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## CLINICAL PSYCHOLOGY & NEUROPSYCHOLOGY | RESEARCH ARTICLE

# Role of inner speech on the Luria hand test

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**Abstract:** This study was conducted to investigate the psychological characteristics of the Luria hand test (LHT), a well-known neuropsychological assessment. We investigated the role of inner speech in LHT using the dual-task paradigm. Additionally, we investigated the relation between LHT and Wechsler Memory Scale—Revised (WMS-R) scores. Performance of the 21 university student participants on the LHT decreased significantly in the articulatory suppression condition, but not in spatial suppression. This result indicates that the inner speech or phonological loop of working memory plays an important role in the LHT. Moreover, only the verbal memory score of the WMS-R was correlated significantly with LHT performance. Based on these results, psychological characteristics of the LHT were discussed.

**Subjects:** Child Neuropsychology; Clinical Neuropsychology; Neuropsychological Rehabilitation; Cognitive Psychology

**Keywords:** Luria hand test (LHT); inner speech; Wechsler Memory Scale—Revised (WMS-R); working memory; dual task

### 1. Introduction

The Luria hand test (LHT; Luria, 1966) is a well-known neurological assessment developed originally by AR Luria, a distinguished neuropsychologist influenced by the theory of LS Vygotsky. In the LHT, participants must reproduce sequenced movements made by the examiner with their hands, such as a “fist–edge–palm”. The Frontal Assessment Battery (FAB), a well-known bedside neurological

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### PUBLIC INTEREST STATEMENT

The Luria hand test (LHT; Luria, 1966), a well-known neurological assessment, has been regarded as a non-verbal test of serial recall. This study investigates the role of inner speech in the LHT using the dual-task paradigm. The LHT is administered under three conditions: control, under articulatory suppression, and under spatial suppression. In the “control condition”, participants are asked to reproduce sequenced movements made by the examiner such as a “fist–edge–palm”. In the “articulatory suppression” condition, participants are asked to reproduce sequential movements, but they are also required to repeat an irrelevant letter. In the “spatial suppression” condition, participants are required to do visually guide sequential tapping when the examiner presents the hand movements. Results indicate that inner speech and kinesthetic information plays an important role in performing the LHT.

assessment, includes the LHT (Dubois, Slachevsky, Litvan, & Pillon, 2000). The LHT score has long been regarded as sensitive to frontal lobe lesions (Christensen, 1979; Luria, 1966). Patients with frontal lobe lesions without palsy were unable to reproduce movements in the same order. They sometimes repeated the same error. Based on these clinical findings, the LHT is regarded as a test of executive or prefrontal function. Moreover, it presumably requires planning and shifting capability (Weiner, Hynan, Rossetti, & Falkowski, 2011). Additionally, the LHT is used in the field of clinical child psychology. The Kaufman Assessment Battery for Children-2 (KABC-2; Japanese KABC-2 Publication Committee, 2013), a well-known and globally used cognitive assessment for children, includes the LHT. The KABC-2 comprises four components: sequential processing, simultaneous processing, planning, and learning. The factorial validity of the KABC-2 has been confirmed (Japanese KABC-2 Publication Committee, 2013). The LHT belongs to the “sequential processing” component together with the number recall task and word order task. These three tasks are regarded as having the same psychological characteristics, involving short-term memory (i.e. the LHT assesses the capacity of visuospatial short-term memory, whereas the other two tests assess the capacity of phonological or auditory short-term memory) and control of sequential mental activity to complete serial recall (Japanese KABC-2 Publication Committee, 2013).

Regarding current cognitive neuroscience, some empirical studies have revealed the importance of inner speech, which is speech without actual articulation, for various higher cognitive functions (Alderson-Day & Fernyhough, 2015). According to an influential theory underpinning Soviet psychology presented by Vygotsky, self-regulating skills originate from interpersonal linguistic interactions early in life (Alderson-Day & Fernyhough, 2015; Hirata, Okuzumi, & Kokubun, 2016; Vygotsky, 1962). Such interpersonal dialog gradually becomes internalized dialog: inner speech. Actually, inner speech is regarded as a tool used to facilitate various voluntary mental activities such as memory, attention, and thinking. A comprehensive review is available in the literature (i.e. Alderson-Day & Fernyhough, 2015). In Baddeley’s multi-component model of working memory, such inner speech is presumably based on functions of the phonological loop, which is responsible for the temporary storage of speech-like information (Baddeley, 2007). In fact, some reports have described that when functions of the phonological loop are interfered with, such as under the articulatory suppression condition, a person’s performance of several complex cognitive tasks is decreased (e.g. cognitive switching task, Emerson & Miyake, 2003; cognitive planning, Wallace, Silvers, Martin, & Kenworthy, 2009). Articulatory suppression is the experimental condition under which the phonological loop capacity is loaded (Baddeley, 2007; Williams, Peng, & Wallace, 2016). However, no report of the relevant literature describes an investigation of the role of phonological loop in the LHT. Reports of earlier studies have characterized LHT as a non-verbal test of serial recall (Japanese KABC-2 Publication Committee, 2013; Weiner et al., 2011). Based on these reports, some authors claimed the LHT as suitable for children with language impairment (Japanese KABC-2 Publication Committee, 2013). If the phonological loop or inner speech plays an important role in LHT, however, this view that the LHT is a non-verbal test of serial recall must be improved. It is reasonable to assume that inner speech is used as a verbal cue to memorize sequential hand movements such as a “fist-edge-palm” in the LHT.

