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Investigation of the link between higher order cognitive functions and handedness

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The study aimed to investigate the hypothesis that in high-functioning individuals the left-handedness phenotype facilitates the performance of executive-related tasks that engage the right hemisphere. The Trail-Making Test and Letter–Number Sequencing, previously indicated to engage the right hemisphere, were applied on 47 right-handers and 50 left-handers. There was a significant effect of handedness on both measures and an interaction effect of gender and handedness on the Trail-Making Test. The findings are considered to support the view that greater engagement of right-hemispheric resources facilitates the performance of higher order functions that orchestrate cognition, such as mental flexibility, inhibitory control, and working memory operations.

Keywords: Brain lateralization; Executive functions; Handedness; Letter–number sequencing, Trail-Making Test.

An important field of research in the areas of neuroscience and neuropsychology covers the working memory schema, conceptualized as the ability to temporarily maintain and manipulate information in a limited-capacity system. At present, a broadly accepted view of working memory is that of a multicomponent model comprising four parts—namely, the phonological loop, the visuospatial sketchpad, the central executive, and the episodic buffer (Baddeley, 2007). The phonological loop and the visuospatial sketchpad are thought to support the temporary maintenance of phonological and visuospatial stimuli, respectively (Baddeley, 2007; Baddeley & Logie, 1999). The episodic buffer operates as a binding mechanism that creates unified formations of experience by bringing together information from the phonological loop, visuospatial sketchpad, and long-term memory (Baddeley, 2007). Finally, the executive component is a supervisory system that controls and regulates the attentional demands required by working memory tasks (Baddeley, 2007; Baddeley & Logie, 1999). According to the current trends, the central executive incorporates various functions, such as the capacity to divide attention, focus attention, switch attention, and provide links between working memory operations and long-term memory formations (Baddeley, 2007; Baddeley & Logie, 1999; Friedman et al., 2008).

Executive functioning is not viewed only as a part of the working memory schema, but instead it is considered as a broader umbrella term for higher order cognitive functions that orchestrate cognition (Miyake et al., 2000; Vaughan & Giovanello, 2010). Selecting strategies, inhibiting prepotent responses, updating working memory representations, shifting between tasks or mental sets, and monitoring performance are some indicative executive processes (Miyake et al., 2000; Vaughan & Giovanello, 2010). Efficient executive functioning is closely linked to the capacity of an individual to manage well with everyday problems, set goals, organize life, modify behavior according to external stimuli, and take proper decisions in everyday social and occupational environments (Grafman & Litvan, 1999; Manstester, Priestley, & Jackson, 2004). Because of

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the prominent role that is attributed to the executive system, numerous studies have investigated topics that are linked to the specific system. The particular area explored and discussed in the present work is the link between handedness and executive functioning.

Our research group in two recent studies has reported alterations in executive functioning between right- and left-handers, by applying the Stroop Color Word task (Beratis, Rabavilas, Papadimitriou, & Papageorgiou, 2010) and the Hayling Sentence Completion test (Beratis et al., 2009). In particular, the Stroop study revealed that in a group of well-educated young adults, those that were left-handers outperformed the right-handers in their ability to inhibit an overlearned response, while the Hayling study depicted the presence of different brain activation patterns between right- and left-handers during the performance of a verbal executive task. Also, the work of Benbow (1986, 1988) and O'Boyle, Benbow, and Alexander (1995) showed that an excess proportion of left-handers have the capacity to discern patterns and manage well with new knowledge, thus indicating an association of handedness with executive-related processes. Additionally, Halpern, Haviland, and Killian (1998), by investigating the data obtained from a medical college admission test, found that left-handers were more likely to obtain high scores on the verbal reasoning subtest. Notably, this particular test engages executive resources because it requires efficient planning, organizational skills, and the capacity to integrate and weight properly various bits of information in order to eliminate the incorrect alternatives and reach to the selection of the correct one (Halpern et al., 1998). Another study that should be mentioned is that of Levander, Levander, and Schalling (1989), which compared left- and right-handed individuals with above-average intelligence. An advantage of the left-handed group was observed in aspects of the executive system, as reflected by the presence of significantly fewer switching difficulties during the performance of a computerized Trail Making Test (TMT). Also, there was a trend in favor of the left-handed group in the Part B of the paper-and-pencil TMT that is considered to engage executive resources, which, however, did not achieve statistical significance (Amieva et al., 1998; Kortte, Horner, & Windham, 2002; Olivera-Souza et al., 2000).

