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ARTICLE

Embodied interaction: Learning Chinese characters through body movements

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Abstract

This experimental study examined the design and effectiveness of embodied interactions for learning. The researchers designed a digital learning environment integrating body joint mapping sensors to teach novice learners Chinese characters, and examined whether the embodied interaction would lead to greater knowledge acquisition in language learning compared to the conventional mouse-based interaction. Fifty-three adult learners were randomly assigned to experimental and control groups. The study adopted a pretest, an immediate posttest, and a delayed posttest on knowledge acquisition. Although higher scores were found for the embodied interaction group in both posttests, only the delayed posttest showed a statistically significant group difference. The findings suggested that active embodied actions lead to better knowledge retention compared with the passive visual embodiment. The body-moving process works as an alternative and complementary encoding strategy for character understanding and memorization by associating the semantic meaning of a character with the construction of a body posture.

Keywords: *Embodied Interaction, Language Learning*

Language(s) Learned in This Study: *Chinese*

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Introduction

The fast development of new technologies in recent years has empowered and transformed many human activities like those in the educational sectors. Devices like the Microsoft Kinect enable users to control computer systems with the limbs, torso, or full bodies without a keyboard and mouse, which, from the human computer interaction (HCI) point of view, is regarded as a means of embodied interactions (Dourish, 2004; Tan & Chow, 2018). In the context of learning and instruction, this implies that learners may interact with computer-mediated learning materials via body movements. Such a learning experience, in this study, is described as embodied interactive learning or learning through embodied interactions.

People use gestures to express ideas and convey information in daily conversations. McNeill (1992) defined gestures as hand and arm movements within a certain space—between the shoulders, and from the waist to the eyes, which formed a virtual box shape. Roth (2001) regarded gestures as movements of the limbs, face or other parts of the body, which came together with verbal or non-verbal instructional communications. Gestures, in a broader sense, refer to movements originating from any part of the human body, for which the effective physical space would be that where any part of the body could reach. Based on this perspective, gestures and locomotion to construct a posture are regarded as body movements, which are the major means for the embodied interactions in this study. The terms of gestures and body movements are used interchangeably in this paper. Over the past decades, researchers have been interested in what role body movements play in learning and instructional activities, and how they achieve that role. Early studies of body movements for learning typically took place in a face-to-face classroom setting without the involvement of computers, and both learners and instructors interacted in the same physical place concurrently (e.g., Valenzeno et al., 2003; Broaders et al., 2007; Cook & Goldin-Meadow, 2006; Cook et al., 2010; Roth, 1994, 2001). In some recent studies, learners used mice, keyboards, or joypads to control avatars, and the researchers argue that this kind of virtual and visual embodiment also helped language learning (Pasfield-Neofitou et al., 2015; Repetto et al., 2015).

In the field of language learning and technology, researchers and practitioners have been trying to understand elements of languages and apply technology to enhance the instruction and learning of languages. For example, Chinese characters are significantly different from the Latin alphabet. They are hieroglyphic, which means that the formation or the shape of a Chinese character may come from the content that it represents. A particular character may be a metaphor or representation of a concept/story by itself. There are three major components of a character, graphic (the shape), semantic (the meaning), and phonology (the sound or pronunciation) (Shen, 2004; Xu et al., 2013), of which the first two are of interest in this study. Since body movements may represent and metaphorize concepts and ideas, it is hypothesized is that embodied interactions should help to connect the graphic and semantic features of characters. Yang et al. (2017) decomposed some Chinese characters into strokes (basic components of a character), or "alphabets" as they wrote in the paper, and associated them with gestures. They used Kinect to encourage students to use such gestures to memorize the strokes, and tested how much students could remember the composition of the characters. Results showed that students in the Kinect group performed significantly better in remembering components of the characters than those using tablets to learn the same content, and the tablet group was significantly better than those in a traditional classroom.

In learning activities that involve embodied interactions, body movements may be performed by either the instructor or the learners. From the learner's point of view, embodied interactive learning can be categorized into two genres. One genre is passive embodiment, in which a learner watches body movement made by others and such movements are the means of instruction. In passive embodiment, learners are receivers of information that is transmitted through visual stimulation by others' body movements. Studies reported by Chang et al. (2013), and Alibali and Nathan (2007) belong to this genre and show that an instructor's or a peer's gestures can gain the learners' attention, help information encoding, and facilitate information communication. The other genre is active embodiment, where a learner constructs and manipulates his/her own body movements. In active embodiment, body movements are part of the learning activities and help a learner to encode information, concretize information, and construct multimodalities to facilitate the cognitive processes in an active way (e.g., Johnson-Glenberg et al., 2014; Johnson-Glenberg & Megowan-Romanowicz, 2017; Lan et al., 2018; Parmar et al., 2016; Radu & Antle, 2017).

In recent studies that compared passive and active embodiments, mixed research results were reported. For instance, in Johnson-Glenberg and Megowan -Romanowicz (2017), there was no statistical difference in the text-based posttest performance between the active embodiment group (moving to control the learning animation) and the passive embodiment group (watching on-screen animations by only mouse-clicking a play-stop button). In the study of Lan et al. (2018), the passive embodiment (watching avatar move on screen) led to significantly better language learning effects than the active embodiment (moving students' own body) did for students with low English-as-a-second-language (ESL) skills. Extending prior research on active and passive embodiments and comparing the two means purposefully, the researchers of this study aim to answer the research question: Will active embodied interactions, enabled by the Kinect, lead to greater recognition of Chinese characters in a virtual learning environment compared to mouse-based interactions (passive embodiment) for the adult learners?

By employing Kinect, the embodied designs in this study required a learner to actively move the whole body including arms and legs to interact with the learning materials for the experimental group, while the control group simply used the mouse to click forward buttons to passively watch the instructional materials. With purposeful technical and instructional designs, the active embodied interactions in this study are closely related to the learning content, and are expected to balance the sensory and motor information to encode the concepts and to externalize the abstract ideas.

