Construct Validity of the Multi-Source Interference Task to Examine Attention in Heart Failure

Miyeon Jung ▾ John Jonides ▾ Marc G. Berman ▾ Laurel Northouse ▾ Todd M. Koelling ▾ Susan J. Pressler

Background: Patients with heart failure (HF) are at risk of cognitive dysfunction, including decreased directed attention. Directed attention is critical for performing daily activities including HF self-care by facilitating one to follow instructions or train-of-thought when there are interferences in which presented stimuli are in conflict with one another. The Multi-Source Interference Task (MSIT) is a computerized neuropsychological test that examines the function of the dorsal anterior cingulate cortex, the neurological substrate for directed attention. However, the MSIT has not been used in past HF studies.

Objective: The purpose of the study was to examine construct validity of the MSIT in HF.

Methods: Baseline data were obtained from a cognitive intervention study among patients with HF (n = 22) and age- and education-matched healthy adults (n = 20). Construct validity was evaluated using t tests to examine differences between patients with HF and healthy adults and congruent and incongruent MSIT trials. Pearson's correlations were computed to examine relationships between the MSIT and Trail-Making Test, Stroop Test, and Attentional Function Index.

Results: Compared with healthy adults, patients with HF demonstrated worse performance (i.e., slower response times and higher error rates) on MSIT. Patients with HF had worse performance on MSIT incongruent trials than congruent trials. Interference z scores of MSIT did not correlate with Trail-Making Tests A and B and Stroop Test interference z scores, but the MSIT interference z scores correlated with perceived attention function measured by Attentional Function Index.

Discussion: Construct validity of the MSIT was supported, in part, among patients with HF. The MSIT is a sensitive measure of detecting worse directed attention among patients with HF compared with healthy adults. The preliminary findings support the use of the MSIT as a measure of directed attention in HF. Confirmation is warranted for current findings in larger samples.

Key Words: attention • cognition • heart failure • neuropsychological tests • psychometrics

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Heart failure (HF) is a public health concern affecting 6.5 million adults, with 1 million newly diagnosed patients with HF annually in the United State (Benjamin et al., 2018). Among patients with HF, cognitive dysfunction is prevalent and, in past studies, has ranged from 25% to 50% (Cohen & Gunstad, 2010; Pressler, 2008). Decreased attention is reported as one of the most frequently decreased cognitive domains in HF (Bauer & Pozehl, 2011; Pressler et al., 2010), found among 15%–27% of patients with HF (Jung et al., 2017). Patients with more attention dysfunction reported lower adherence to the HF self-care regimen that can lead to more frequent rehospitalizations and higher mortality rates (Cameron et al., 2010; Dickson, Tkacs, & Riegel, 2007). However, past studies were limited by lack of guiding theoretical framework of attention and measures that do not account for multiple dimensions of attention.

Attention has multiple dimensions, including directed attention and involuntary attention that are widely accepted (James, 1890; Kaplan & Berman, 2010). Involuntary attention is an effortless attention automatically captured by novel stimuli (e.g., wild animals, moving objects). Contrastingly, directed attention is an effortful attention that regulates focus by ignoring distractions that interfere with one's focus of attention (James, 1890). Therefore, directed attention is critical for following instructions or train-of-thought when there are competing stimuli or interferences in which the stimuli are in conflict with one another (Berman, Jonides, & Lewis, 2009; Kaplan & Berman, 2010; Weissman, Mangun, & Woldorff, 2002). However, directed attention in HF currently receives little focus, and the use of directed attention measures in HF is limited.