This study uses the dual-task paradigm (Emerson & Miyake, 2003) to investigate the role of inner speech on the LHT. The LHT is administered under three conditions: control, under articulatory suppression, and under spatial suppression. In the control condition, participants are required to perform the LHT under normal circumstances. In the “articulatory suppression” condition, they are asked to reproduce sequential movements, but they are also required to repeat an irrelevant letter when the examiner presented hand movements. Therefore, participants must memorize the sequence of hand movements without using the phonological loop. If participants use inner speech when performing the LHT, then articulatory suppression can be expected to diminish the LHT performance. In the “spatial suppression” condition (Holland & Low, 2010), participants are required to do visually guided sequential tapping when the examiner presents the hand movements. Therefore, participants are asked to memorize the hand movement sequence without using visuospatial short-term memory. This condition reveals that the negative effect of articulatory suppression

differs from failure of attentional control on a dual task. Moreover, if participants rely on the visuospatial short-term memory when performing the LHT, then spatial suppression is expected to diminish the LHT performance more than under the control condition.

This study also investigated the relation between the LHT and Wechsler Memory Scale—Revised (WMS-R; Japanese WMS-R Publication Committee, 2001), a well-known comprehensive memory assessment battery. As described above, the LHT is believed to have a visuospatial short-term memory task aspect. The relation between the LHT and other visuospatial short-term memory tests, however, has not been well investigated. The WMS-R can assess the capacity for verbal–auditory memory and visual memory. The LHT’s validity as a visuospatial short-term memory test might increase when the visual memory score of the WMS-R is correlated with the LHT.

To summarize, this study was designed to investigate the relation between inner speech or phonological loop of the working memory and the LHT using the dual-task paradigm, and to clarify what individual differences in the WMS-R are interrelated most strongly with LHT performance. We expect that the LHT performance decreased in both articulatory suppression and spatial suppression conditions, and that the visual memory score of the WMS-R is related closely with LHT performance.

## 2. Methods

### 2.1. Participants

Participants were 21 right-handed university students (6 men, 15 women; mean age  $21.8 \pm 2.9$  years), none of whom reported any neurological or psychiatric disorder or any physical difficulty. The test purpose was explained to each. Only participants who consented freely and voluntarily to participate were included. Ethical approval for the study was obtained from the Research Ethics Board at Tokyo Gakugei University.

### 2.2. Materials

#### 2.2.1. Luria hand test (LHT)

According to numerous previous studies related to the LHT (Dubois et al., 2000; Japanese KABC-2 Publication Committee, 2013; Weiner et al., 2011), stimuli of three kinds were used: fist, edge, and palm. The “fist” is presented as a hand closed tightly with the fingers bent against the palm. The “edge” is a vertical chopping motion with the hand on a table. The “palm” is the palm down with fingers extended together.

#### 2.2.2. Wechsler Memory Scale—Revised (WMS-R)

The Wechsler Memory Scale—Revised is used to assess general memory skill. This test, which can assess the memory capacity of adults aged 16–74 years, consists of 13 sub-tests that make up total memory and two sub-component scores such as verbal and visual memory. The verbal memory component includes two tasks: a text memory task (logical memory) and a word-paired memory task (verbal paired associates). In these two verbal memory tasks of the WMS-R, each verbal stimulus was presented with no visual cue. The visual memory component includes three tasks: memorizing a geometrical figure (figure memory), drawing of a memorized geometrical figure (visual recall), and memorizing a combination of a geometrical pattern and a color task (visual paired associates).