The common aspect that underlies the aforementioned studies that detected an advantage of the left-handers in executive-related processes is that all of them focused on high-functioning individuals, and, therefore, generalization of the findings should be made with caution. Other studies that used samples with different characteristics failed to find differences between right- and left-handers or even detected the opposite pattern (Nicholls, Chapman, Loetscher, & Grimshaw, 2010; Thilers, MacDonald, & Herlitz, 2007). Notably, the presence of handedness-related functional variations in executive operations is supported by findings that indicate the existence of structural differences between right- and left-handers in frontal brain regions (Geschwind, Miller, DeCarli, & Carmelli, 2002), in brain areas, therefore, that are considered to subserve the executive system (Baddeley, 2007; Goldman-Rakic, 1996; Miller & Cohen, 2001; Robbins, 2005). Also, according to Benbow (1986) and Halpern et al. (1998), left-hand preference, at least in the case of high-functioning individuals, is linked to advantageous performance on those executive-related processes or tasks that involve right-hemispheric engagement. The interpretation of this set of findings that the aforementioned investigators provide is based on the work of Geschwind and Galaburda (1985a, 1985b). According to this approach, left-handedness is related to high testosterone exposure or high sensitivity to testosterone during endometrial life that facilitates the development and possibly the functioning of the right hemisphere.

Two executive-related tasks that involve activation of the right hemisphere, according to brain imaging findings, are the Letter–Number Sequencing (LNS; Haut, Kuwabara, Leach, & Arias, 2000) and Part B of the TMT (Jacobson, Blanchard, Connolly, Cannon, & Garavan, 2011; Nakahachi et al., 2010; Shibuya-Tayoshi et al., 2007). LNS is considered to engage the executive component of working memory because it requires not only the temporary storage of information, but also the manipulation of the information that is temporarily maintained (Emery, Heaven, Paxton, & Braver, 2008; Shelton, Elliott, Hill, Calamia, & Gouvier, 2009). In particular, the assessed individuals are required to repeat numbers in ascending order and letters in alphabetical order that are initially presented orally by the assessor in a mixed-up order. The TMT is comprised of Part A and Part B. It was originally designed as a part of the Army Individual Test Battery (1944) and is now a standard component of the Halstead–Reitan Neuropsychological Test Battery (Reitan & Wolfson, 1993). Abilities such as visual search, motor speed, and spatial skills are examined in both parts of the test (Crowe, 1998; Gaudino, Geisler, & Squires 1995). Contrary to Part A, Part B is considered to assess aspects of executive control, such as mental flexibility (Kortte et al., 2002; Olivera-Souza et al., 2000). Also, another executive control process that appears to be engaged in Part B is inhibitory control because the participants have to suppress the tendency to connect successively numbers or letters when the pencil is on a number or a letter, respectively (Amieva et al., 1998).

In view of the above considerations, an objective of the current study was to investigate the hypothesis that in the case of high-functioning young individuals, the phenotype of left-handedness provides an advantage during the performance of executive-related tasks that engage the right hemisphere, such as the LNS and Part B of the TMT. Because there is some evidence that left-handers are at greater risk of developing conditions that affect cognition, such as depression and hypertension (Bryden, Bruyn, & Fletcher, 2005; Elias, Saucier, & Guylee, 2001), exclusion criteria were applied that had as target psychiatric or medical confounds linked to cognitive attenuation. A similar approach, as far as the exclusion criteria are concerned, was used by Gunstad, Spintznagel, Luyster, Cohen, and Paul (2007), who found superior TMT performance in left-handers as compared to right-handers that were free from medical or psychiatric conditions, despite the fact that their study did not focus on high-functioning young individuals.