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The Multi-Source Interference Task (MSIT) is a theory-driven computerized neuropsychological test, which was developed to examine the function of the dorsal anterior cingulate cortex (Bush, Shin, Holmes, Rosen, & Vogt, 2003). This brain area is the neurological substrate for directed attention (Nee, Jonides, & Berman, 2007) and known to function abnormally among people with attention-deficit hyperactivity disorder. Activation of the dorsal anterior cingulate cortex was consistently found during neuropsychological tests with conflicts (e.g., Stroop Test) but independent from emotional or simple motor processing (Bush et al., 2003). To maximize activation in the dorsal anterior cingulate cortex, the MSIT neuropsychological test is programmed by combining three interference effects: Stroop effect, Eriksen flanker effect, and Simon effect. The Stroop Test uses color-based words, and participants are instructed to name the ink color or to read the color words. The Stroop effect is the phenomenon of worse performance while naming the ink colors compared with reading the color words and when the ink color and the color word are not matched (e.g., word "red" written in blue ink; Stroop, 1935). The Eriksen flanker effect refers to the phenomenon of worse performance on identifying the target letter when the target is flanked by incongruent distractor letters (e.g., KKHKK) than when it is flanked by the same letter (e.g., HHHHH; Eriksen & Eriksen, 1974). The Simon effect is the phenomenon of worse performance produced by spatial incongruence between the target location and the response key location (e.g., when the target appears on the right and the designated response key is located on the left; Simon & Berbaum, 1990). Therefore, people with poor directed attention are susceptible to the interference and perform poorly when there are nonmatched trials, which result in interference from incongruence.

This computerized neuropsychological test of MSIT has five more strengths in addition to the strengths that the test is theory-based and validated with brain imaging studies. First, it is less sensitive to literacy and language than other attention measures because it uses only Arabic numbers (i.e., 1, 2, and 3) and one alphabet letter (i.e., X). Second, it measures attention performance using a computer program that has less chance of observer bias and scoring errors than traditional paper–pencil-based neuropsychological tests. Third, the MSIT presents trial types of congruent and incongruent in a random order, and the randomization of trials can prevent adopting a strategy on some blocks of trials and reduce practice effect. For the same reason, the MSIT has the potential to be used in evaluating cognitive intervention effects over time. Fourth, this test can be easily administered inside brain imaging scans (e.g., functional magnetic resonance imaging [fMRI]). Fifth, the MSIT is enjoyable to complete because it has a game-like format. Despite these strengths, to our knowledge, the MSIT was not administered previously among patients with HF, and its validity is unknown in this population who is at risk of directed attention dysfunction.

Therefore, the aim of this study was to examine construct validity of the MSIT among patients with HF (Polit & Beck, 2008). Hypotheses included the following: (a) MSIT performance in HF is significantly worse than healthy adults; (b) performance of patients with HF on the MSIT incongruent trials is worse than performance on the MSIT congruent trials in terms of higher error rates and longer response times; and (c) performance on the MSIT is positively correlated with two other tests: Trail-Making Test and Stroop Test. A research question was proposed to examine the relationship between MSIT and perceived effectiveness of directed attention.

METHODS

Sample

This study used baseline data from a randomized crossover experimental study conducted to improve attention by completing a cognitive intervention among patients with HF. Results of the crossover study were reported previously (Jung et al., 2017). Only baseline data were included for the evaluation of construct validity to eliminate possible effects of the interventions. The sample for this study consisted of 22 patients with HF and 20 age- and education-matched healthy adults; the sample size was justified based on the aims for the parent study (Jung et al., 2017). For this study of validating MSIT in HF, effect sizes were calculated from means and standard deviations in a previous study among eight healthy young adults (Bush et al., 2003). Effect size differentiating congruent and incongruent trials was large (Cohen's d = 1.94 for response times and Cohen's d = 1.70 for accuracy), and sample size of 5 was needed for Hypothesis 2 in this study. Patients with HF were recruited from an HF outpatient clinic at a tertiary care medical center. The healthy adults were recruited using an online recruitment site linked to the medical center. Inclusion criteria for participants with HF were as follows: adults ($\geq$21 years), diagnosed with HF, able to hear, and able to read the English language. Inclusion criteria for healthy adults were the same, except for the diagnosis of HF. Exclusion criteria for both groups were as follows: a Mini-Mental Status Examination score of lower than 24, attention-deficit disorder, major neurological and psychiatric disorder, uncorrected vision, and color blindness.

Procedures

The study was approved by an institutional review board at a university in the Midwest. Written informed consent was obtained from all participants before their participation. Trained research assistants who were nursing students visited participants' homes and administered neuropsychological tests of attention before and after the cognitive interventions to improve attention. Demographic and clinical characteristics

were collected from the interview and electronic chart review at baseline.

