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PREDICTING COGNITIVE STATUS OF OLDER ADULTS BY USING DIRECTIONAL ACCURACY IN EXPLICIT TIMING TASKS

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INTRODUCTION

The early effects of age-related cognitive decline on explicit timing have been widely reported in literature [1,2]. However, it is not clear to what extent the reported decline in older adults' timing ability is caused by its underlying cognitive components such as internal pacemaker (i.e. clock) and working memory [3,4]. Furthermore, the duration of the investigated intervals in timing tasks was shown to be a critical factor due to recruitment of different brain regions in judgments of shorter and longer intervals [5].

In the previous research of our team [6], we used a retrospective verbal estimation task to assess the explicit timing ability for a duration beyond the size of working memory (i.e. 40 seconds). Our findings showed significant effect of aging and cognitive status on timing ability as well as a significant correlation between the signed error of estimations and cognitive scores of the participants. The cognitive score of participants was assessed by the Montreal Cognitive Assessment (MoCA) [7], which is a brief measure of global cognitive function originally developed to detect Mild Cognitive Impairment (MCI). It includes a number of subtests for examining cognitive components such as visuospatial ability, executive function, attention, language, abstraction, short-term memory and awareness of present time and location. This test has also been found to have higher classification accuracy for the detection of cognitive decline compared to the Mini-Mental State Examination (MMSE) test [8] another commonly used test to measure cognitive impairment.

Despite of finding the significant correlation, only less than %10 of the MoCA score variation could be explained by the variation of the signed error in the verbal estimation task. Moreover, the verbal estimation method is known to be affected by "quantization problem" due to participants' tendency to use round numbers in their responses [9]. Consistent with the reported susceptibility of measures of variability to the quantization problem, we found coefficient of variation of timing estimations to be the least sensitive measure to both aging and cognitive decline [6]. More importantly, the cognitive processes involved in our task could be related to both the speed of the internal clock and the performance of working memory, while the contributions of these components to the observed decline were not further clarified.

To address the above short comings, in the current study we used two non-verbal paradigms for assessing the underlying cognitive components in explicit timing of older adults: Interval Production for assessing the speed of internal clock and Interval Re-production for assessing the performance of working memory [10]. We examined three target intervals inside the size of working memory (i.e., 2, 6, 10 s) for each of the above-mentioned paradigms and investigated how well the measures of internal clock and working memory are predictive of cognitive function in older adults. We hypothesized that using a more detailed paradigm and a wider range of target intervals would lead to more predictability of variations in cognitive scores.

METHOD

Participants

Thirty six older adults (19 females) with an age range of 61 to 87 years (68.4 ± 5.1 yr) and MoCA range of 23 to 30 (27.9 ± 2.0) were recruited for this study. There were no significant differences in terms of the participants' ages and MoCA scores between males and females. All participants signed an informed consent approved by the Biomedical Research Ethics Board of the University of Mantioba.

Experiments

To assess the cognitive processes involved in explicit timing, two virtual reality (VR) based version of Interval Production and Interval Reproduction tasks were designed using C++.NET (Microsoft Visual Studio 2010) and OpenGL environments. The program consists of a user-interface, a keyboard-handler control system and an output module which records participants performance in an excel file. For handling the graphic components of the program OpenGL, Glut (OpenGL Utility Toolkit) and GLUI (GLUT-based User Interface) were used.

In the Reproduction task, the participants witness a VR room. By pressing the Enter key on the keyboard, a random object appears at the center of the room (Fig. 1). The object stays in the room for an interval of time (e.g. 2, 6 or 10 sec) and then disappears. After disappearance of the object, the participants are expected to give their non-verbal estimation of the object's duration, without counting the interval, by using the following method: pressing the Space button for initiating the interval, waiting equal to the time that the object had been appearing in the room and then pressing Space button again for ending the interval. The color and shape of the objects are selected randomly by the program but the appearance interval would be selected by a pseudo-random sequence.

At the start of the experiment, in addition to asking participants not to count for interval estimation they were instructed to announce the color and shape of the appeared object loudly as soon as possible (i.e. distraction task) for interfering with the probable initiation of counting process. This distraction task was selected as a simplified version of verbal repetition of random digits [11]. The random digit repetition has been shown to cause lower accuracy and higher variability [10] and was not found superior to articulatory suppression and not-to-count instruction [12].

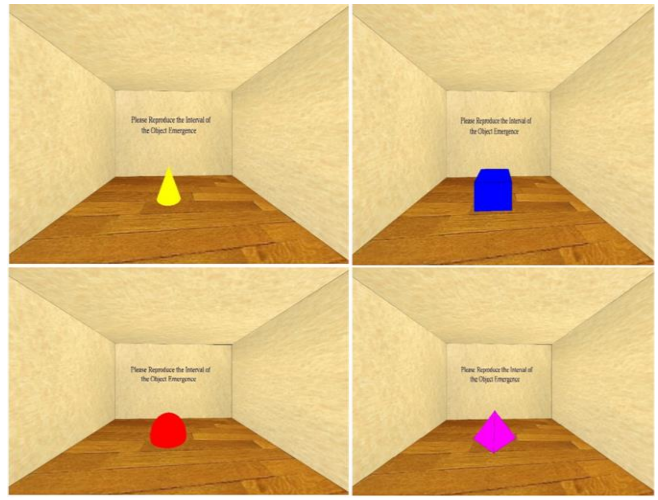

Figure 1: View of the Interval Reproduction task

In the Production task, an instruction on the wall asked participants to generate an interval of 2, 6, or 10 seconds by pressing the Space button, waiting for the requested time (without counting) and pressing the Space button again. The participants were instructed to press the button for the second time as soon as they felt the requested time interval "was finished".