Although we did not make a specific directional hypothesis about the presence or not of interaction effects between handedness and gender on the elected cognitive tasks, we decided to explore this issue because of previous research observations indicating that the effects of handedness and gender on cognitive patterns are not always independent from each other (Beratis et al., 2010; Gordon & Kravetz, 1991; Nagae, 1985; Thilers et al., 2007). Further support toward the exploration of potential interaction effects is provided by findings that indicate greater right-hemispheric activation of males than females during the performance of tasks that engage executive resources (Bell, Willson, Wilman, Dave, & Silverstone, 2006; Speck et al., 2000) as well as by the observation that performance is positively associated with right-hemispheric activation in executive-related tasks (Unterrainer et al., 2004; Unterrainer et al., 2005). These gender-related variations in the profile of hemispheric engagement could possibly interact with handedness-related brain lateralization differences, thus leading to cognitive performance patterns that are related not only to handedness, but also to the interaction of gender and handedness.

In summary, the present study had the following purposes: first, to investigate the hypothesis that in high-functioning young individuals the phenotype of left-handedness facilitates the performance of executive-related tasks that engage the right-hemisphere; and, secondly, to shed more light on the ways that handedness and gender could interact on tasks that engage executive resources.

METHOD

Participants

One hundred individuals were asked to participate in the study without payment, and all of them accepted. All were healthy, with no reading disabilities or neurologic signs, and met certain gross criteria concerning handedness, as described below. Those who failed to reach these criteria were not included in the initial sample. Participants were university students, university graduates, and postgraduate students of the National University of Athens, and their native language was Greek. Their field of studies was medicine, electrical, and computer engineering, law, or mechanical engineering. These study fields are among the most popular in Greece, requiring a very high performance in national exams for acceptance (Greek Ministry of Education, 2012). This selection process for admission to the study was chosen for obtaining a study sample comprised of high-functioning adults. Individuals included in the initial sample denied the use of any illicit substances or alcohol dependence. Moreover, they were screened for medical conditions interfering with cognition, such as epilepsy, multiple sclerosis, schizophrenia, affective psychosis, brain injury, and cerebrovascular pathology. They had normal or corrected-to-normal visual acuity.

In reference to handedness, a two-level procedure was applied. The screening criteria of the first level were used for collection of the initial sample. Three questions were asked for left-handers and four for right-handers. A left-hand preference in the three questions asked (hand writing, hand throwing, and hand used for holding knife without a fork) was required for participation in the initial left-handed group. For right-handers, in addition to right-hand preference in the three questions asked above, a positive answer in the following question was required: “Do you consider yourself as a strong right-hander?” These criteria were applied in order to exclude from the study the vast majority of ambidextrous and those who were not strong right-handers.

The application of the Edinburgh Handedness Inventory (EHI) in the initial groups of left- and right-handers constituted the second level of the procedure and aimed at obtaining greater accuracy in the assessment of handedness (Oldfield, 1971). The version of the inventory used includes 10 questions about a person's hand preference in different actions (writing, drawing, throwing, using scissors, using toothbrush, using a knife without a fork, using a spoon, the upper hand when using a broom, striking a match, opening a box). The participants were instructed to score 1 in the appropriate column (left/right) for the items with relevant preference, and 2 for the items with absolute preference. In cases that a preference did not exist they should score 1 in both columns. The degree of laterality was defined with the use of the following formula: $H = 100 \times (\text{NR} - \text{NL})/(\text{NR} + \text{NL})$, where NR and NL are the total score of the column for the right hand and left hand, respectively. In the group of left-handers, an $H < 0$ was required (Oldfield, 1971). The participants in the group of strong right-handers should select right hand in the 10 assessed actions, in two of which they could select the left hand as well. Under these criteria, three individuals were defined as ambidextrous or not strong right-handers and were excluded from the analysis. A smaller cutoff value was chosen for the left-handed group because of their less lateralized nature (Geschwind et al., 2002) and the possibility of some adaptation by left handed people to a world predominantly organized for the right-handers (Oldfield, 1971).