Measures

Multi-Source Interference Task This test was administered to measure directed attention. In this study, this test was completed using a laptop keyboard programmed with E-Prime 2.0 software (Psychology Software Tools, Inc., 2012). Three numbers (i.e., 1, 2, or 3) or letters (i.e., X) were displayed on a computer screen, and participants were instructed to report the number that was different from the other numbers as quickly as possible, not sacrificing accuracy. Participants were asked to use their index, middle, and ring fingers to respond on the number keys 1, 2, and 3 on the laptop keyboard within 2 seconds. As shown in Figure 1, congruent trials have the target number that is always matched with its position (i.e., 1XX, X2X, or XX3), whereas incongruent trials have the target number that is never matched with its position (e.g., 331, 211, or 232). A series of 192 trials (eight sessions, 24 trials per session) were administered to each participant based on the protocol developed by Bush and Shin (2006). Reliability was supported with consistent brain activation among healthy young adults (Bush et al., 2003). The construct validity of the MSIT was supported in healthy young adults by producing reliable activation of the dorsal anterior cingulate cortex as measured by fMRI and detecting worse performance during trials with interference (Bush et al., 2003; Bush & Shin, 2006).

Trail-Making Test This test is designed to measure attention and mental tracking and is composed of two parts (Bowie & Harvey, 2006; Reitan, 1958). Part A includes 25 numbered circles, and participants were asked to connect the circles in order as quickly as possible. Part B features 25 circles with numbers (1–13) and letters (A to L), and participants were asked to connect the circles by alternating between numbers and letters in ascending order as quickly as possible. Longer completion time indicates poorer attention. Test–retest reliability for Part A ranged from very low (r = .36) among schizophrenia patients to very high (r = .94) among vascular disorder patients. Test–retest reliability for Part B was above .65 among diverse populations (Lezak, Howieson, Bigler, & Tranel, 2012). In HF (n = 21), the 1-week test–retest correlations were .79 for Part A and .81 for Part B (Bauer et al., 2012). Construct validity was supported among people with closed head injury and healthy adults (Shum, McFarland, & Bain, 1990). An fMRI study showed that the test was sensitive to the frontal lobe activation among 12 healthy adults (Zakzanis, Mraz, & Graham, 2005).

Stroop Test This test was to measure the inhibition function of attention and is a well-validated measure of interference (Lezak et al., 2012). In this study, the Stroop Test was programmed for laptop computer use with E-Prime 2.0 software (Psychology Software Tools, Inc., 2012). The test used four colors (red, blue, yellow, and green). Four computer keys on the keyboard were designated for each color. There were two commands, which included reporting the words of the color names (reading the letters) or their print ink colors. Participants were asked to press the key responding to the color names or print colors based on commands. When the color names are not matched to the print colors, the trials are deemed incongruent. A total of 72 trials in three sessions were administered to each participant to be consistent with prior studies (Dixit, Goyal, Thawani, & Vaney, 2012; Hermens & Walker, 2012). Test–retest reliability was satisfactory among healthy young adults (Franzen, Tishelman, Sharp, & Friedman, 1987). Construct validity of the paper version of the Stroop Test was supported when used with traumatic brain injury patients by showing they had impaired performance (Ponsford & Kinsella, 1992). The test was found as sensitive to frontal lobe damage in findings from a meta-analysis (Demakis, 2004).

Attentional Function Index The Attentional Function Index (AFI) is a 13-item self-report questionnaire designed to measure perceived effectiveness of directed attention (Cimprich, 1990; Cimprich, Visovatti, & Ronis, 2011). Participants were