Literature Review

Degrees of Embodied Learning Interactions

Researchers in the embodied cognition community assert that body movements incorporate people's thoughts, ideas, and content knowledge, and situate them through the interaction with physical environments. Instruction and learning are mediated by and embedded in body movements, which include gestures, formation of body postures, and other manipulations of the body. Body movements embody the corresponding content by externalizing the intrinsic sensations and perceptions that construct knowledge and cognition (Anderson, 2003; Wilson, 2002; Wilson & Foglia, 2011). Understanding of the world is situated in the interactions with the world through body movements—indicators of the mental representation of the outside world that is being embodied (Nemirovsky & Ferrara, 2009). The connection between the body and the environment contributes to meaning making (Anderson, 2018).

Johnson-Glenberg et al. (2014) developed a spectrum specifying four degrees of embodiment in learning technology according to the amount of motoric engagement, gestural congruency, and perception of immersion (Johnson-Glenberg et al., 2014). In their taxonomy, the fourth degree features the highest level of embodied interactive learning. In this level, learners engage themselves in the learning environment with extensive motoric applications. The embodied interactions are designed to be highly congruent to the learning content. The learners perceive a high sense of immersion. In contrast, in the first degree of embodied learning, learners have limited movements of body parts which are normally irrelevant to learning content, often watching or observing videos or simulations, and feel little immersiveness. The second and third degrees of embodied learning are on the spectrum between the first and fourth degree, depending on the extent to which the body movements are involved in learning and are related to the learning content. In a later study, Johnson-Glenberg and Megowan-Romanowicz (2017) further clarify the construct magnitude within the degrees of embodiment. Based on the Johnson-Glenberg et al. (2014), and the Johnson-Glenberg and Megowan-Romanowicz (2017) taxonomy, we classify the embodied interactions into three categories—high, medium, and low body involvement. In the high degree of embodied interaction, body movements are closely related to what the learners are going to learn; and it is opposite for the low degree of embodied interaction.

Body Movements and Cognitive Processing

Body movements can enhance information encoding and retention. Barsalou (2008, 2010) reported that body movements in instructional settings activate cognitive processing of abstract concepts for the learners. Situated body movements ground a learner's experiences and cognition, and prompt recall of prior incidents and cognition. Body gestures and movements also link former experiences to the current situation, and reapply them for future cognitive activities and practices (Barsalou, 2010; Kontra et al., 2015; Mizelle & Wheaton, 2010; Radu & Antle, 2017). Chang et al. (2013) did a small-scale study on gestures that mimicked typical body movements representing eight categories of intelligences, such as musical, interpersonal, and kinesthetic ones (e.g., playing the violin, waving hands to someone, and dribbling a basketball). The researchers examined 16 college students' immediate and delayed retention of those concepts linked to gestures, and found that the gesture-based multimedia presentation had positive effects on learners' performance in concept retention. In an earlier article, Cook and Goldin-Meadow (2006) examined how children, using gestures, solved math problems adding three integral numbers together with both equivalent and nonequivalent addends on two sides of the equation. One of the findings of Cook and Goldin-Meadow (2006) was that children gesturing in the learning activities were more likely to retain and generalize knowledge than those not gesturing.

Lee et al. (2012) helped 39 non-English speaking college students learn conversational English in a simple computer learning game. The researchers prompted students to interact with the in-game virtual characters using body gestures like hand raising, waving, pointing, and so on. Lee et al. (2012) noticed that body motions involved in authentic learning experiences could increase enjoyment and sense of authenticity, which was a positive factor facilitating cognitive activities. The researchers further pointed out that embodied interactions in the game-like scenario felt more realistic to the learners, and motivated students to learn. Hung and Chen (2018) applied the latest joint-capturing device to enable 30 participants to interact with a video lecture on a general medical topic with their body gestures, and found that these participants did better on a content comprehension test than their 30 counterparts who simply watched the video lecture. The researchers attributed these results to the learning clues and well-balanced cognitive load that the gestures had brought to the learning process.

A review of related studies indicates the following roles of body movements in cognition during learning. First, body movements motivate a learner (Lee et al., 2012; Vrellis et al., 2014), inspire a learner's cognitive activities (Gallagher & Lindgren, 2015; Lindgren, et al., 2016), and help a learner recall experiences and prior knowledge to trigger the transfer between real-life and to-be-learned knowledge (Lee et al., 2012; Chao et al., 2013). Second, body movements help learners encode and reinforce content knowledge. For those items that are encoded through gestures, learners can access and apply them more frequently in memory. Gesture production may inspire learners to form metaphoric representations that can later be accessed (Cook & Goldin-Meadow, 2006; Weisberg & Newcombe, 2017). Certain gestures help learners strengthen the connections between concepts and emotions via externalized movements (Lee et al., 2012). Third, body movements facilitate the transfer between the concrete or observable and the abstract by creating representations that link content knowledge to a learner's perception and cognition. Body gestures serve as metaphors, and enrich knowledge representations, thus promoting information encoding and retention (Gallagher & Lindgren, 2015; Weisberg & Newcombe, 2017).

Body Movements Contribute to Multimodality in Language Learning

A learner normally employs multimodal channels in cognition processes, such as visual, auditory and kinetic channels. Based on the dual coding theory (Clark & Paivio, 1991), if we encode information in both verbal and non-verbal modalities, learning may be reinforced. Body movements, as a typical non-verbal modality, can serve to compensate for the verbal modality and enhance the learning experience. Tran et al. (2017) argued that the interlinked information about the concrete world consists of both perceptual features and action-related properties, and then "during later retrieval, the activation of one feature" will facilitate "the activation of associated features" (p. 11).