Two males and 1 female (all ambidextrous) failed to reach the criteria and were excluded from the study. Of the 97 individuals enrolled in the study, 47 (22 males) were right-handed, and 50 (25 males) were left-handed. The mean degree of laterality in male and female right-handers was 99.0 ± 4.5 (range 79–100) and 98.6 ± 4.9 (range 79–100), respectively, and in male and female left-handers it was –82.8 ± 26.2 (range –11 to –100) and –76.5 ± 31.4 (range –8 to –100), respectively. Table 1 shows the field of studies of the participants according to gender and handedness. The age of the male right-handers was 26.6 ± 3.2 years (range 22–34), of the female right-handers 26.2 ± 3.8 years (range 21–36), of the male left-handers 25.8 ± 3.6 years (range 20–33), and of the female left-handers 25.1 ± 3.9 years (range 20–34). One-way analysis of variance (ANOVA) showed absence of statistically significant age differences among the four groups, $F(3, 93) = 1.16, p > .05$.

The study was approved by the Ethics Committee of the Eginition University Hospital, and informed consent was obtained from the subjects studied.

Forty-two participants of the current study (9 male right-handers, 11 female right-handers, 10 male left-handers, 12 female left-handers) participated in two previous studies of our research group that focused on the effect of handedness on the Stroop Test and the Hayling Test (Beratis et al., 2009; Beratis et al., 2010). Because the administration of the Stroop Test and the Hayling Test was made in parallel with electrophysiological recording that lasted for more than an hour, the LNS and TMT investigated in this study were administered in a different session.

TABLE 1
Number of individuals in each study field according to gender and handedness

	Left-handers		*Right-handers*	
Study field	*Male*	*Female*	*Male*	*Female*
Medicine	10	12	8	9
Electrical & computer engineering	7	5	6	8
Mechanical engineering	5	4	3	3
Law	3	4	3	5

Trail Making Test

The version of the TMT used has two subtasks (Reitan, 1979): Part A (TMT-A) and Part B (TMT-B). Each subtask is shown on a white paper (A4 dimension), and the participants are asked to connect randomly located circles, as fast as possible. Part A includes circles with numbers only (1–25) that have to be connected in numerical order, while Part B includes circles with both numbers (1–13) and letters (A–M) that have to be connected alternately. A pretest with only 8 items is administered before each part. During the practice phase, in case of an error, correction is made by the assessor, and instructions are given again. The order of the administration is fixed, first Part A and afterwards Part B. The applied assessment procedure requires correction of errors as they occur by the assessor, and performance is based only on the time (s) that is needed to complete each part (Reitan, 1979).

Letter–Number Sequencing

A series of numbers and letters are read aloud to the participant in a mixed-up order at an approximate rate of one item per second. The participant is instructed to recall first all numbers in numerical order and then all letters in alphabetical order. The starting list length consists of one number and one letter, and then it increases by one for each successive block. Each block includes three trials, and the administration procedure ends if an individual misses all three items of a specific block. The obtained score corresponds to the total number of correct trials (Wechsler, 1997).

Statistical analysis

The completion time of the first and second parts of the TMT as well as the total number of correct trials on the LNS were used as outcome variables. Each of these variables was subjected to univariate ANOVA with sex (male/female), handedness (left-handers/right-handers), and their interaction as the independent factors. Correlation analysis was conducted between degree of handedness and performance on TMT-A, TMT-B, and LNS. In this analysis, the whole sample was studied together and not each gender-handedness group separately because, as shown by preliminary analysis, the relatively small size of each group and the small variation of the laterality index did not allow for the correlations to attain statistical significance within each group. Also, the effect of handedness on TMT-B was investigated in an analysis of covariance (ANCOVA) that used TMT-A as a covariate. This aimed to study the effect of handedness on TMT-B after controlling for the influence of TMT-A on TMT-B. The level of association between TMT-B and LNS was assessed with the corresponding coefficient of determination (R^2). Accordingly, the coefficient of alienation ($1 - R^2$) reflects the lack of association between the two measured outcomes. Significance was set at .05. The Statistical Package for the Social Sciences (SPSS), Version 17 (Chicago, ILL) was used to analyze the data. Post hoc power analysis was performed with the use of the G*Power analysis program (Erdfelder, Faul, & Buchner, 1996).