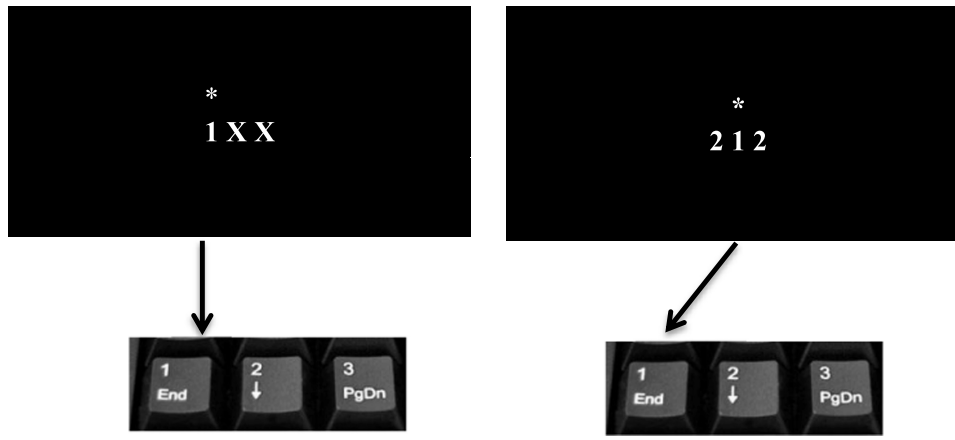

FIGURE 1. Examples of congruent and incongruent trials in the Multi-Source Interference Task.

asked to answer each question about their perceived effectiveness in doing common daily activities that require directed attention. Response scales were from 0 to 10 for each item, and possible scores range from 0 to 130. Higher scores indicate better perceived attention function. Internal consistency was satisfactory among women with breast cancer (Cronbach's alpha = .92). In the current sample of 22 patients with HF and 20 healthy adults, Cronbach's alphas were .81 and .90, respectively. Construct validity was supported among 172 breast cancer women (Cimprich et al., 2011).

Statistical Analysis

Both raw and standardized z scores of the neuropsychological tests were used for analysis in order to examine directed attention coping with the interferences. The z scores were computed by calculating the distance from the mean scores of the pooled sample (patients with HF and healthy adults). Scores that were below zero indicated better performance than average. Separate z scores were computed for error rates and response times, and differences between congruent and incongruent trials were calculated from error rates and response times z scores. The two z scores of the difference, which are interference z scores, were then averaged to provide a single score of performance that differed by the presence of interference, which was the overall interference z score.

Descriptive statistics were computed to summarize sample characteristics. Construct validity was assessed by t tests and correlations (Campbell & Fiske, 1959; Polite & Beck, 2008; Westen & Rosenthal, 2003). Independent t tests were computed to examine differences between patients with HF and healthy adults (Hypothesis 1) and differences of MSIT performance between congruent and incongruent trials (Hypothesis 2). Pearson's correlation coefficients were computed to examine relationships between MSIT and the Trail-Making Test and the Stroop Test, which are theoretically consistent measurements with MSIT (Hypothesis 3). The research question was examined by using Pearson's correlations between MSIT and AFI. All analyses were completed using IBM SPSS 21. The significance level was set at $p < .05$.

RESULTS

The sample characteristics are presented in Table 1. Among patients with HF, age was correlated with MSIT response times in both congruent ($r = .639$, $p = .001$) and incongruent trials ($r = .569$, $p = .006$), but not the error rates. More years of education were associated with lower MSIT error rates in congruent trials ($r = -.491$, $p = .020$).

Hypothesis 1—the worse MSIT performance in patients with HF than healthy adults—was partially supported (Table 2). Specifically, compared with healthy adults, patients with HF had higher MSIT error rates in congruent trials (0.65% vs. 0.05%, $p = .032$) and longer MSIT response times in incongruent trials (1077 ms vs. 701 ms, $p = .029$). However, overall interference z scores from MSIT, which were the differences between congruent and incongruent trials in both error rates and response times, were not significantly poorer in patients with HF compared with healthy adults.

Hypothesis 2—the worse MSIT performance on incongruent trials than congruent trials in patients with HF—was supported. Patients with HF demonstrated significantly better performance on congruent trials compared with incongruent trials in both error rates by 5.4% (0.65% vs. 6.04%, $p < .001$) and response time by 308 ms (769 ms vs. 1077 ms, $p \leq .001$; Table 2). Differences in z scores between congruent and incongruent trials were larger in response times ($M = 0.24$, $SD = 0.87$) than error rates ($M = 0.14$, $SD = 0.97$).