Each task consisted of 9 trials with 3 repetitions of each target interval in a pseudo-random sequence such that two identical intervals were not consecutive and no apparent ascending/descending trend was presented in trial sequences (e.g. 2-6-10 or 10-6-2). At the beginning of each experimental session, every participant was given two practice trials for each paradigm. No feedback was given to the participants during the experiment.

Data Analysis

For both tasks, the difference in time between two button strikes were recorded by the program as the participants' estimation of the observed or requested interval. Following our previous study that showed the superiority of the signed error over absolute error and coefficient of variations, we used the signed error as our main measurement. Thus, the performance of the participants were averaged for each target interval and the Relative Signed Error(RSE) was calculated as follows:

$$RSE_t^p = \frac{\left(Ave.\left(Est_t^p\right) - t\right)}{t} \quad (1)$$

where p indicates the paradigm of the test (i.e. Production, Reproduction) and t indicates the target interval (i.e. 2, 6 and 10 s). The six calculated signed errors (3 for Production and 3 for Re-production task), as well as the participant's age and gender were given as predictors for a linear regression model to determine the best predictors for the participants' MoCA scores using backward method (probability of F-to-remove >= 0.1). Before applying the final regression model, the required assumptions for multiple regression were checked including lack of outliers, lack of collinearity of data, independence of errors, normal distribution of errors and homogeneity of variance of data.

RESULTS

Descriptive statistics for the participants' performance are summarized in Table 1. An analysis of the standard residuals was carried out, which showed that the data contained no outliers (std. residual min = -2.31, std. residual max = 1.45). The histogram of the standardized residuals indicated that the data contained approximately normally distributed errors, as did the normal P-P plot of standardized residuals, which showed the data points closely lied on the diagonal line.

Testing the assumption of collinearity indicated that none of the predictors held a Variance Inflammation Factor (VIF) greater than 10 or a Tolerance factor less than 0.1 except for Production-6s-Error and Production-10s-Error due to having a high Correlation Coefficient (CC) among them (CC = 0.95, p < 0.00). Since Production-6s-Error showed an additionally high correlation with Production-2s-Error (CC = 0.75, p < 0.00), this predictor was excluded from further analysis. After removing the Production-6s-Error all of the predictors held acceptable VIF and Tolerance values. Multicollinearity was not a concern anymore. The scatterplot of the standardized residuals showed that the data met the assumptions of homogeneity & linearity of variance.

Table 1: Descriptive statistics for the participants' performance. RSE stands for Relative Signed Error

Predictor	***Mean ± Std.***	***[Min., Max.]***
$RSE_{2\,sec}^{Pro.}$	0.02 ± 0.30	[-0.68 ,0.72]
$RSE_{6\,sec}^{Pro.}$	-0.04 ± 0.24	[-0.60 , 0.57]
$RSE_{10\,sec}^{Pro.}$	-0.06 ± 0.26	[-0.64 , 0.56]
$RSE_{2\,sec}^{RePro.}$	0.02 ± 0.39	[-0.73 , 1.08]
$RSE_{6\,sec}^{RePro.}$	-0.23 ± 0.23	[-0.63 ,0.46]
$RSE_{10\,sec}^{RePro.}$	-0.23 ± 0.15	[-0.62, 0.16]

The final regression model was found to be significant ($F(2, 33) = 5.06$, $p < .01$, $R^2 = 0.24$) using only two predictors of 6- and 10-second reproduction errors. The age factor was excluded in a pre-final step of the model selection. The analysis showed that the 6s-Reproduction-Error did not significantly, but marginally, predict the value of the MoCA score (Beta = -0.34, $t(33) = -1.82$, $p < .08$)~~,~~. H~~h~~owever, the 10s-Reproduction-Error significantly predicted the value of the MoCA score (Beta = 0.60, $t(33) = 3.18$, $p < .003$).

CONCLUSION

Our results show that only the signed errors of 6- and 10-second reproduction errors explain a significant amount of the variance of cognitive scores in older adults. This suggests the measures of working memory are able to provide more reliable associations with the variation of older adults' cognitive scores rather than the measure of internal clock and age. It is known that the proper function of working memory depends on the prefrontal and parietal cortices [13]. Therefore, the found connection between the measures of working memory and the cognitive decline of older adults is consistent with the neurological studies indicating dementia-related atrophies of the prefrontal and parietal cortices [14]. Moreover, the exclusion of 2-second interval in the final model is consistent with the studies suggesting the primary role of the caudate and the putamen, not affected by dementia, in timing intervals below 3 seconds [15]. The next step of our research is to conduct the same set of experiments on younger adults to distill out the effect of normal aging on the investigated cognitive components.

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