Macedonia and Knösche (2011) showed that during language learning, learners had better memory for words encoded with gestures, and they tended to use the words encoded through gestures more frequently when making new sentences. Gestures act as another source of modality for students to encode and retrieve words they learn. In a later article, Macedonia and von Kriegstein (2012) conducted a comprehensive review and asserted that gestures enhanced foreign language learning. They noticed that body gestures were closely related to novel words, and the sensory motor image formed by a learner's body movements could enrich memory coding in a complex and deep way. They further stated that forming a "complex code involving sensory and motor information is deep and so improves retrievability and resistance to decay" (Macedonia & von Kriegstein, 2012, p. 397). Lan et al. (2018) taught 69 elementary students English listening comprehension utilizing embodied learning strategies. They acknowledged the positive impact of embodiment on the language learning process by enhancing students' attentional control with English phrases taught during the process. In Hsiao and Chen (2016), the researchers taught six English words for six different colors to 105 preschoolers with either an embodied or non-embodied approach. Study results showed that students experiencing the embodied approach performed significantly better. The researchers argued that the students managed to combine the body movements and learning material for better understanding. Pasfield-Neofitou et al. (2015), through two case studies on foreign language (Chinese) learning in Second Life, reported that embodiment learning had positive effects on the vocabulary learning.

Embodied Learning Interactions: DIY or Just Watching

Past studies consisted of both active and passive embodiment, with varied degrees of embodied interactions. In the context of this study, we regard 'do-it-yourself' (DIY) body movements which require the actual locomotion of a learner to experience the instruction as active embodiment; conversely, those embodied interactions that do not originate from the leaner, are regarded as passive embodiment. In the latter situation, a learner normally just watches the body movements of an instructor (humans or animated figures) or simply clicks the mouse button to trigger someone or something on a screen to move. In early studies without computers, researchers tended to utilize passive embodiment with medium or low body involvement. Recent researchers have been exploring both active and passive embodiments with medium or high body involvement with the help of modern ICT, like the Kinect.

Repetto et al. (2015) simulated body movements for the Czechish language learning in a virtual environment. The researchers recruited 42 adult volunteers to learn fifteen Czechish verbs in a virtual park explored via a head mounted device. The participants in the experimental group used a game-like joypad to direct their virtual bodies to move within the virtual park, while the baseline groups simply listened to the instruction while in the virtual park. The results showed the experimental group had better recognition rate of Czechish verbs than the control group did. The aforementioned Pasfield-Neofitou et al. (2015) study employed virtual embodiment (controlling the movements of avatars) and provided evidence that there were positive effects on the vocabulary learning. Hung et al. (2015) applied active embodied interactions using Kinect to teach 60 college students the procedural knowledge for flag semaphore. The learners interacted directly with the learning material using their body movement. The researchers found better performance in semaphore-message sending in the experimental (embodied interactions + storyline) group than the baseline (embodied interactions only) group. In the Yang et al. (2017) study mentioned above, the researchers decomposed some Chinese characters into strokes (basic components of a character), or "alphabets" as they put in the paper, and associated them with certain gestures. The researchers used Kinect to encourage students to use gestures to memorize the orders and relations among these strokes of Chinese characters, and tested how well students remembered the composition of the characters. As mentioned above, results showed that students in the Kinect group performed significantly better in remembering components of the characters than those using tablets to learn the same content, and the tablet group performed significantly better than those in a traditional classroom.

Summary

The existing research findings reveal that embodied interactions can facilitate information encoding and retention, offer an alternative modality for information processing, situate the learning experience, and engage learners in the learning activities. However, studies exploring adult learning effects comparing full-body, high-degree active embodiment and mouse-click passive embodiment when learning a language topic remain scarce. Chang et al. (2013) applied Kinect for adult learners to actively trigger the learning content in their pilot study, but did not have a baseline group in the design. Lee et al. (2012) were interested in students' motivation when using Kinect. And in Johnson-Glenberg et al. (2014)'s highly active embodied research design, the body movements were accompanied by social collaborative activities and hence it was hard to determine the relative learning effectiveness of the body movements. Participants in Johnson-Glenberg et al. (2014) were K-12 students and the subject areas were mostly within middle-school science. In the study of Hung and Chen (2018), the learners sat in front of a computer screen and did only very limited hand movements (opening and closing a fist). In Yang et al. (2017), the embodied interactions were associated with the Chinese character strokes only, but not the meaning of the particular character. Even though the learners remembered the shape and sequence of strokes to form a character, it was not clear if they could recall the meaning of that particular character in a long term for the lack of knowledge retention test (Yang et al., 2017). In light of this gap in the research, the present study introduced an embodied intervention that required learners to actively use whole-body movements that were closely related to the content knowledge to interact with the learning materials and compared the learning effect with a baseline situation.

Methodology

The researchers utilized an experimental, two-group, pre- and posttest design to study participants' knowledge acquisition (Chinese character recognition and meaning identification) under two different interaction modes (Kinect vs. mouse).

Participants

Sixty-eight adult participants were recruited in this study. Some dropout occurred due to unexpected reasons, such as no-shows, termination in the middle of the study for unexpected emergencies, and on-site technical faults. Fifty-three of the registered participants completed the study and their data was used for the final analyses. Among these 53 participants, a majority (90.57%, $n = 48$) were registered students at a southern US university. The rest (9.43%, $n = 5$) were full-time staff members in the same university. Participants took the study intervention individually. The researchers randomly assigned each participant to either the control or experimental group. The demographic information of the participants is reported in the results section.

Hardware Configuration and Software Development

The interventions took place in a multimedia studio room with a furniture-free space of at least 3 x 5m^2 on the university campus. Major equipment included a Dell Latitude 3000 Mobile Workstation, a cordless optical mouse, a Microsoft Kinect V2 device and its Windows PC adaptor, a 59-inch widescreen TV (as the display), a 5-meter HDMI cable and a 110v power surge protector. Figure 1 shows the basic layout where the study was done.