### 2.3. Procedure

Each participant was assessed in two sessions. The LHT was administered to participants in the first session and the WMS-R to the second. The WMS-R was conducted on another day. These sessions were conducted in a private room at Tokyo Gakugei University.

#### 2.3.1. Luria hand test (LHT)

In this study, the LHT was administered under the following three conditions. Under the “control condition”, participants, with their preferred hand, were asked to reproduce sequenced movements

made by the examiner such as a “fist–edge–palm”. In the “articulatory suppression” condition, they were asked to reproduce sequenced movements, but they were also required to repeat an irrelevant Japanese vowel sound (e.g. a-i-u-e-o, pronounced ah, ee, oo, ay, oh) when the examiner presented the hand movements. In the “spatial suppression” condition (Holland & Low, 2010), when the examiner presented the hand movements, participants were required to tap five red marks sequentially, as in a figure eight, on the desk inside their visual field. In the two dual-task conditions, such as under articulatory and spatial suppression, participants first practiced articulating or tapping in time with a 1 Hz electrical metronome beat. The experimenter checked that participants did not deviate from the metronome beat when carrying out the articulation or tap in each condition.

The presented stimulus sequences were increased from 2 to 6. The stimuli were not reinforced by counting along with each stimulus, or by saying “rock, scissors, and paper” in Japanese. The fist is the same as the rock. The palm resembles the paper using the game of “rock, scissors and paper”. However, the stimuli were never named by the experimenter in this measurement. For this study, the number of sequences was defined as the stimulus span. Each stimulus span comprised two trials: The second trial was presented after participants completed the first trial. Three sets of each stimulus span were prepared using the Japanese version of the KABC-2 test manual (Japanese KABC-2 Publication Committee, 2013) as a reference. According to the Japanese version of the KABC-2, a participant was given problems of increasing stimulus span within each condition, starting with two-sequential problems, and increasing up to six-sequential problems. Measurements were taken first with one of the three conditions: control, articulatory, and spatial suppression. Measurements for the second condition were taken when measurements under the first condition had finished. The third condition was conducted after finishing measurements under the second condition. Measurements were taken in respective conditions in random order for each participant.

According to Conway et al. (2005), the weighted score of each condition was calculated following the procedures described hereinafter. If two trials of each stimulus span were reproduced in the correct order, then a participant was awarded 1 point. If only one trial was reproduced correctly, a participant was awarded .5 points. Zero points were given if neither trial was reproduced correctly. These points were multiplied by a fixed numerical value of each stimulus span: a two-stimulus span was 1, a three-stimulus span was 2, a four-stimulus span was 3, a five-stimulus span was 4, and a six-stimulus span was 5. The sum of these calculated values was used as the participant’s representative value of each condition. These scores were 0–15.

#### 2.3.2. Wechsler Memory Scale—Revised (WMS-R)

According to the Japanese version of the test manual, the WMS-R was conducted. A norm attached to the test manual (Japanese WMS-R Publication Committee, 2001) was used when raw scores were converted to standard revised scores. The standard revised scores (mean of 100; standard deviation of 15) were calculated for two components such as verbal and visual memory.

#### 2.4. Statistical analysis

Software (SPSS ver. 22.0; SPSS Inc.) was used for statistical analyses. Significance was inferred for  $p < .05$  in all analyses. Analysis of variance (ANOVA) was used to analyze the LHT weighted score of each condition. When differences between conditions were significant, the data were subjected to *post hoc* analysis using Bonferroni’s test. Differences between standard revised scores of the WMS-R were also examined using *t*-tests for dependent groups. Pearson’s correlation was used to analyze the relation between scaled measures such as the LHT’s weighted score of each condition and two WMS-R’s standard revised scores. A Bonferroni-adjusted test of significance was used for this correlation analysis.

### 3. Results

Table 1 presents descriptive statistics of each measure. One-way ANOVA revealed a significant difference among the three conditions of the LHT ( $F_{2,40} = 22.510, p < .001, \text{partial } \eta^2 = .530$ ). Post-hoc analysis also revealed that the score of the articulatory suppression condition ( $M = 6.76, SD = 2.72$ )

**Table 1. Means and standard deviations of respective tasks**

					Post hoc test	
		Score	F	p	Control	AS
LHT	Control	11.23 (3.78)	22.51	< .001		
(Weighted score)	Articulatory suppression (AS)	6.76 (2.72)			p < .001	
	Spatial suppression (SS)	9.98 (2.70)			p = .059	p < .001
			t	p		
WMS-R	Verbal memory	101.00 (11.88)	1.45	.161		
(Standard revised score)	Visual memory	106.29 (11.13)				

was significantly lower than those of the other two conditions. No significant difference was found between the control (M = 11.23, SD = 3.78) and spatial suppression condition (M = 9.98, SD = 2.70). Averages of each standard revised score of the WMS-R were around 100. The mean memory capacities of the present sample were of an age appropriate level. The verbal memory score of the WMS-R was not significantly different from the visual memory score ( $t(20) = 1.454, p = .161, \text{partial } \eta^2 = .096$ ).