Hypothesis 3—positive correlations between MSIT and the Trail-Making Test as well as the Stroop Test—was partially supported (Table 3). Raw score analysis illustrated that MSIT response times in congruent trials had significantly moderate correlations with Trail-Making Test A ($r = .43$, $p = .045$). Similarly, MSIT incongruent trials response times had significantly moderate correlations with Trail-Making Tests A and B and Trail-Making Test interference z scores that were calculated from differences between Part A and Part B ($r = .47$, .52, and .45, respectively). However, overall interference z scores of MSIT were not significantly correlated with Trail-Making Test interference z scores ($p = .358$) and the Stroop interference z scores ($p = .703$).

For the research question regarding the relationships between the MSIT and AFI, lower MSIT overall interference z scores were moderately correlated with higher AFI total scores ($r = -.50$, $p = .018$). This result means that participants with better MSIT performance had better perceived effectiveness of directed attention. The relationship was more prominent in MSIT response times than error rates (Table 3). Patients with HF had significantly worse AFI scores than healthy adults (84.6 vs. 109.8, $p = < .001$; Table 1).

DISCUSSION

Results of this study were that the MSIT had satisfactory construct validity to examine directed attention function among the sample of patients with HF. The MSIT was sensitive to detect differences in performance between patients with HF and age- and education-matched healthy adults. Healthy adults are known to have better directed attention than patients with HF even after controlling for age and education. Patients with HF performed the test more slowly and had more errors than healthy adults in this study and than healthy young adults from published data (Bush et al., 2003). The response times and error rates among healthy young adults were an average of 479 ms response times and 0.5% error rates in congruent trials and 787 ms response times and 4.1% error rates in incongruent trials (Bush et al., 2003). Patients with HF in this study showed an average of 769 ms response times and 0.65% error rates in

TABLE 1. Descriptive Statistics of Sample Characteristics (*N* = 42)

Characteristic	Total (*N* = 42)	Patients with HF (*n* = 22)	Healthy adults (*n* = 20)	*t* or χ^2 (*p*)
Age, mean (*SD)* in years	58.9 (11.9)	58.9 (12.5)	58.8 (11.6)	0.029 (.977)
Education, mean (*SD*) in years	14.9 (2.2)	14.6 (2.4)	15.3 (2.0)	–1.022 (.313)
MMSE, mean (*SD*)	28.1 (1.7)	27.4 (1.9)	28.8 (1.2)	–2.904 (.006)*
Gender, *n* (%)				0.349 (.757)
Male	21 (52.5)	13 (59)	10 (50)	
Female	19 (47.5)	9 (41)	10 (50)	
Race, *n* (%)				4.171 (.244)
African American	4 (10)	3 (14)	1 (5)	
Asian	2 (5)	2 (9)	0 (0)	
White	35 (83)	16 (73)	19 (95)	
More than one race	1 (2)	1 (4)	0 (0)	
Ethnicity, *n* (%)				0.266 (.876)
Hispanic	2 (5)	1 (5)	1 (5)	
Non-Hispanic	37 (88)	19 (86)	18 (90)	
Unknown	3 (7)	2 (9)	1 (5)	
Marital status, *n* (%)				0.155 (.758)
Married	26 (62)	13 (59)	13 (65)	
Not married	16 (38)	9 (41)	7 (35)	
Employment, *n* (%)				3.536 (.171)
Employed	13 (31)	4 (18)	9 (45)	
Not employed	5 (12)	3 (14)	2 (10)	
Retired	24 (57)	15 (68)	6 (45)	
Handedness, *n* (%)				2.027 (.243)
Right-handed	34 (81)	16 (73)	18 (90)	
Left-handed	8 (19)	6 (27)	2 (10)	
AFI total score, mean (*SD*)	96.6 (21.1)	84.6 (19.9)	109.8 (13.3)	–4.864 (<.001)*
Effective action subscale	52.2 (13.1)	44.3 (12.6)	60.9 (6.4)	–5.460 (<.001)*
Attentional lapses subscale	22.7 (5.9)	20.6 (7.0)	25.0 (3.3)	–2.614 (.014)*
Interpersonal effectiveness subscale	21.7 (6.9)	19.7 (7.3)	23.9 (5.7)	–2.082 (.044)*
Number of people having chronic disease requiring mental efforts, *n* (%)	26 (62)	22 (100)	4 (20)	28.431 (<.001)*
LVEF, mean (*SD*)	—	37.6 (14.5)	—	—
BNP, mean (*SD*)	—	273.0 (328.3)	—	—
NYHA class, *n* (%)	—		—	—
II		9 (41)		
Between II and III		4 (18)		
III		8 (36)		
IV		1 (5)		

Note. AFI = Attentional Function Index; BNP = brain natriuretic peptide; HF = heart failure; LVEF = left ventricular ejection fraction; MMSE = Mini-Mental Status Examination; NYHA class = New York Heart Association classification.

