Bistable Figure Reversals are Related to Symbol Search Performance: Incremental Validity of Symbol Search as a Measure of Attention and Visual Working Memory

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Abstract

Preliminary fMRI research has suggested that both bistable figure reversal and Symbol Search (a measure of processing speed) utilize the same neural pathways during task execution, namely the dorsolateral prefrontal cortex. The fMRI findings predict a positive relationship between Symbol Search (SS) and bistable figure reversal (BFR). In Study 1, a bistable Necker Cube and the *My Wife/My Mother-in-law* figure were presented on cards, and participants indicated reversals by tapping on a table. The frequency of perceptual reversals was positively correlated with performance on SS (WAIS-III) but not with Picture Completion scores (a measure of visual processing). In Study 2 the Necker Cube was presented on a computer screen, and eye movements were monitored. Participants indicated reversals by pressing a response button. Again, the frequency of perceptual reversals of the Necker Cube was positively correlated with performance on SS (WAIS-IV, this time). No correlation was found with looking strategy, as indexed by eye movement variables. The present study provides incremental validity for interpreting and highlighting SS as a measure of attention and working memory.

Keywords: Symbol Search •Bistable Stimuli •Processing Speed•Attention•Working Memory

"And it's these gaps, these discrepancies, these failures of prediction..., which are the key to how the brain and the mind work" ---Richard Gregory, 1923-2010.

Introduction

The visual system tells us a lot more about an object than is presented in the distal stimulus. At times, the same distal stimulus allows more than one reasonable interpretation (i.e., it facilitates bistable perception), and the bistability can provide a "key to how the brain and the mind work" [1]. For the present work, bistability may also help us better understand the mechanisms underlying tasks associated with processing speed. The processes that control our perceptions of a bistable(ambiguous) figure, such as the Necker Cube, have been a source of considerable debate [2] especially with respect to understanding the phenomenon from a bottom-up vs. top-down perspective [3,4].The task involves seeing a single figure as having more than one possible interpretation and noticing the alterations in interpretation. Attention and processing speed appear related to an individual's rate of mentally manipulating the Necker Cube [5] under instruction [6] illustrated that when participants are instructed to speed up Bistable Figure Reversals (BFRs), they show substantial independent voluntary control over the competing percepts.

Symbol Search(SS) is a core subtest of the [7] processing speed factor. SS involves scanning a target set of two symbols, which have alphanumeric-like features, to determine whether either target appears in a separate group of five symbols. The task requires the match to be exact. Groth-Marnat& Wright [8] indicated that SS measures several different skills, including speed of visual search, speed of processing information, planning, encoding information in preparation for further processing, visual-motor coordination, and learning ability.

Both BFR and SS tasks appear to share some cognitive features, while having different components. Reversing a Necker Cube does not involve visual search, for example, as there is only one figure instead of many. Also, there is minimal visual-motor coordination needed for voluntary reversals of the Necker cube or other bistable figures, at least when compared with SS. Possible associations between mental reversals of bistable figures and a processing speed task, such as SS, are compelling, as the study of BFR is well established in the laboratory under varying conditions. In addition, preliminary fMRI research suggests similar neural pathways are associated with performance on both BFRs and SS. For example, deGraf et al [9] reported a causal role of the dorsolateral prefrontal cortex (DLPFC) in voluntary, but not passive, switching of a bistable figure (i.e. an ambiguous sphere). Sweet et al [10] Showed involvement of the DLPFC on a version of SS modified for presentation during an fMRI experiment. The involvement of DLPFC in SS and BFR reasonably suggests that SS performance may be related to BFR. Specifically, we expected hat voluntary BFR counts would be positively correlated with SS scores (i.e., more stimulus reversals would be associated with higher SS scores). Furthermore, towards a possibility of attributing the hypothesized positive BFR-SS correlation to shared DLPFC processing, BFR counts were also correlated with performance in Picture Completion. Unlike SS, Picture Completion (PC) involves visual processing with limited involvement from working memory [8],and it has not been strongly linked to DLPFC processing. As such, no BFR-PC relationship was expected. Evidence of the predicted relationships among BFR, SS, and PC would contribute incrementally to the validity of SS performance as a measure of attention and visual working memory.