RESULTS

Figure 1 illustrates the TMT-A, TMT-B, and LNS mean values ($\pm SD$) of the male and female left- and right-handers.

Table 2 lists the F-values, the significance values, and the corresponding effect sizes of handedness (left-handers/right-handers), sex (male/female), and their interaction on TMT-A, TMT-B, and LNS. Neither of the two factors (handedness and gender) nor their interaction had a significant effect on TMT-A. Conversely, the main effect of handedness and the interaction effect of handedness and gender on TMT-B were significant. Finally, both handedness and gender had a significant main effect on LNS.

The main effect of handedness on TMT-B and LNS reflects the higher performance of the left- than the right-handers observed on both tasks. The main effect of gender on LNS indicates the higher performance of the males than the females. Finally, the interaction effect between gender and handedness on TMT-B indicates the presence of greater differences between left- and right-handed females than between left- and right-handed males.

The correlation analysis that was performed revealed a significant association between degree of handedness and TMT-B ($r = .23$, $p = .025$) as well as between degree of handedness and LNS ($r = -.24$, $p = .022$). In both cases these significant associations reflected the improvement on performance that accompanied the transition from strong right-handedness toward left-handedness. On the other hand, the correlation between degree of handedness and TMT-A did not attain statistical significance ($r = .17$, $p = .106$).

Moreover, the ANCOVA analysis that treated TMT-A as a covariate revealed a significant effect of handedness on TMT-B that indicates the higher performance of left-handers than of right-handers, after controlling for performance differences on TMT-A, $F(1, 94) = 11.01$, $p < .001$, $\eta^2 = .19$.

The R^2 value between LNS and TMT-B, known as the coefficient of determination, which indicates the amount of shared variance between the two variables, was .10 (10%). Thus, the coefficient of alienation that represents the lack of association between the two variables was .90 (90%).

Post hoc power analysis based on the current significant findings revealed that for the applied alpha level of .05 and the sample size of the study, the power of the analysis ranged between .82 and .84. Consequently, the study was sufficiently powered.

DISCUSSION

The results revealed that in the case of high-functioning young individuals, left-handedness provides an advantage during the performance of executive-related tasks that engage the right hemisphere—namely, the TMT-B and LNS. This pattern of findings was obtained by the ANOVA models that revealed a significant effect of handedness on both tasks as well as by the correlation analysis that showed that performance improved as the degree of left-handedness increased. Notably, the effect of handedness on TMT-B was evident after controlling for differences on TMT-A performance. Moreover, the analysis that was performed showed the existence of a significant interaction effect between handedness and gender on