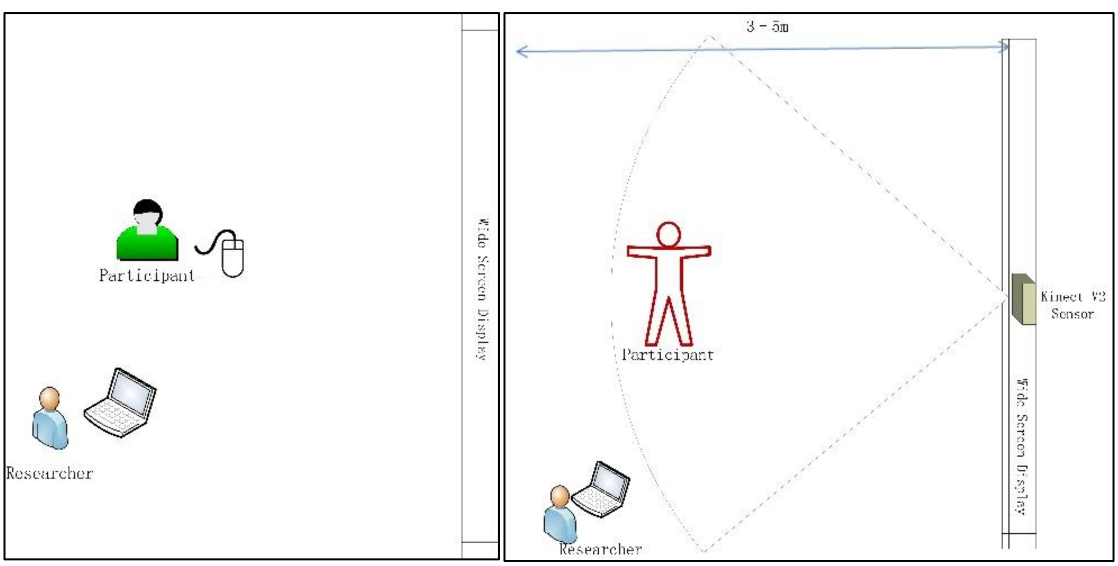

Figure 1. Physical layouts of the intervention (mouse interaction on the left; Kinect interaction on the right)

The instructional material in the research was constructed with Unity 3D 5.x, C# programing language, and MS Kinect V2 for Windows SDK 2.0. A wrapper application package, *Kinect V2 with MS-SDK* (Version2.6; Filkov, 2015), in the Unity3D online asset store was also used. Figure 2 illustrates the general software architecture of the system design.

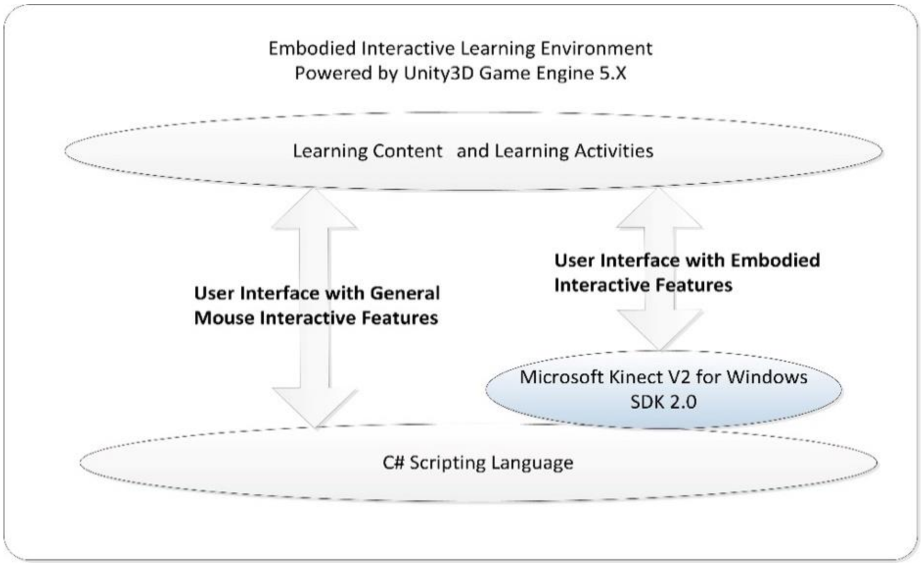

Figure 2. The general software design architecture of the instructional system

Procedures

Every participant received a pretest measuring their prior knowledge of the content to be learned. The pretest consisted of 10 items about the characters that the students were supposed to learn and was hosted via the online Qualtrics service. After the pretest, the actual intervention started. The leading researcher accompanied every participant during the whole session, and followed identical guidance and scripts for each. A participant could not ask any questions related to the learning content during the learning process, but could ask about unexpected technical issues. At the same time, to avoid possible bias in speech (e.g., tones, rhythm, pronunciation and intonation, missing or adding of sentences), a pre-recorded narration was played for every participant.

After the learning session, the participant took a 10-item immediate posttest (posttest 1) on the characters learned. Three days later, a delayed posttest (posttest 2) was given to the participants to examine their knowledge retention. Like the pretest, the posttests were also administered through the Qualtrics service. The average time of the whole on-site intervention was around forty minutes, including a brief orientation, pretest and posttest 1, and the instructional intervention.

Instructional Material

The instructional material covered 10 basic Chinese characters and their meanings in English. Details regarding the instructional material is listed in Appendix A. The ten characters were chosen because they are basic characters for novice learners, and were easily associated with Kinect-enabled body movements. The primary difference between the experimental and the control groups was the means of interaction with the instructional materials (participants using Kinect-enabled embodied interactions vs. participants using mouse-based interactions). The embodied interactions were expected to facilitate learning by:

- Moving the body to control the avatar may draw attention and raise curiosity.
- Swiping the arms and hands may stimulate and alert the learner that it is time to learn.
- Moving the whole body and adjusting it to a certain posture may actively embody and reinforce the content information, and associate the content knowledge to the modality of body movements.
- Setting the body in a specific posture that indicates some certain meaning related to the Chinese character involves imagination, muscular activities, sensations, and so on, all of which are combined to couple the abstract and the concrete, to transfer the meanings of the characters to

actively-constructed body movements, and to help future retrieval of the information.

- The whole body-moving process serves as an alternative/complementary strategy to understanding the character, forming a direct connection between a concrete posture and what a character represents (no "translation" in-between).

A learner in the control group only clicked one button to go over the instructional materials. Figure 3 shows the live pictures during the intervention.

