtained mean data are plotted in Figure 1, which depicts that high-WM span group (93.21 %) were significantly (F (1, 41) = 6.539, p = .014, ηp2 = .138) more accurate in classifying digit and letter as compared to low-WM span group (87.67 %). Accuracy was larger under 1000 ms RSI (93.74%) as compared to 600 ms (90.67%) and 200 ms RSIs (87.37%) and performance in repeat trials (93.27%) was more accurate than switch trials (87.89%). These findings are supported by significant main effects of preparation time, F (2, 82) = 223.938, p < .001, ηp2 = .845, and trial type, F (1, 41) = 134.37, p < .001, ηp2 = .766.

A two-way interaction of WM span group and preparation time, F (2, 82) = 3.457, p = .036,

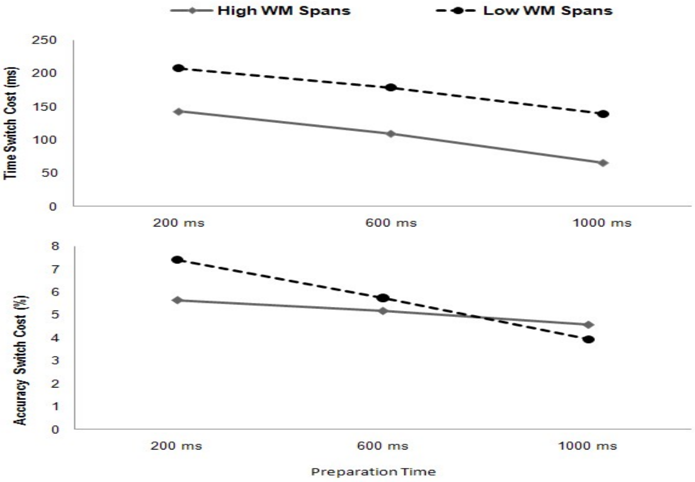

Fig. 3. Time switch cost and Accuracy switch cost as a function of WM span group and prepartion time

ηp2 = .078 was found significant suggesting that low-WM span group (8.48%) showed larger improvement as a function of increasing RSIs as compared to high-WM span group (6.19%). The interaction of preparation time and trial type F (2, 82) = 42.617, p < .001, ηp2 = .510 was also significant indicating that switch trials (8.92%) showed larger improvement in performance as RSI increased than repeat trials (5.79%). Both the groups showed different pattern of improvement in accuracy on repeat and switch trials across RSIs resulting in a significant three-way interaction of WM span group, preparation time and trial type, F (2, 82) = 11.851, p < .001, ηp2 = .224.

Reaction Time (ms) Performance

Figure 2 indicates that high-WM span individuals were fast responders (965.58 ms) than low-WM span individuals (1123.68 ms) with overall better performance on repeat trials (974.37 ms) as compared to switch trials (1146.28 ms). Preparation time also affected RT performance with faster responses under 1000 ms RSI (946.20) than 600 ms (1041.42 ms) and 200 ms (1146.28 ms) RSIs.

These observations were supported by the significant main effects of WM span group, F (1, 41) = 40.407, p < .01, ηp2 = .496, preparation time, F (2, 82) = 533.376, p < .01, ηp2 = .929, and trial type, F (1, 41) = 304.168, p < .01, ηp2 = .881. Switch trials showed larger improvement in RT across RSIs (19.24 %) as compared to repeat trials (15.46%). These findings resulted in a significant two-way interaction of WM span group and trial type, F (1, 41) = 14.820, p < .001, ηp2 = .265, and preparation time and trial type F (2, 82) = 100.022, p < .01, ηp2 = .709. None of the other interaction was found to be significant.

Further, a separate 2 (WM span group) x 3 (Preparation time) mixed factorial analysis of variance (ANOVA) was calculated for both repeat and switch trials. WM span differences on repeat trial was only marginally significant, F (1, 41) = 3.77, p < .06, ηp2 = .084, though it was highly significant for switch trials, (p = .008). The interaction of WM span group and preparation time, F (2, 82) = 3.27, p = .043, ηp2 = .074 was found to be significant only for repeat trials.

Switch Costs

Time and accuracy switch costs were computed from reaction time and accuracy data. Further, these data were submitted to a 2 (Working memory span group: high vs. low) x 3 (Preparation Time: 200 ms, 600 ms and 1000 ms) mixed factorial ANOVA. Figure 3 shows that low-WM span group (175.12 ms) showed a larger time switch cost as compared to high-WM spans (105.93 ms) with overall smaller time switch cost in 1000 ms RSI (102.45 ms) than 600 ms (143.99 ms) and 200 ms (175.14 ms) RSIs. These findings revealed significant main effects of WM span group, F (1, 41) = 14.82, p < .001, ηp2 = .265, and preparation time, F (2, 82) = 100.023, p < .001, ηp2 = .709.

Accuracy switch cost was found to be larger in 200 ms RSI (6.51%) followed by 600 ms (5.45%) and 1000 ms (4.26%) RSIs (Figure 3). The main effect of preparation time was significant, F (2, 82) = 42.582, p < .001, ηp2 = .509. The interaction of WM span group and preparation time was also significant, F (2, 82) = 11. 842, p < .001, ηp2 = .224, indicating that low-WM spans (46.85%) showed larger improvement than high-WM spans (18.85%) with increase in preparation times.

Discussion

The present study examined working memory span differences on analogue of task switching. In this study, task switching was used as a measure of executive attention and implemented in the form of predictable switching, in which participants switch back and forth between digit tasks and letter tasks. Executive attention was assumed to be involved in coordinating switching between these two tasks, including the manipulation and maintenance of task-sets (Rogers & Monsell, 1995; Rubinstein et al., 2001).