*$p < .05$.

congruent trials and 1077 ms response times and 6.04% error rates in incongruent trials. This worse performance among patients with HF is consistent with previous literature in which different neuropsychological tests were administered (Bauer et al., 2012; Pressler et al., 2010; Vogels et al., 2007). However, when MSIT scores were interpreted with the overall interference *z* scores, which were average scores of error rates and response times differences between congruent and incongruent trials, there was no significant difference between patients with HF and healthy adults. The different results between raw scores and overall *z* scores may be because patients with HF performed worse not only in congruent but also in incongruent trials compared with healthy adults. However, the results need be interpreted cautiously because, first, the sample size was small and the education level in this sample was relatively high; second, poorer directed attention in HF may be not specific or limited to managing interference; and third, there may be the response times and error rates trade-off, which is explained in that participants tend to sacrifice accuracy or do not give the response within time limit (which was 2 seconds in MSIT) in exchange for keeping a similar response time.

TABLE 2. Descriptive Statistics of Multi-Source Interference Task Performances (*N* = 42)

Attention measures	Patients with HF (*n* = 22)	Healthy adults (*n* = 20)	*t*	*p*
Error rates				
Congruent trials, %	0.65 ± 1.21	0.05 ± 0.24	2.279	.032*
Incongruent trials, %	6.04 ± 3.41	4.36 ± 3.72	1.527	.135
Interference *z* score for error rates (Incongruent – Congruent *z* score)	0.14 ± 0.97	–0.16 ± 1.03	0.985	.331
Response times				
Congruent trials, ms	769 ± 130	701 ± 116	1.785	.082
Incongruent trials, ms	1077 ± 132	977 ± 153	2.268	.029*
Interference *z* score for response times (Incongruent – Congruent *z* score)	0.24 ± 0.87	–0.27 ± 1.08	1.684	.100
Overall interference *z* score	0.19 ± 0.77	–0.21 ± 0.85	1.310	.198

Note. HF = heart failure; ms = milliseconds.
*$p < .05$.

In addition, MSIT was valid in detecting worse performance on incongruent trials than congruent trials. Congruent trials did not have any conflicts, so required less directed attention compared to incongruent trials. Contrastingly, incongruent trials were designed to provide conflicts between the target number and the location of the number in order to examine directed attention from the interference. Therefore, different performance was expected between the congruent and incongruent trials as a valid measure of directed attention. Consistent with the previous studies among healthy young adults (Bush et al., 2003; Bush & Shin, 2006), interference produced different performance among patients with HF in this study, as evidenced by 308 ms slower response times on average during MSIT incongruent trials than congruent trials. The magnitude of the differences was more prominent in response times, but clinical importance of the differences of 0.3 seconds in response times and 5% in error rates merits further study.

Relationships between the MSIT overall interference *z* scores and the well-validated attention measures of Trail-Making Test and Stroop Test were not significant. However, there were significant moderate relationships between MSIT raw scores and the Trail-Making Test and the Stroop Test among patients with HF. This finding may be because participants were asked to perform the test as quickly as possible, but accuracy was prioritized over speed. This specific test instruction may result in similar error rates but different response times in MSIT, as shown that there were nonsignificant error rates but significant slower responses times when the test was relatively more difficult in MSIT incongruent trials. Thus, when the scores from error rates and response time were averaged, the significant differences may disappear. The response time and error rate trade-offs were found in a similar test of directed attention, called Attention Network Test, that uses flankers instead of numbers (MacLeod et al., 2010). In the

TABLE 3. Correlations Between the Multi-Source Interference Task and Other Attention Measures in Patients With Heart Failure (*n* = 22)