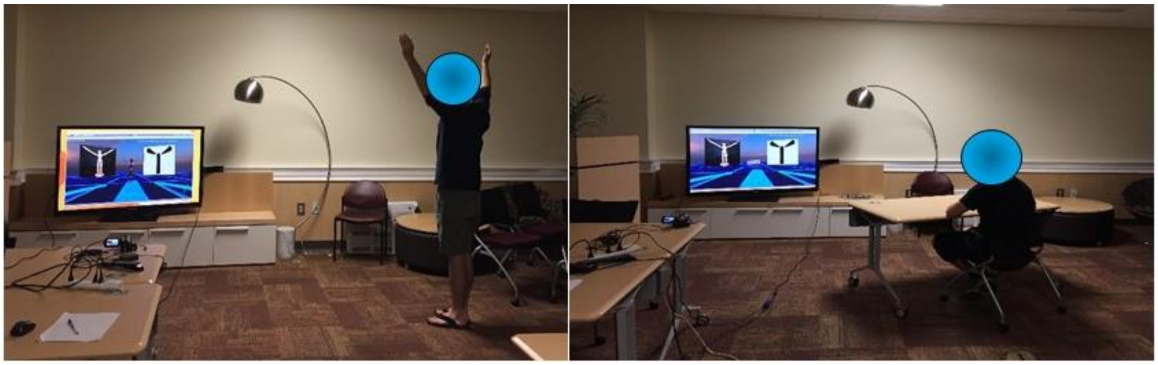

Figure 3. Live pictures from the intervention. Learning through embodied interactions (left); Learning with mouse (right).

Measurement

The test items examined how well the learners could recognize the 10 characters taught in the intervention. In each test, 10 multiple-choice questions worth a total of 10 points (1 point per item) were used. Each item assessed the recognition of a single character regarding its meaning. The pretest and posttest 1 applied the same 10 items, with the sequence of questions shuffled. The delayed posttest 2 was carefully designed to be homogeneous (see Appendix B). Thus, all items for all 10 characters across the tests were of the same difficulty level in testing whether the participants remembered what the 10 Chinese characters represented. The correct answers to the 10 items were also evenly distributed among choices A (20%), B (30%), C (30%), and D (20%) to minimize the effects of guessing. Two Chinese-teaching experts were consulted separately, and they agreed that the items satisfied the purpose to test each of the characters learned and that the items were valid in nature. The actual Cronbach's alpha for the pretest, posttest 1 and posttest 2 were .86, .86, and .83 respectively, which indicated good reliability (George & Mallery, 2003). The items are listed in Appendix B with corresponding answer keys. Test scores were analyzed using ANCOVA.

The researchers also provided survey questions (see Tables 4 and 5) after Posttest 1 to see how the participants perceived their learning experience. The questions were mostly related to user experience, and were adapted from surveys that the researchers had used in other studies. Survey questions differ in how the participants perceived the passive visual embodiment (Table 4), and how the participants perceived the role of the active embodied interactions (Table 5). Answers to the surveys were expected to help the researchers understand the test results, and to complement the study discussion.

Results

Descriptive Data and Assumptions Test

Among the 53 participants, one participant went through the study intervention without any observed attention or effort, leaving all zero scores for the pre- and post-tests. And three other participants turned out to have previously learned Chinese and received full scores for all the tests. Therefore, the test results of these four participants were excluded from the final data analyses. Table 1 shows the demographic information of the remaining participants (n = 49), and Table 2 illustrates the descriptive data of the test results.

Table 1. *Participants' Demographic Information*

	Kinect Group n = 24		Mouse Group n = 25	
	No	**%**	**No**	**%**
Gender				
Male	8	33.33	9	36.00
Female	16	66.67	16	64.00
Age				
18 - 20	7	29.17	9	36.00
21 - 25	11	45.83	7	28.00
26 - 30	4	16.67	3	12.00
31 - 35	2	8.33	2	8.00
36 - 40	0	0	2	8.00
51 - 55	0	0	1	4.00
56 - 60	0	0	1	4.00
Educational Background				
Business & Admin	1	4.17	2	8.00
Education	6	25.00	6	24.00
Engineering	0	0	1	4.00
Liberal Arts	2	8.33	2	8.00
Science	6	25.00	8	32.00
Social Sciences	6	25.00	4	16.00
Other	3	12.50	2	8.00

Table 2. *Descriptive Data of the Test Results*

	Pretest		Posttest 1		Posttest 2	
	M	***SD***	***M***	***SD***	***M***	***SD***
Kinect-group	2.83	1.97	9.29	1.23	9.42	.93
Mouse-group	2.60	2.34	8.96	1.67	8.56	1.73

ANCOVA was used for the data analyses. The researchers first inspected the assumptions (random independent samples, normality, homogeneity of variance, and independence of the covariate and the dependent variables) for the ANCOVA test. The participants were randomly assigned to either group independently, but the tests scores were not normally distributed. *Levene's* tests (in Table 3) showed non-significance, endorsing the homogeneity of the variances. Considering the robustness of ANCOVA when there is violation of data normality but without violation of the variance homogeneity (Harwell & Serlin, 1988; Olejnik & Algina, 1984; Rheinheimer & Penfield, 2001), the researchers continued to use ANCOVA for this study test. Statistics further informed that the covariate (Pretest) was independent of the instructional treatments (Kinect and mouse) when Posttest 1 (F = 2.41, p > .05) and Posttest 2 (F = 3.67, p > .05) were set as the dependent variables respectively.

Table 3. *Levene's Test of Equality of Error Variances*

Tests	F^*	$df1$	$df2$
Pretest	.27	1	47
Posttest1	.46	1	47
Posttest2 (delayed)	2.75	1	47

*α value set at .05

Findings

Using group (Kinect and Mouse) as the independent variable, Posttest 1 scores as the dependent variable, and Pretest as the covariate, the ANCOVA test did not indicate statistical significance ($F = .50$, $p > .05$) between the Kinect group ($n = 24$, $M = 9.29$, $SD = 1.23$) and the mouse group ($n = 25$, $M = 8.96$, $SD = 1.67$). Using the group (Kinect and Mouse) as the independent variable, Posttest 2 as the dependent variable, and Pretest as the covariate, the results showed statistical significance ($F = 4.55$, $p = .04$) between the Kinect group and the Mouse group.