Method

Study 1

Participants

Forty-one participants (N = 33 female; mean age = 23.34 years, SD = 7.69) were tested. All participants had normal or corrected-to-normal visual acuity. The demographic information is more fully presented in Table 1.

Materials

Participants completed two performance measures from the WAIS-III, *SS* and *Picture Completion (PC)*. *SS* requires that participants scan a group of symbols and indicate whether either one of the two target symbols appears a separate group of five symbols on the same line. The reliability coefficient (r_{xx}^{a}) for SS is .77[11].Participants must complete as many items as possible in 120 seconds. *PC* consists of 25 pictures, and each picture has a part missing. The reliability coefficient (r_{xx}^{a}) for PC is 0.84[11]. Participants must identify what part is missing within the time limit set forth for each stimulus. It measures the ability to observe details and attend to features of the environment. In examining the structure and cross-age invariance of the WAIS from within the framework of the Catell-Horn-Carroll (CHC) ability factors, Benson, [12] report that PC is associated with Visual Processing (Gv), while SS is associated with Processing Speed (Gs). Both show very similar loadings on general intelligence: *g* (SS: 0.52 loading on *g*, PC: 0.53 loading on *g*).

Two bistable figures printed on 4" x 6" cards(and presented in Figure 1) were utilized to measure BFR counts. The bistable Necker Cube [13], and the bistable "My Wife and My Mother-in-Law" Figure [14-16] are commonly-utilized figures in psychology. Each bistable figure was presented on a table in front of the participants.

Procedure

First, participants were allowed 15 seconds to practice mental reversals of the Necker Cube. Following this, the instruction was for participants to engage in mental reversals of the Necker Cube (Figure 1a) as many times as possible within a 1-minute period. Participants indicated each reversal by tapping on the table. Next, participants were allowed 15 seconds to practice mental reversals of the "My Wife and My Mother-in-Law" figure (Figure 1b). Following this, the instruction was for participants to engage in mental reversals of the faces as many times as possible within a 1minute period. Again, participants indicated each reversal by tapping on the table.

Results

The average *SS* score was 10.41 (SD = 3.19), indicating that the participants exhibited scores close to average for the test (Scaled Score mean/SDs in WAIS-III manual are 10/3). The average PC score was 8.34(SD = 2.66), somewhat below the mean and SD for the test (10/3). The mean number of Necker Cube reversals was 30.54 (SD = 19.27). The mean number of *My Wife and My Mother-in-Law* reversals was 45.22 (SD = 27.41).

Pearson product-moment correlation analyses were conducted to test the hypotheses presented in the Introduction. As was hypothesized, analyses revealed a positive Pearson product-moment correlation between *SS* and Necker Cube BFR count, *r* (39) = 0.392, p <0.011. As was hypothesized, *SS* was also correlated with *My Wife and My Mother-in-Law* BFR count, r (39) = 0.435, p <0.004. Performance on the control task of *Picture Com*pletion was not correlated with either Necker Cube BFR count, (r (39) = 0.024, *n*s) or *My Wife and My Mother-in-Law* BFR count (r (39) = 0.206, *ns),* as predicted. Finally, while not statistically significant, the correlation between Necker Cube BFR count and *My Wife and My Mother-in-Law* BFR count rended in a positive direction, r (39) = 0.256, p = 0.11.

Discussion

Study 1 found processing speed, as reflected in SS performance, to be directly related to frequency of reversals of two different bistable figures. In addition to processing speed, SS is a measure of attention and working memory for visual information [8,9] reported that they,"...identified a cerebral source of voluntary control over bistable perception, directly revealing top-down modulation mechanism originating in the frontal cortex" (pg. 2329). The DLPFC appears to play a role in resolving or shifting the perception of ambiguous stimuli and in directing attention. This is interesting because the features of the stimuli remain the same, but the interpretation changes. In processing bistable stimuli, attention does not involve searching, as there is nothing to search through. When working on SS, individuals are not attempting to resolve inherently ambiguous stimuli but to search for a possible matching target in a group of symbols. Some of the distracting symbols may have similar features to the targets. However, the match (or non-match) is based strictly on the physical qualities of the targets, not upon their interpretation. Under both tasks in the present study, individuals were asked to work as rapidly as possible. Sweet et al [10] indicate that DLPFC is activated during SS-like tasks as well, suggestive of the network being involved in immediate visual memory, attention, and visual processing speed. These two tasks theoretically share these characteristics, while differing on the demands of visual-motor coordination and visual search.