	MSIT congruent trials raw score *r* (*p*)		MSIT incongruent trials raw score *r* (*p*)		MSIT interference *z* score *r* (*p*)		MSIT overall interference *z* score *r* (*p*)
	Error rates	Response times	Error rates	Response times	Error rates	Response times	
Trail-Making Test A	.26 (.255)	.43* (.045)	–.21 (.340)	.47* (.026)	–.30 (.173)	.12 (.597)	–.12 (.585)
Trail-Making Test B	.28 (.202)	.46 (.303)	.18 (.426)	.52* (.013)	.08 (.734)	.16 (.472)	.14 (.531)
Trail-Making Test interference *z* score (B – A)	.25 (.269)	.40 (.067)	.28 (.207)	.45* (.035)	.19 (.398)	.15 (.507)	.21 (.358)
Stroop, error rates *z* score	.14 (.536)	.33 (.140)	.21 (.357)	.39 (.074)	.16 (.492)	.17 (.450)	.20 (.384)
Stroop, response times *z* score	–.48* (.025)	–.10 (.653)	–.33 (.137)	–.12 (.591)	–.16 (.490)	–.05 (.817)	–.13 (.569)
Stroop, overall interference *z* score	–.22 (.317)	.23 (.311)	–.05 (.823)	.27 (.222)	.03 (.899)	.12 (.598)	.09 (.703)
AFI total score	–.08 (.716)	.05 (.841)	–.42 (.051)	–.14 (.543)	–.39 (.075)	–.45* (.038)	–.50* (.018)
Effective action	–.18 (.421)	.03 (.881)	–.39 (.071)	–.10 (.651)	–.32 (.142)	–.33 (.132)	–.40 (.069)
Attentional lapses	–.05 (.828)	–.07 (.755)	–.27 (.234)	–.23 (.302)	–.24 (.273)	–.40 (.069)	–.38 (.081)
Interpersonal effectiveness	.13 (.551)	.13 (.555)	–.22 (.332)	.02 (.915)	–.26 (.239)	–.26 (.239)	–.32 (.152)

Note. AFI = Attentional Function Index; MSIT = Multi-Source Interference Task.
*$p < .05$.

current study, the direction of the relationship was negative between error rates and response times in MSIT incongruent trials, but not statistically significant (Spearman rho's $r = -.006$, $p = .097$). Among patients with HF with higher error rates of more than 5% ($n = 13$), the directional relationship seemed stronger in graphical analysis but was still not statistically significant.

The MSIT performance scores were moderately and significantly associated with perceived AFI scores in this study. Relationships between performance-based test scores and perceived cognitive effectiveness questionnaire scores have been rarely examined in HF, and this is one of the first studies that examined the relationship in HF. Poor performance on MSIT may indicate that patients may have more difficulties in performing daily cognitive activities, including HF self-care. For example, without directed attention, patient education related to self-care will be more difficult, and following the recommended self-care regimen after the education may not be effective (e.g., controlling daily sodium intake). However, this proposition needs to be confirmed in HF before discussing possible usefulness of MSIT in patient outcomes.

This study has two limitations, with the first limitation being that the small sample, which was justified for only Hypothesis 2 in this study because no prior study examined relationships with other neuropsychological tests, may limit the validity and needs further testing in a larger sample. Second, MSIT may be influenced by computer literacy in this sample with relatively older ages. All patients with HF in this study completed MSIT successfully, but it is possible that different populations may face confounding effects of computer literacy. Although the validity of the MSIT was satisfactory in this study, the test may not be relevant to some people who have vision deficits, severe neuropathy fingers or severe arthritis, or severe cognitive impairment who cannot follow the instructions.

CONCLUSION

Evidence was provided to support construct validity of MSIT in patients with HF to examine directed attention dealing with interferences. Analyzing both raw scores and interference z scores of MSIT is suggested to examine directed attention based on this study. In the clinical setting, there are always multiple stimuli that compete with information or cognitive processes, and directed attention plays an important role in those situations. Measures examining directed attention such as MSIT should be included in addition to attention measures examining other dimensions of attention. Investigating associations of MSIT with behavioral changes, for example, HF self-care activities, would be merited in future studies.

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