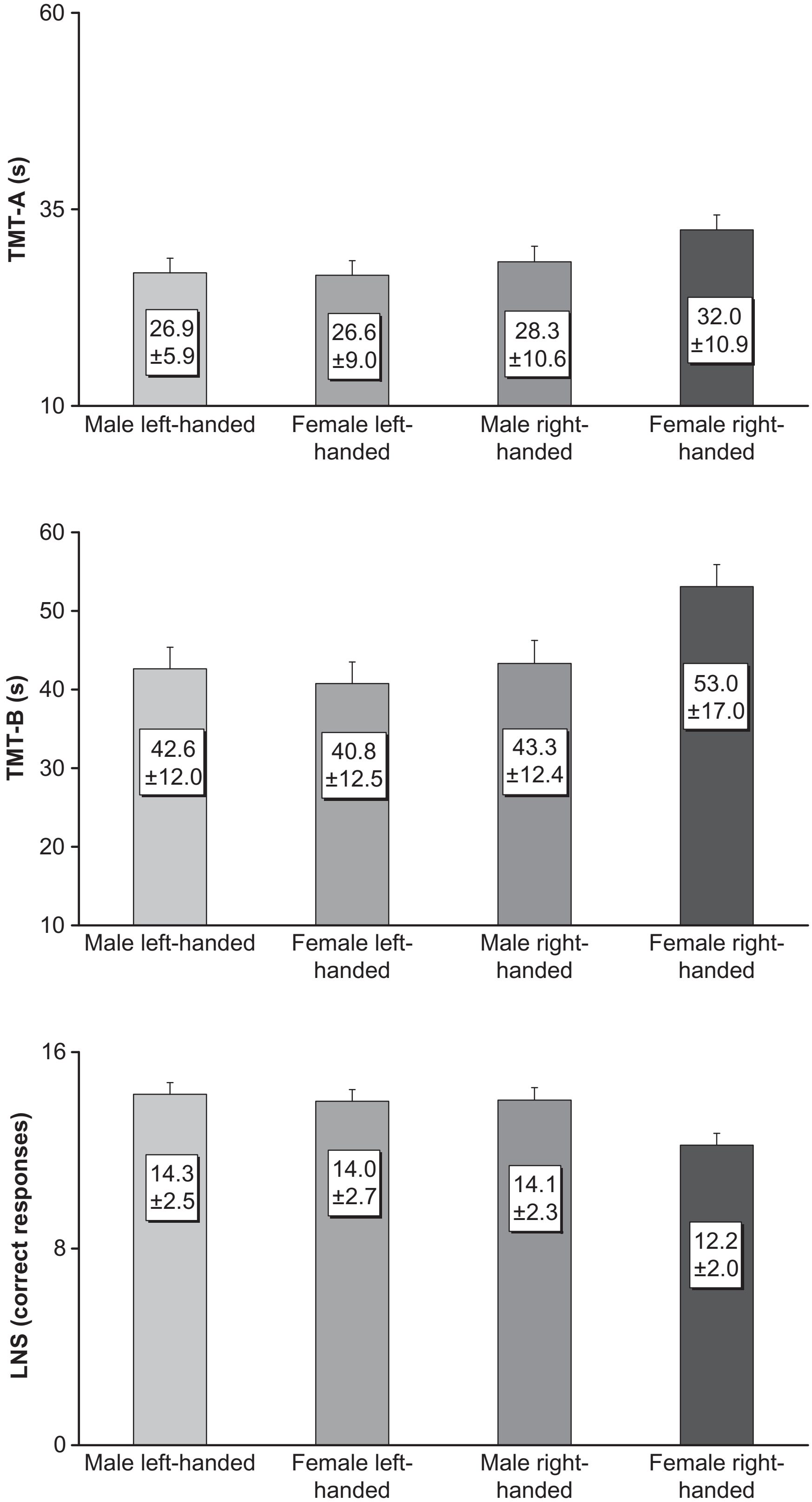

Figure 1. Performance, mean (±*SD*), of male and female right- and left-handers in the following tests: Trail-Making Test Part A (TMT-A), Trail-Making Test Part B (TMT-B), and Letter–Number Sequencing (LNS).

TABLE 2
Effects of handedness, gender, and their interaction on the neuropsychological measures

	TMT-A			*TMT-B*			*LNS*		
Factor	*F(1, 93)*	*p*	η^2	*F(1, 93)*	*p*	η^2	*F(1, 93)*	*p*	η^2
Handedness	3.24	*ns*	.034	5.42	.022	.055	4.31	.041	.045
Gender	0.79	*ns*	.008	1.99	*ns*	.021	4.71	.033	.049
Handedness × Gender	1.12	*ns*	.012	4.35	.040	.045	2.55	*ns*	.027

Note. Effects of handedness: left-handers/right-handers; gender: male/female. TMT-A = Trail Making Test, Part A; TMT-B = Trail Making Test, Part B; LNS = Letter–Number Sequencing; *ns* = nonsignificant.

TMT-B that reflects the presence of greater differences between female left- and right-handers than between male left- and right-handers. In reference to the main effect of gender, a significant difference in favor of males was observed in the case of the LNS. As far as TMT-A is concerned, which is not considered as a measure of executive control, the effects of handedness, gender, and their interaction were not significant. Also, two counterpart observations that add to the understanding of the present findings is the amount of shared variability between LNS and TMT-B, which is 10%, as estimated by the coefficient of determination, and the amount of unshared variability between the two tasks, which is 90%, as estimated by the coefficient of alienation.