It is noteworthy that performance on neither of the bistable figures was related to PC, which is associated with visual alertness and visual recognition and identification/long term visual memory [8]. PC is related to individuals' alertness to the environment and ability to notice discrepancies. Although one must notice discrepancies in SS to some extent, PC does not involve immediate memory and thus should be less relevant to abilities needed inreversing a single ambiguous stimulus. Both the Necker Cube and *My Wife and My Mother-in-Law* are physically identical respectively, regardless of the interpretation being rendered at the moment. Holt and Matson [17] postulated Necker Cube reversals to be related to general intelligence. Given that PC and SS are both loaded on g (general intelligence) at almost identical levels, current findings suggest that resolving the ambiguity of a bistable figure is likely less associated with general intelligence *per se* and more related to specific sub-abilities in the factor structure of intelligence.

Study 2

Changes in methods, even seemingly small ones, can affect original findings [18]. Study 2 assessed the replicability of the main finding of Study 1

Table 1. Demographic Statistics.

Gender(n/%)	Race (n/%)	Marital Status(n/%)	Education (n/%)
Male 8 (19.5%)	African American 8 (19.5%)	Single 37 (90%)	High School 4 (9.7%)
Female 33 (80.5%)	Asian 4 (9.7%)	Married 1 (2.4%)	Some College 33 (80.5%)
	Native American 1 (2.4%)	Separated/Divorced 2 (4.9%)	College Graduate 4 (9.7%)
	White 24 (58.5%)	Lives with Partner 1 (2.4%)	
	More than 1 Race 1 (2.4%)		
	Other 3 (7.3%)		

Table 2. Demographic Statistics.

Gender (n/%)	Race(n/%)	Marital Status(n/%)	Education (n/%)
Male 20 (31.7%)	African American 24 (38%)	Single 51 (80.9%)	High School 7 (11.1%)
Female 43 (68.7%)	Native American 1 (1.6%)	Married 7 (11.1%)	Some College 32 (50.7%)
	Asian 11 (17.4%)	Separated Divorced 3 (4.8%)	College Grad 21 (33.3%)
	White 25 (39.7%)	Other/DNR 3 (4.8%)	Postgrad 2 (3.2%)
	Multi/Other 2 (3.2%)		N/R 1 (1.6%)

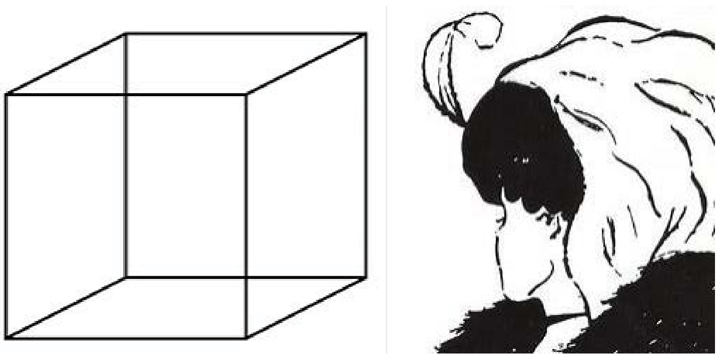

Figure 1. Two bistable figures used in Study 1. (A) Necker cube and (B) My Wife and My Mother-in-Law

when aspects of stimulus presentation were modified. Given the literature that motivated the present work [9,10] and the results of Study 1, it was hypothesized that Necker Cube BFR count would be positively associated with SS scores, notwithstanding the changes in method. Finally, a typically ignored aspect of visual information processing studies is looking behavior. For insight on whether looking strategy was related to Necker Cube BFR count, correlations between eye movement indices on the Necker Cube (i.e., Number of Fixations, Average Fixation Duration, and Average Saccade Amplitude) and Necker Cube BFR count were explored.

Method

Participants

Sixty three participants were tested (N = 43 females; mean age = 26.63, SD = 9.941).All participants had normal or corrected-to-normal visual acuity. Demographic details are presented in Table 2.