Accordingly, statistical results showed that in the immediate posttest, the embodied interactions enabled by Kinect brought no statistically better performance than traditional mouse interactions for adult learners when learning basic Chinese characters. But in the delayed posttest, the embodied interactions enabled by the Kinect did lead to statistically better knowledge retention than traditional mouse interactions for adult learners. Based on the fact that the mouse group turned out to include older participants, a correlation test (Pearson's χ^2) was run between the age groups and the delayed posttest results. The results showed no significant association between the age and the posttest performance for both groups ($p_m > .05$; $p_k > .05$), hence the concern about possible age effect was eliminated. To further validate the study results and address the issue of the data non-normality, the non-parametric test, Mann-Whitney U, was conducted to examine the group difference in both posttests. The Mann-Whitney U tests showed the same statistical results ($U_1 = 271.5$, $p > .05$; $U_2 = 211.5$, $p = .05$) in terms of learning effects comparisons between the two groups, endorsing the robustness and the results of the ANCOVA tests.

At the same time, paired t-tests indicated that for both study groups (see Figure 4), Posttest 1results ($t = 14.12$, $p < .001$; $t = 13.52$, $p < .001$) and Posttest 2 results ($t = 14.25$, $p < .001$; $t = 15.33$, $p < .001$) were significantly higher than the Pretest.

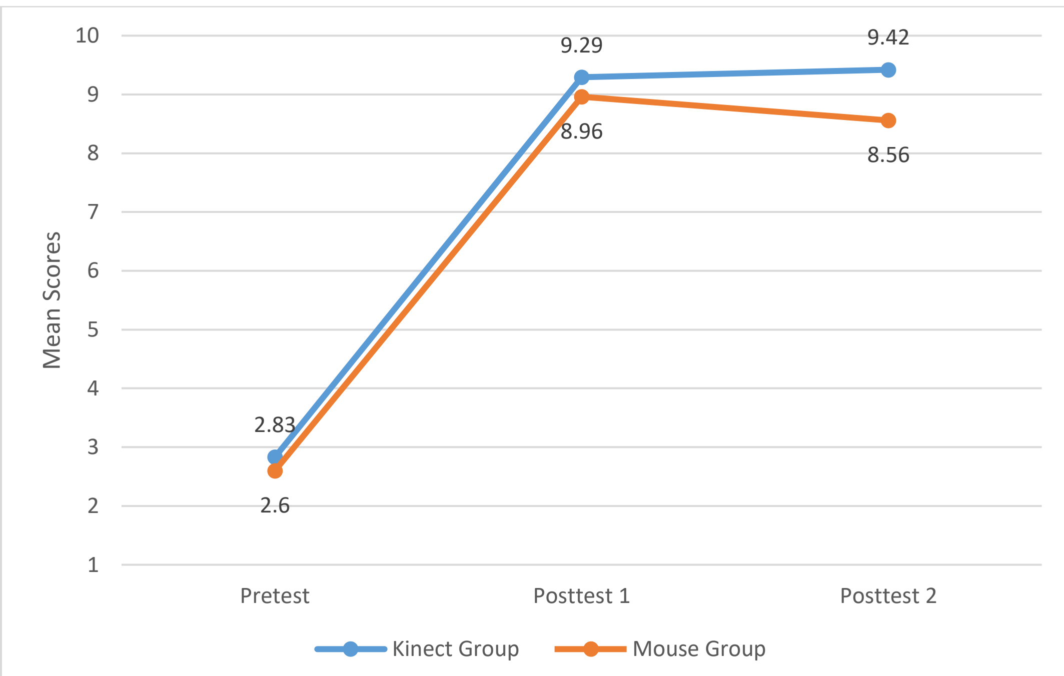

Figure 4. Mean scores for both groups increased significantly

Results for the Survey Questions

The survey questions for the mouse group were about how the participants perceived their learning experience, as shown in Table 4 below.

Table 4. *Survey Results of Mouse Group*

	Strongly agree	Somewhat agree	Neither	Somewhat disagree	Strongly disagree
I think the learning session I have just experienced is instructive in general.	68%	32%	0	0	0
I found it easy using the mouse to interact with the learning material.	84%	16%	0	0	0
I think I have mastered the knowledge about the topic through this intervention.	16%	56%	20%	8%	0
I think the postures of the wooden doll match well with the corresponding Chinese characters for me to understand the meanings.	48%	36%	8%	8%	0

The survey questions for the Kinect group in this part were also about how the participants perceived their learning experience, especially how they perceived the role of the embodied interactions in learning, shown in Table 5 below.

Table 5. *Survey Results of Kinect Group*

	Strongly agree	Somewhat agree	Neither	Somewhat disagree	Strongly disagree
I think the learning session I have just experienced is instructive in general.	92%	8%	0	0	0
I found it easy using my body gestures to interact with the learning material.	79%	17%	4%	0	0
I think I have mastered the knowledge about the topic through this intervention.	38%	45%	13%	4%	0
During the intervention, I realized that using my body movements and gestures was part of my learning process.	88%	8%	0	0	4%
I think that using the body movements and gestures as prompted in the intervention has helped my understanding the learning content.	79%	17%	0	0	4%
I think that my postures match well with the corresponding Chinese characters for me to understand the meanings.	71%	25%	0	0	4%
I think it was helpful to see how I performed with a shown avatar.	75%	15%	4%	0	4%
I think I can learn better if I use the mouse to interact with the learning materials rather than using the Kinect-enabled body movements to interact.	4%	0	13%	29%	54%

The first four questions for both groups were similar, and were about to what extent the learners were satisfied with the intervention. Reading the survey results, the researchers found that learners in both groups regarded the interventions as instructive, with the learners in the Kinect group significantly more satisfied than the mouse group (92% versus 68% strongly agree; $\chi^2(1) = 4.22$, $p < .05$). Numerically more learners (83%) in the Kinect group than in the mouse group (72%) thought they had mastered the learning content ($\chi^2(1) = .90$, $p > .05$). And it is interesting to notice that a much higher (38%) percentage of participants in the Kinect group strongly thought they had mastered the knowledge than their counterparts in the mouse group (16%), although the statistical result approached but did not reach significance ($\chi^2(1) = 2.90$, $p = .08$). The last four questions in the Kinect group reflected how participants perceived their embodied learning experience. It is satisfying to know that all participants thought it instructive to learn through their body movements, and an absolute majority of learners (96%) thought that such movements matched well the meanings of the characters. A majority (83%) agreed that using their body movements to physically interact with the learning materials would lead to better learning outcomes than using conventional ways.