The higher performance demonstrated by the left-handed group on TMT-B and LNS is in agreement with the hypothesis of the study, which expected in the case of high-functioning young adults, screened for medical conditions interfering with cognition, an advantage of the left-handedness phenotype during the performance of executive tasks that involve right-hemispheric activity. The formulation of this hypothesis was based on the work of Benbow (1986) and Halpern et al. (1998), which provided evidence that left-handers outperform right-handers, at least when focusing on high-functioning individuals, in processes or tasks that engage the right hemisphere. Notably, the present findings fit with those of Gunstand et al. (2007) who found superior TMT-B performance in left-handers than in right-handers who were free from medical or psychiatric confounds linked to cognitive attenuation, despite the fact that their study did not focus on high-functioning young individuals.

Tasks such as the TMT-B and the LNS are complex tasks that, according to previous brain imaging studies, are not controlled by a single area, but instead by various brain regions (Haut et al., 2000; Jacobson et al., 2011; Nakahachi et al., 2010; Shibuya-Tayoshi et al., 2007). Moreover, despite the findings that indicate a more prominent role of the right hemisphere, it appears that the left hemisphere is also engaged (Haut et al., 2000; Jacobson et al., 2011). Notably, the corpus callosum, which plays a pivotal role in interhemispheric communication, is considered to manifest handedness-related differences in favor of left-handers (Driesen & Raz, 1995; Polich & Hoffman, 1998). Thus, the effect of handedness that was observed on the two executive tasks could be mediated by handedness-related differences in the corpus callosum that provide an advantage to the left-handed group in reference to the communication of the brain regions that are subserving the specific tasks. An additional reason that could explain the advantage of the left-handedness phenotype in this group of high-functioning young adults derives from earlier studies that have suggested that engagement of the right hemisphere in this kind of executive test could reflect the application of visual imagery strategies (Gerton et al., 2004; Haut et al., 2000). This is because the presence of a more developed right hemisphere in left-handed individuals could facilitate the use of visual imagery strategies and enhance their performance.

Interaction effects of handedness and gender have also been reported in previous studies (Beratis et al., 2010; Gordon & Kravetz, 1991; Nagae, 1985; Thilers et al., 2007). In the present study, the greater differences between female left- and right-handers than between male left- and right-handers could be explained by taking into consideration various sets of findings. Such observations are those indicating a more efficient use of the right hemisphere by left-handers (Benbow, 1986; Halpern et al., 1998), a greater use of right-hemispheric resources by males than females during the performance of tasks that include executive components (Bell et al., 2006; Speck et al., 2000), and a positive association between performance and extent of right-hemispheric involvement in executive-related tasks that engage the specific hemisphere (Unterrainer et al., 2004; Unterrainer et al., 2005). If the critical factor is the degree of right-hemispheric engagement, then the lower accessibility of right-handed females to right-hemisphere resources than in the other groups could potentially explain why female right-handers manifested the lower levels of performance in the second part of the TMT.

A pivotal issue that needs to be discussed is whether or not the differences between left- and right-handers on TMT-B actually derive from the executive component of the task. Both parts of the TMT assess motor speed, visual search, and spatial skills (Crowe, 1998; Gaudino et al., 1995). In addition, Part B is considered as an executive measure because it engages mental processes, such as shifting ability, mental flexibility, and inhibitory control (Amieva et al., 1998; Kortte et al., 2002; Olivera-Souza et al., 2000). The present findings show that after controlling for the influence of TMT-A, the effect of handedness on TMT-B becomes more apparent. Hence, the view that the TMT-B differences between left- and right-handers are executive related is corroborated.