Apparatus

In this study, the Necker Cube was presented on a computer monitor. Eye movement indices were recorded using an Eyelink-II eye tracker. This is a head-mounted unit which compensates for head movements during recording. Gaze positions (sampled at 500 Hz) were monitored by corneal reflection and pupil tracking. The gaze positions are accurate within 0.5° - 1.0° of visual angle, after calibration. While Necker Cube viewing was binocular, eye tracking was monocular (i.e., the right eye for each participant). The Eyelink-II software reported moment-to moment duration of fixations, and amplitudes of saccades.

Materials and Procedure

Participants completed self-report inventories and SS from the WAIS-IV. There are some differences between SS for WAIS-III (used in Study 1) and WAIS-IV. On the WAIS-III, an individual is asked to mark either the Yes/No checkbox to indicate their answer, while on the WAIS-IV, the individual is asked to make a slash mark on a matching symbol, or mark the No box if neither target appears in the symbol group. According to the WAIS-IV manual, the reliability coefficient for SS is 0.82 [7] with a high correlation with Coding (r=0.65), the other subtest on the Processing Speed factor.

As was the case in Study 1, following a brief practice period, the instruction was for participants to engage in mental reversals of the Necker Cube (Figure 1A) as many times as possible within a 1-minute period. Participants indicated each reversal by pressing a response button.

Results

The average SS score for participants was 10.64 (SD =2.8). Participants averaged 27.83 (SD = 17.98) Necker Cube reversals. Study 2 similarly, revealed a positive correlation between the BFR count and SS, $r\ (62) = 0.530$, $p < 0.001$. Thus, higher SS scores were associated with greater frequency of reversing the Necker Cube. With respect to looking strategy on the Necker Cube, *SS* and Necker Cube BFR count were not significantly correlated with Number of Fixations, Average Fixation Duration or Average Saccade Amplitude (all r's<0.14).

Discussion

Given the replication crisis in Psychology [19-21] it was important to replicate the findings supporting the predicted direct relationship between SS and BFR Count. In Study 2, Necker Cube reversals were directly related to SS scores. This presents a replication of the main findings in Study 1, despite some differences in method. In Study 1, participants were administered SS from the WAIS-III, while in Study 2, participants received SS from the WAIS-IV. The reliability coefficient for SS from the WAIS-IV is 0.82 [7] for SS from the WAIS-IV is correlated with the WAIS-III version at 0.72 [7].This illustrates that the two versions of *SS* are relatively consistent with each other, as a measure of processing speed.

There are notable differences between Study 1 and Study 2. First, the WAIS-IV stimuli (used in Study 1) are larger than the WAIS-III version (used in Study 2), and the instructions for the task were modified [7]. Second, the Necker Cube was presented differently in the two studies. In Study 1, it was presented on a 4" x 6" card, and the participant viewed the card on a table. In Study 2, the Necker Cube was presented on a computer screen while the participant was wearing a head-mounted eye tracker. Despite the differing conditions, the relationship between SS and Necker reversals remained. The replication of this finding under modifications in procedures suggests a relatively robust relationship exists, and that the two tasks (SS and BFR) clearly share important processing characteristics.

General Discussion and Conclusion

We have all probably experienced how fragile some findings can be in the laboratory. Sometimes, seemingly minor alterations in the method can affect relationships between variables under study, causing some researchers to curse, re-examine their purpose in life, or consider a trip to the pub. The current findings might be useful to note because a similar relationship emerged despite the shifts in method across the different projects. The technical manual for the WAIS-III notes that the inter-correlations between *SS* and *PC* among the various age groupings ranges from 0.4-0.47, suggesting a modest degree of shared variance in Performance IQ, but with differing secondary constructs. The differences between SS and PC appear more relevant for perceptual alterations than their similarities. Together the findings highlight the important role of attention and visual working memory for SS, which might represent the key abilities tapped by SS despite the processes of visual search and visual-motor coordination.

In conclusion, understanding processes involved in bistable perception of unchanging distal stimuli can play a significant role in the quest to determine how perception works. Preliminary fMRI research has suggested that both BFR sand SS utilize the same neural pathways during task execution, namely the DLPFC. By showing a direct relationship between SS and BFRs, the present study provides incremental validity for interpreting and highlighting SS as a measure of attention and working memory abilities.

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