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A male advantage for spatial and object but not verbal working memory using the n-back task

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ABSTRACT

Sex-related differences have been reported for performance and neural substrates on some working memory measures that carry a high cognitive load, including the popular n-back neuroimaging paradigm. Despite some evidence of a sex effect on the task, the influence of sex on performance represents a potential confound in neuroimaging research. The present study investigated sex-related differences in verbal, spatial, and common object versions of the high cognitive load "n-back" working memory task. Eighteen male and 18 female undergraduates completed all 3 versions of the task. A mixed ANOVA, with Sex (male and female) as the between-subjects factor and Condition (verbal, spatial, and object) as the within-subjects repeated measure revealed that males were significantly more accurate than females on the spatial and object versions of the n-back task and performed equivalently to females on the verbal version of the task. Although the expected female advantage for verbal working memory was not found using this effortful n-back task, these results support a male advantage for high cognitive load spatial and object working memory. Future research should take into account the influence of sex on performance of the n-back task, and examine sex-related differences in working memory using other paradigms.

1. Introduction

The present study investigated sex-related differences in high cognitive load working memory measures using verbal, spatial, and object versions of the "n-back" task. The n-back task (e.g., Cohen et al., 1997; Gevins & Cutillo, 1993) is a continuous performance working memory measure that, in its higher cognitive load conditions (i.e., 2-back and 3-back), makes strong demands on working memory. The task is a popular paradigm for studying working memory in neuroimaging research, and has shown a female advantage for its verbal version (Speck et al., 2000) and is associated with sex-specific neural patterns (Goldstein et al., 2005; Speck et al., 2000). Despite this evidence, research on sex-related differences on the n-back task is lacking. The different versions of the n-back task (e.g., verbal and spatial) also tend to vary in difficulty (e.g., Nagel, Ohannissien, & Cummins, 2007; Nystrom et al., 2000; Postle, D'Esposito, & Corkin, 2005), leading to another potential confound. Examining the influence of sex across different versions of the n-back task will add to the validity of the paradigm.

Sex-related differences in cognition are well established, with a male advantage found for some spatial measures (e.g., Voyer, Voyer, & Bryden, 1995) and a female advantage found for some verbal measures (Crossley, D'Arcy, & Rawson, 1997; Kramer, Delis, & Daniel, 1988; Norman, Evans, Miller, & Heaton, 2000; Weiss et al., 2006) and object-location memory measures (Silverman & Eals, 1992; Sykes-Tottenham, Saucier, Elias, & Gutwin, 2003; Voyer, Postma, Brake, & Imperato-McGinley, 2007). A growing body of research supports sex-related differences for working memory measures that carry high cognitive loads. In addition to Speck et al. (2000)'s finding of a female advantage for the verbal n-back task and a number integer working memory task, Duff and Hampson (2001) and Lejbak, Vrbancic, and Crossley (2009) reported a female advantage for an object-location task that had a significant working memory component. Studies of estrogen and the n-back task further support the notion of a sex-related difference on the paradigm. For example, Keenan, Ezzat, Ginsburg, and Moore (2001) found that estrogen supplementation facilitated performance on a verbal n-back task, and Grigorova, Sherwin, and Tulandi (2006) found that estrogen suppression worsened performance on both verbal and non-verbal n-back tasks.

Not all high load working memory studies have found a female advantage or a sex-related difference. A male advantage for a high cognitive load spatial working memory task (Cattaneo, Postma, & Vecchi, 2006) and a spatial span task has been reported (e.g., Orsini, Simonetta, & Marmorato, 2004), although not consistently (e.g., Robert & Savioe, 2006). Goldstein et al. (2005) found no effect for sex using a measure similar to the letter n-back task in a behavioral fMRI study, despite finding differences in neural activation (see above). Similarly, Nagel et al. (2007), who performed a strictly

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behavioral study, did not find any sex-related differences using a letter and spatial n-back paradigm. A degree of inhibition, however, was required in Nagel et al.'s task; participants were shown letters in different locations, and were instructed to respond to either the letters or the spatial position.

Although there is mainly overlap between the sexes for neural patterns associated with cognition, neural processing can vary with sex in degree of activation and neural region, particularly when the cognitive domain demonstrates a sex-related difference. For example, sex-related differences in neural activation have been found for spatial cognition (e.g., Hugdahl, Thomsen, & Ersland, 2006; Jordan, Wüstenberg, Heinze, Peters, & Jäncke, 2000), language (e.g., Baxter et al., 2003; Weiss et al., 2003), and memory (e.g., Nyberg, Habib, & Herlitz, 2000; Piefke, Weiss, Markowitsch, & Fink, 2005). Sex-related differences in neural activation also have been reported for working memory tasks. For example, Speck et al. (2000) found less lateralized activation in males compared to females on a verbal n-back task and integer working memory task. Using a measure similar to the n-back task, Goldstein et al. (2005) found a different pattern of neural activation in females compared to males (i.e., neural activation was higher for females in the middle, inferior, and orbital prefrontal cortex). In light of the contrasting findings regarding sex-related difference on n-back performance, and the different patterns of neural activation on this task, further investigation of sex-related differences on the n-back task is warranted.