As mentioned above, an effect of handedness was present on both LNS and TMT-B. The absence of a strong association between the two measures indicates that this parallel pattern obtained by the two tasks is not due to a high amount of shared variability between them. Likewise, the corresponding coefficient of alienation was close to 1, which indicates that the two measures are in essence independent from each other. Hence, the effect of handedness on executive-related tasks that engage the right hemisphere appears to be broader and not specific to a certain executive task or to a set of overlapping executive tasks. This view is supported also theoretically because the two tasks are considered to engage distinct executive resources; the LNS is conceived as a working memory measure, and the TMT-B is considered to focus on mental flexibility and inhibitory control.

The present research focused on investigating handedness-related effects and not the main effect of gender on aspects of cognitive performance. Nonetheless, the greater performance of males than females observed on LNS is in agreement with the findings of van der Sluis et al. (2006) and Dolan et al. (2006) who found an advantage in favor of males on a working memory index that included the LNS. As far as the current work is concerned, the specific pattern of findings could be considered to reflect the important role of the right hemisphere during the performance of executive-related tasks. This suggestion is based on previous studies that have indicated a greater use of right-hemispheric resources by males than females as well as that right-hemispheric involvement facilitates the performance in executive-related tasks (Bell et al., 2006; Speck et al., 2000; Unterrainer et al., 2004; Unterrainer et al., 2005). Notably, the proposition about the critical role attributed to the right hemisphere, at least in the case of high-functioning individuals, is in agreement with the effects of both gender and handedness observed in the current study.

An advantage of this work that renders originality is the exploration of the link between handedness and executive-related tasks that engage the right hemisphere in high-functioning individuals free of medical conditions that affect cognition. The pattern of findings that was obtained, especially the advantage of left-handers as compared to right-handers, could be considered to support the view that the greater engagement of the right hemisphere facilitates the performance of processes deemed to orchestrate cognition, such as mental flexibility, inhibitory control, and working memory operations. Future studies by applying brain imaging applications could strengthen the outcomes of the present study and further our understanding about the role that the brain lateralization profile plays on higher order cognitive functions.

Potential limitations of the study that should be considered are the following. First, generalization of the findings should be made with caution because the participants were exclusively intelligent, highly educated young healthy adults, without a neurologic or psychiatric history. Environmental factors, mainly pre- and perinatal brain trauma, may contribute to handedness (Bakan, 1977; Orsini & Satz, 1986; Powls, Botting, Cooke, & Marlow, 1996; Satz, 1972). Also, in neurological conditions, such as epilepsy (Bryden et al., 2005; Lewin, Kohen, & Mathew, 1993), learning disabilities (Geschwind & Behan, 1982; Steenhuis, Bryden, & Schroeder, 1993), and mild mental retardation (Batheja & McManus, 1985; Pipe, 1990) the incidence of left-handedness is higher than that in the general population. Therefore, the procedure followed for the selection of the handedness groups could have a considerable impact on the observed pattern of findings. Furthermore, because the ambidextrous individuals were excluded from the study, the sample analyzed is not indicative of the whole spectrum of handedness. This choice was made because the study aimed at comparing two well-defined and distinct handedness subpopulations. Nonetheless, future work could add to our understanding by studying the whole range of handedness, with the inclusion of ambidextrous individuals. Also, a reasonable target for further research is to explore whether the findings are associated specifically with the tests applied in the current study or are generalized across various procedures that are used to investigate the assessed cognitive domains.

In conclusion, the findings of this study indicate the presence of an effect that is handedness related on tasks that engage higher order cognitive processes, such as mental flexibility, inhibitory control, and working memory operations that put a heavy load on the executive component of the working memory schema. Such higher order cognitive functions are pivotal in people's lives because they are closely linked to the capacity of an individual to manage well with everyday problems, set goals, organize life, modify behavior according to external stimuli, and take proper decisions in everyday social and occupational environments. Thus, the current observations could help to improve our understanding about the link that exists between variations of hemispheric lateralization, as reflected by differences in the phenotype of handedness, and cognitive or behavioral patterns that subserve a successful adaptation to the outside world. As far as the clinical relevance of the findings is concerned, works like the present one could pave the way to better understanding of the influence of intrahemispheric and interhemispheric lateralization differences among individuals on the pattern, severity, and course of impairments that are commonly found in higher order cognitive functions in a large number of clinical conditions.

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