Studies suggest that, working memory capacity tasks rely on executive control (e.g. Conway et al., 2001; Kane et al., 2001; Kane et. al, 2007). In the present study, participants with high- and low- WM span differed in both attention demanding switch trials and relatively automatic repeat trials of task switching. High-WM spans could classify targets more quickly and accurately than low-WM span participants. High-WM span group also showed lesser time switch cost as compared to low-WM span group. This finding supports previous studies (Brand, 2007; Lehto, 1996) in which working memory and task switching performance were directly examined and the first hypothesis of this study that high-WM span individuals would perform better than low-WM span individuals. However, on accuracy switch cost the difference between high- and low- WM span groups were not significant.

Furthermore, findings suggested that performance were faster and more accurate in larger preparation time i.e. 1000 ms RSI, followed by 600 ms RSI and 200 ms RSI conditions, replicating several previous findings (Monsell, Sumner, & Waters, 2003; Nieuwenhuis & Monsell, 2002; Rogers & Monsell, 1995). Accuracy switch cost and time switch cost also decreased providing evidence for benefit of preparation time. Researches (Altmann, 2004; Altmann, 2007; Koch, 2001) distinguished preparation benefit on switch trials (switch specific preparation) and preparation benefit that accrue on both switch and repeat trials (generic preparation).

In present study preparation effect was evident in both repeat and switch trials (Altmann, 2004; Koch, 2001) however, switch trials showed maximum benefit as compared to repeat trials. Thus, the present study shows generic preparation on reaction time and accuracy performances, which is a bit specific to switch trials, which is why preparation times reduced time and accuracy switch costs but, could not succeed to remove them completely, and residual switch costs remained (e.g. Meiran, 2000; Rogers & Monsell, 1995). Further, high and low-WM span participants differed in use of preparation intervals to improve performance. Low-WM span participants showed more improvement in accuracy and more decrement in accuracy switch cost performance measures. Low WM-span took more advantage of preparation intervals. These findings corroborated with the second hypothesis of the study that two working memory span groups would show different trends of preparation effect.

Implication of Executive Attention Theory of Working Memory Capacity

The results of the current study suggested that high- and low- working memory span participants probably differ in task switching abilities whereby low WM span individuals have difficulty in adopting a new task set and inhibiting the previous task set. Findings of the present study were consistent with those researches in which performance of two extreme working memory groups were compared on several attention (anti-saccade task, Stroop task etc.) and cognitive tasks (Bleckley et al. 2003; Colflesh & Conway, 2007; Conway et al., 2001; Kane et al., 2001; Kane & Engle, 2003; Heitz & Engle, 2007; Redick & Engle, 2006; Unsworth et al., 2004). These attentional tasks required maintenance of task goal and controlled response while inhibiting prepotent and automatic reflexes, suppression of distracting information etc. These researches suggested that individuals who were high in working memory capacity are better at controlling aspects of their attention to actively maintaining goal relevant information and to inhibit task irrelevant information in order to successfully perform a task, than individuals who were low in working memory capacity (Engle, 2002; Kane et al., 2007).

In other words, these researches suggest that high working memory span group have better executive attention as compared to low working memory span group, which was also evident in the present study as the high span group showed an overall better performance and lesser time switch cost as compared to the low working memory span groups. However, there are some contradictions to the above findings as Kane et al., in 2003 (as cited in Kane et al., 2007) have reported several studies in which they failed in four successive experiments to find any significant difference in switch costs between high- and low-span participants. Few other studies found no effect of working memory capacity on task switch cost (Kane & Engle, 2000; Miyake et al., 2000; Oberauer et al. 2000; Oberauer et al., 2003).

In the present study, reaction time performance of low working memory span group was worst on repeat trials as well as switch trials. Repeat trials are assumed to be less regulated by executive control, thus performance of low working memory span group should have been analogous to their counterparts, which was not found. Therefore, executive attention aspect of working memory capacity is not the sole explanation of findings of the present study. In addition to the executive attention framework of the working memory capacity, there are other plausible explanations for these findings such as task specific hypothesis, which states that the relation between working memory and other cognitive performances can be found if the processing portion of working memory task requires the same skills (e.g. Daneman & Carpenter, 1980). In the present study, the task required switching from letter task to digit task and vice versa, whereas operation span task required to switch from processing part (solving equation) to storage part (memorizing letters). Both tasks involve performing dual tasks, thus it may be assumed that participants who performed better on one task can also do better on another task. Findings of the present study may be comprehended with processing speed hypothesis. Salthouse, Fristoe, McGuthry & Hambrick (1998) suggested that 35 to 40% task switching ability can be accounted for processing speed and processing speed remains stable within individual across testing occasions and does differ from person to person.

Thus, low working memory capacity individuals may be slower to process all information, and this leads them to get low scores on cognitive task as well as on working memory task (e.g. Heitz & Engle, 2007). Motivation might be an additional factor, which can influence performance as some individuals are simply more motivated than others to do well on all type of tasks including working memory task and tasks of higher-order cognitive ability.

Conclusion

In the present study, variation in working memory capacity was examined with task switching. Findings of this study revealed that individuals with high working memory capacity were faster and accurate on task switching performance measures than individuals with low working memory capacity. Though, low working memory span group showed more benefit of preparation time as compared to high working memory span group on accuracy performance measures. Thus, findings of the present study offered evidence for executive attention view of working memory capacity as high WM span group screened by operation span task outperformed low WM span group.

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