Table 2 presents correlation matrices of the measures. The LHT score of the control condition was correlated significantly and positively with the verbal memory component of the WMS-R ( $r = .803, p < .001$ ). Higher LHT scores of the control condition were associated with higher verbal memory scores. The LHT score of the spatial suppression condition was correlated significantly and positively with the verbal memory score of the WMS-R ( $r = .717, p < .001$ ). However, the LHT score of the articulatory suppression condition was not correlated significantly with the verbal memory score of the WMS-R ( $r = .202, p = .381$ ). Moreover, the visual memory score of the WMS-R was not correlated significantly with each LHT score (Control:  $r = .134, p = .562$ , articulatory suppression:  $r = .129, p = .579$ , spatial suppression:  $r = .093, p = .688$ ). Finally, the LHT score of the control condition was correlated significantly and positively with the score of the spatial suppression condition ( $r = .803, p < .001$ ).

**Table 2. Pearson's correlation between respective scores**

	1	2	3	4	5
1. LHT control	-				
2. LHT articulatory suppression	.286	-			
3. LHT spatial suppression	.803*	.402	-		
4. WMS-R verbal memory	.803*	.202	.717*	-	
5. WMS-R visual memory	.134	.129	.093	-.046	-

Note: Significance cutoffs are based on adjusted  $p$  values. For this set of results, the Bonferroni adjusted  $p$  value cutoff is .005 (.05/10).

\*Denote correlations that are significant at this level.

#### 4. Discussion

This report is the first ever of a study investigating the role of inner speech in LHT. As described in the *Introduction*, the LHT has been regarded as a non-verbal test of serial recall (Japanese KABC-2 Publication Committee, 2013; Weiner et al., 2011). Results of this study, however, indicate that the inner speech or phonological loop of the working memory plays an important role in the LHT. Performance on the LHT was significantly lower in the articulatory suppression condition, but not in the spatial suppression condition. The patterns of these results were consistent with findings of earlier studies that clarified the role of inner speech in several higher cognitive functions using the dual-task paradigm (Alderson-Day & Fernyhough, 2015). Results of this study also suggest that the LHT does not strongly require visuospatial short-term memory in typically developed adults.

In this study, articulatory suppression was applied to the memorizing phase of the presented stimuli. Participants had to memorize the sequence of hand movements without using the phonological loop in the articulatory suppression condition. If the phonological loop was used normally, then the presented stimuli might be labeled verbally in the memorizing phase. Emerson and Miyake (2003) reported that such sub-vocal verbal coding process, i.e. inner speech, helped to produce various motor actions. Articulatory suppression is thought to disrupt this process and thereby decrease LHT performance. However, the stimuli of this study were presented to each participant without naming by the experimenter. Probably, participants *spontaneously* labeled the stimuli, perhaps as “rock”, “scissors”, and “paper”. As described in *Methods*, the “fist” of the LHT is the same as a “rock”, and “palm” resembles a “paper” gesture used in the “rock, scissors and paper” game. The game is widely known, not only among Japanese children but also among adults. One can reasonably infer that a verbal labeling strategy using this strong stereotyped rule occurred spontaneously in our participants. Actually, some study participants described that they used this verbal labeling strategy of the “fist” labeled as “rock”, the “palm” as “paper”, and the “edge” as “scissors”. It is particularly interesting that the “edge” of the LHT does not look at all like “scissors”. Unfortunately, we did not conduct this interview for all participants. We conducted this interview of nine participants. All nine reported that they used a verbal labeling strategy using the “rock, scissors and paper”. To clarify details related to this point, a spontaneous naming task of stimuli used in the LHT should be conducted. Based on this consideration, one can reasonably infer that verbal serial recall is necessary to complete the LHT, i.e. the LHT seems to have a verbal sequential memory task aspect.