Discussion

In this study, the researchers concentrated on active embodiment featuring a high degree of body involvement when comparing active and passive embodied interactions. Learners actively moved their own bodies, and the whole-body movements were closely related to the meaning of the Chinese characters. Statistic results showed significant learning effects of the interventions on content retention of the Chinese characters for both active (Kinect) and passive (mouse) groups. Notably, the delayed posttest indicated a significantly higher average score of the Kinect group than that of the mouse group, suggesting better knowledge retention for the embodied interaction group. For the immediate posttest, the result of the Kinect group was also slightly higher than that of the mouse group, although not to a statistically significant degree. During the intervention, moving the body to control the avatar draws attention and raises a learner's curiosity to focus. Moving the whole body and adjusting it to a certain posture actively embodies and reinforces the content information, and links the content knowledge to the modality of body movements. While moving and adjusting the body to a specific posture associated with a Chinese character, a participant may proactively imagine what the character resembled and apply cognitive and physical effort to make the match. Such a process encompasses imagination, muscular activities, and sensations, all of which are combined together to couple the abstract and the concrete, to transfer the meanings of the characters to actively-constructed body movements, and to help future retrieval of the content knowledge. As stated in the study results, during the intervention, a majority (96%) of the participants regarded using their body gestures and movements as part of their learning process, and acknowledged that such embodied interactions in the intervention matched the meanings of the corresponding Chinese characters well, which therefore helped them to understand the learning content.

In the immediate posttest, the results show no significant difference between the learning outcomes in the two groups. Such results may be attributed to the following reasons. First, regardless of the means of interaction with the learning material, participants in both groups receive visual clues from the wooden dolls on the screen (see Figure 2 for reference). Chinese characters are not random symbols, but 'pictures' that are "grounded upon historical stories and possess meaningful interpretation" (Xu & Padilla, 2013, p.414), and in the current study, the wooden dolls serve as the "meaningful interpretation [that] provided students with a framework and contextual clues to learn and retain Chinese characters" (Xu & Padilla, 2013, p.414). In Chinese learning, compared with pronunciation and writing, it is relatively easier for non-native speaker learners to learn the characters' meanings (Shen, 2010). The wooden dolls clearly represent the concepts and ideas, and pair the meanings with the characters. This way, the learners may have developed strong cognitive associations of the characters in their minds.

Second, the study results implied that visual embodiment also contributes to the knowledge acquisition. In the mouse group, even though active embodied interactions were not involved, participants are visually stimulated by the wooden dolls, and the content knowledge is visually embodied while the visual working memory processes and encodes the figures with corresponding meanings. And such a visual and passive embodiment may have boosted the working memory to the extent that the extra muscular embodiment in the Kinect group would not contribute additional value or impact in the immediate posttest in which participants depend very much on their fresh working memory. This interpretation is supported by prior research of Repetto et al. (2015) who asked participants in the experimental group to observe how their virtual bodies move while teaching a collection of Czechish verbs and found positive learning effects. Pasfield-Neofitou et al. (2015), while teaching Chinese in Second Life, also reported positive effects when using visual embodiment (controlling and observing the movements of avatars with a mouse) to teach vocabulary. In these empirical studies, the embodied experiences were accomplished indirectly, or passively in our context, through avatars in virtual spaces. Researchers in psychology and neuroscience studying the mechanism of Chinese learning have reported that visual stimulation and processing in working memory leads to "more efficient processing and refined responses in brain regions" (Opitz et al., 2014, p. 1); and when learning Chinese characters, visual working memory will boost "additional activation in the precuneus, presumably reflecting mental image generation of the learned characters" (Opitz et al., 2014, p. 1). Since the meaning of most Chinese characters have nothing to do with the phonemes, added visual-orthographic processing and visual short-term storage that take place in the fusiform gyri are essential compared with alphabetic languages. Where and how visual-orthographic processes operate in the brain is out of the scope of this study. However, the discussions of Chinese character learning among the neuroscience literature endorse that visual working memory has unique contributions to the acquisition of Chinese characters (Opitz et al., 2014).

Ultimately, there may be an inherent influence from the participants' learning abilities as well. The learning of Chinese characters in this study mostly requires memorization only, which merely reflects factual and conceptual knowledge in the knowledge dimensions (Krathwohl & Anderson, 2009). Based on the fact that the participants are well-educated, and there are only ten picture-like characters with English meanings clearly listed, it could be rationally inferred that even with brute force utilization of their working memory, the participants may memorize a reasonable number of characters over a short period of time, and score well in the immediate posttest. In other words, the background of the participants and the nature of the learning content could have had a ceiling effect on the learning results. The concept of a ceiling effect may vary in content across disciplines. In this study, the ceiling effect referred to the participants' understanding of the characters in both groups that were brought by the advanced learning proficiencies and backgrounds of the participants (Judson, 2012; Rifkin, 2005). Such a ceiling effect may have blurred the boundaries among the outcomes introduced in different interaction modes, the multimedia instructions, and participants' existing learning competencies, and could have limited the influence of the embodied interactions.

Compared with existing studies on the learning effects of embodied interactions on children, embodied interactions may have divergent learning effects on adults. A reasonable justification may be that adults and children have different learning abilities, which may reduce or magnify the effects of embodied interactions. In their study, So et al. (2012) revealed that both adults and children learned certain English words better with body movements than without ($p = .001$ for the adults; $p < .001$ for the children; same words for both adults and children). Noticeably, the p value for the children was smaller than that for the adults, which may serve as an indirect indication and support of this implication. Because of their mature intelligence, adult learners may be less dependent on different approaches to interacting with the learning materials. The nature and the difficulty level of the content knowledge may moderate the effectiveness of embodied interactions for adult learners, unless novel approaches of interactions have revolutionarily changed the way the learners think.