The present study investigated sex-related differences in a high cognitive load n-back working memory task. Males and females were compared on verbal, spatial, and common object versions of the 2-back task. Based on previous research using high cognitive load working memory tasks, females were expected to outperform males on the verbal version (i.e., letter) of the 2-back task, and males were expected to perform at least equivalently or better than females on the spatial version (i.e., location) of the task. Although sex-related differences in object working memory have been investigated less extensively, we hypothesized that females would have an advantage for the object version (i.e., common objects) of the task, based on Duff and Hampson's findings (2001) and our report of a female advantage on common object-location memory (e.g., Lejbak et al., 2009), and McGivern et al.'s (1997) report of a female advantage for object recognition memory. Also consistent with this hypothesis is the report by Postle, D'Esposito, and Corkin (2005) that object working memory is dependent on verbal substrates.

Establishing performance on the n-back task taking into consideration important normative individual differences, such as sex, will strengthen the n-back paradigm's utility to inform brain–behavior relationships. If a sex-related difference on the n-back task exists, it will encourage future research using the paradigm to consider the influence of sex. There may be occasions when it is inappropriate to combine behavioral and neuroimaging data from both sexes. Finally, this research will advance the growing literature concerning sex-related differences and working memory, and potentially have theoretical implications for models of working memory.

2. Methods

2.1. Participants

Participants were recruited from a Department of Psychology undergraduate research pool. Ethics approval was granted by the university's Behavioral Ethics Research Board. Informed consent was obtained and demographic information (e.g., age, handedness, etc.) was collected in a brief paper-and-pencil questionnaire. A priori exclusionary criteria included nonfluent English, age greater than 35 years, uncorrected vision or hearing, and history of head injury, hormone disorder, or severe psychiatric disorder. Females taking hormonal birth control medication were included in the study due to the large number of university students taking birth control (i.e., over two-thirds in our sample).

One male was excluded because of nonfluent English, and 1 female was excluded due to age (i.e., over 35 years). Four left-handed participants (2 males and 2 females) were included in the analyses because they were evenly distributed between the groups and the pattern of results did not differ when they were excluded. One male and 6 females were excluded from the analyses because they performed below chance on one or more of the experimental tasks. After the exclusions, 36 participants (18 males; 18 females) were included in the final analyses. Average age was 18.6 (SD 1.2) years for males (age range = 17–21 years) and 19.1 (SD 2.8) years for females (age range = 17–28 years).

2.2. Materials

2.2.1. Supplementary tasks

Estimate of verbal ability. The Wide Range Achievement Test, Third Edition (WRAT-3) Reading Subscale (Wilkinson, 1993) was used as an estimate of verbal ability (Spreen & Strauss, 1998, p. 165). The task was administered and scored according to standardized protocol. The maximum raw score is 57.

Spatial ability. The Mental Rotations Test (Vandenberg & Kuse, 1978) was used to demonstrate sample representativeness on a cognitive task with established sex-related differences. Participants were shown line drawings of a target 3-D cubed object, and were asked to determine which 2 of the 4 responses were the same objects rotated in space. Participants had 3 min to complete 12 questions. One point was awarded for each correct answer, and .33 points were deducted for each incorrect answer. The maximum score is 24.

2.2.2. Experimental tasks

N-back task. Verbal, spatial and common object versions of the n-back working memory task required participants to make decisions about the stimulus they saw "2-back" as each new stimulus was presented. The verbal n-back task consisted of a series of letters presented in the centre of the screen. The letters were lower case and presented in Courier New font with a font size of 72. All 20 consonants were used (vowels were excluded). To increase similarity to the verbal version, the spatial version consisted of a black circle (3 cm diameter) that moved around in 20 different locations (i.e., in a 4 row by 5 column array).

The common objects version of the n-back task included 20 objects that were similar to the images used by Snodgrass and Vanderwart (1980). The images were taken from the International Picture Naming Project at the Centre for Reading and Language, University of California San Diego website (see Szekely et al., 2004). The images have been shown to be similar to the Snodgrass and Vanderwart images for naming agreement, familiarity, complexity, imagery judgments, and naming latencies (Rossion & Pourtois, 2004). The objects were chosen to ensure an equal number of semantic categories (e.g., fruit, vegetables, furniture, and transportation) and an equal number of typically "male", female" and "neutral" objects (McGivern et al., 1997).

Dependent measures for the n-back included number of correct answers and average reaction time. The maximum score for correct answers on each version is 168.

2.2.3. Procedure

After providing informed consent, participants filled out a brief demographic questionnaire and were tested individually in a