The spatial suppression did not diminish LHT performance significantly in this study. This result implies that visuospatial short-term memory plays no important role in the memorizing phase of the LHT. The LHT and WMS-R relation apparently supports this view, as discussed below. Contrary to our assumption, the visual memory score of the WMS-R was not correlated significantly with LHT performance. Only the verbal memory score was correlated significantly with LHT performance for the control and spatial suppression conditions. We first discuss the relation between LHT performance under the control condition and the verbal memory score of the WMS-R. As described in the *Introduction*, the LHT belongs to the “sequential processing” component together with the number recall task and word order task in the KABC-2. The number recall and word order tasks of the KABC-2 resemble a text memory task that consists of the verbal memory component of the WMS-R. Such similarity of verbal memory tasks might be the reason that the verbal memory score of the WMS-R was correlated significantly with LHT performance under the control condition. These tasks conducted in this study were regarded as having the same psychological characteristics, such as control of sequential mental activity to complete the verbal serial recall. It might be said that this result replicates those of an earlier study that confirmed the factorial validity of the KABC-2 (Japanese KABC-2 Publication Committee, 2013). However, the definition of the LHT as a non-verbal test of serial recall (Japanese KABC-2 Publication Committee, 2013; Weiner et al., 2011) must be improved. As described above, we assume that our participants spontaneously labeled each stimulus verbally in the LHT. The relation between LHT performance and the verbal memory score of the WMS-R also suggests that this tendency of using a spontaneous naming strategy to memorize presented stimuli might rely on a participant’s verbal short-term memory capacity.

It is noteworthy that performance under the articulatory suppression condition is not correlated with the verbal memory score. This result implies that the LHT under this condition assessed another type of short-term memory: not verbal sequential memory. We assumed that articulatory suppression prevents the participation of inner speech or of the phonological loop of working memory when one takes the LHT. The LHT score obtained under articulatory suppression was low, but it was not zero. What sensory information was used to execute this condition? One possibility is that kinesthetic information plays an important role. The LHT is performed according to a participant's motor action. The kinesthetic information is necessary to produce the motor action (e.g. Latash, 2008). It is likely that participants used not only inner speech but also kinesthetic information to memorize the sequenced hand movements of the LHT. If so, it is not surprising that the LHT score under articulatory suppression was not zero. The characteristics of the kinesthetic short-term memory, unfortunately, have not been fully investigated (Baddeley, 2007). Investigation of the LHT performance under tourniquet ischemia, an artificial condition used for partial blocking of afferent kinesthetic information from the arm (e.g. Kouzaki & Masami, 2008), is necessary to confirm this hypothesis.

If information of only two kinds, such as inner speech and kinesthetic information, plays an important role in performing the LHT, then there is no wonder that the visual memory score of the WMS-R was not correlated strongly with LHT performance. Additionally, it is reasonable to infer that the verbal memory score of the WMS-R was correlated significantly with LHT performance under spatial suppression. These results suggest that LHT under the control and spatial suppression condition has the same psychological characteristics that inner speech and kinesthetic information used in the memorizing phase of the presented stimuli. The significant relation between the LHT score of the control and spatial suppression condition support this view. Visuospatial short-term memory reportedly plays no important role in LHT performance. However, it is noteworthy that memory task characteristics are included in the visual memory component of the WMS-R. No task conducted in this component of the WMS-R can assess the sequential aspect of the visuospatial memory. Della Sala, Baddeley, Allamano, and Wilson (1999) reported a discrepancy between non-sequential visuospatial memory and sequential visuospatial memory. The non-sequential visuospatial memory can be assessed using a pattern span task resembling the tasks conducted in the visual memory component of the WMS-R. Moreover, sequential visuospatial memory can be assessed using the Corsi span task. The relation between the LHT and the Corsi span task must be investigated. Baddeley (2007) pointed out that few attempts have modeled serial recall using visuospatial or kinesthetic information. We expect to examine this issue in future studies.

Finally, a visually guided tapping task conducted in the spatial suppression condition seemed to use the kinesthetic information from the upper arm in addition to visuospatial information. Why did this concurrent task not interfere with the LHT performance? The kinesthetic information from each digit and forearm might have an important effect on the LHT. Differences between the role of kinesthetic information related to the LHT and visually guided tapping task must be investigated.

#### 4.1. Limitations

The small sample used for this study limits its generalizability. New insights into the psychological characteristics of the LHT, however, were obtained from this pioneer work. Future study will be necessary to take larger-scale measurements and to assess the reliability and generalizability of this study. Moreover, the sex ratio of participants was not equal in this study. After resolving this point, gender differences in the LHT performance must be investigated using the dual-task paradigm. Finally, the spontaneous naming task of stimuli used in the LHT should be conducted along with the LHT and other memory tests that can assess visuospatial sequential memory.

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### Competing interests

The authors declare no competing interest.

### Erratum

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