In the delayed posttest, the Kinect group outperformed the mouse group significantly in the retention of the Chinese characters three days after the intervention. Information processing theory and the memory model (Atkinson & Shiffrin, 1968; Baddeley & Hitch, 1974; Driscoll, 2005; Richey, 1986) inform us that working memory is limited, and it is crucial to encode chunks of transient information to bridge the working memory and the long-term memory. The long-term memory serves as a repository to store the encoded information to be retrieved when necessary. Active gestures may help learners strengthen the connections between concepts and emotions via externalized movements, which build embodied analogies to map the unfamiliar to concrete locomotion (Lee et al., 2012; Tran et al., 2017; Weisberg & Newcombe, 2017). Research specifically investigating Chinese learning has further suggested that paired association can help with visual processing skills when memorizing characters in a visual-orthographic approach over a short period of time (Opitz et al., 2014; Siok & Fletcher, 2001), and have further proposed that for characters to remain in long-term memory, there should be some sort or level of rehearsal of the learning materials (Xu & Padilla, 2013). In the Kinect group, the extra muscular embodied interactions serve as a profitable sort of rehearsal for the learners to refresh their minds. In the delayed posttest results, there was a loss (4.5%) of the mean score compared with the immediate posttest in the mouse group, and a gain (1.4%) of the mean score in the Kinect group. A potential interpretation is that the waning of the visual embodied effect may have decreased the performance for the mouse group, while the active embodied interactions may have compensated for the loss. The body-moving process provides an alternative and complementary strategy to understanding and memorizing the character, forming a direct connection (no 'translation' in-between) between a concrete posture and the semantic meaning of a character. The visual embodiment happens only on the site of the intervention and its effect declines as the meaningful interpretation in working memory diminishes. Yet the physical and muscular embodiment have accompanied the participants for a longer time. As one participant reported in a later informal conversation, "I couldn't help moving my body when I did the off-site posttest. That definitely helped a lot. I can still remember some of them now".

This study also revealed distinct results from Lan et al. (2018) that reports better language learning effects through passive embodiment than through active. A possible reason may be that in this current study, the active embodiment involved simulating whole body movements modelled by an avatar (the wooden figure) with instant performance feedback. Learners were able to dynamically adjust their construction of the postures to suit the corresponding Chinese character. However, in Lan et al. (2018), although learners also moved as directed by a 2D picture, there was a lack of substantial interaction between the movements and the static 2D pictures. In other words, learners' body movements in Lan et al. (2018) barely bring any content-related responses from the learning materials. Essentially, the discrepancy between these two studies may mainly because of how the active embodiment was designed to convey the content knowledge. This current study not only made the embodiment visible, but also offered opportunities for reflection.

Limitations and Directions for Future Research

Some limitations in this study exist. First, the total time for the intervention was merely forty minutes. Embodied interactions in intervention designs like this could have had limited impact on learning due to the time limit. Some participants may not have familiarized themselves with how to interact with the learning materials through their bodies before the invention was over. In addition, it should also be noted that the mouse group might have spent slightly different amounts of time looking at the screen because a learner in the mouse group did not have to move the whole body as well as look at the screen. In addition, the adult participants were educated adults with reasonably better-than-average learning abilities. They had developed intelligence to understand concepts and to learn skills. Such a sample might be less representative of general adult learners. Finally, the number of participants who contributed to the final data analysis was less than anticipated due to unexpected dropouts.

Future researchers should improve the duration and frequency of the intervention. For instance, the participants may attend the intervention once a week for four consecutive weeks. This way, the effects of different approaches to interacting with the learning materials may be accumulated and there will also be abundant longitudinal data to support possible research results. At the same time, it will be interesting to take away the visual clue (the wooden doll in this study context) and ask participants in the experimental group to perform any body movements that they may think of to help them learn the content. And for the control group, the researchers could follow think-aloud protocols without any visual clues, and analyze how they memorize the characters using their own imagination and creativity.

Future research could also employ instruments and research methods from other fields like psychology and neuroscience to examine how the participants' visual attention, memory, and brain are working while learning through embodied interactions. For example, a researcher may use an eye-tracking device to record and analyze how and how long participants are paying attention to the learning materials and their embodied interactions. A researcher may also capture electroencephalograph records of the participants to study the electrical activities of the brain, and to analyze the participants' reactions to varied sorts of stimulation related to embodied interactions.

The researchers of the current study call for more empirical studies to evaluate the learning effects of embodied interactions enabled by modern technologies in language learning settings so as to afford innovative and alternative approaches to language education.

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Appendices

Appendix A. Instructional Material

General Instructional Goals

After the instruction, the participants who have no/very little knowledge about the content will be able to

- recognize the Chinese characters taught (knowledge and comprehension).

Instructional objective

Given a simple Chinese character, students will be able to explain what the essential meaning it stands for.

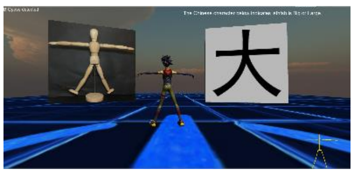
Learning content

Ten Chinese characters: 大，小，人，上，中，下，吊，山，火，丫

The essential meanings of these characters in English are: big or large, small or little, a human, up or above, between or in the middle, down or below, to hang, a mountain or a hill, fire or flame, and a tree branch.

Table 6 lists how the intervention goes together with the corresponding necessary scripts, as well as two screen captures.

Table 6. *Instructional Scenarios and Corresponding Scripts for Chinese Characters Learning*

Steps	Necessary Scripts
Step 1 – Warming up	The Chinese language is essentially different from the Roman languages. It is hieroglyphic, which means that the formation or the shape of a Chinese character may come from the content that it represents. In this short session, you will see ten Chinese characters. Simply think of them as pictures. Corresponding English meanings will be given at the same time. At the end, you will be able to recognize any one of the ten characters and inform what they represent. Don't worry. You are not required to pronounce them.
Step 2 – Learning the characters   It should be noted that for both mouse and Kinect versions, a participant will repeat the 10 characters for 3 times to keep a consistent exposure to the learning content.	(*Kinect version*) Now we'll do some exercises stretching our arms and legs. On this screen, you see an animated avatar. And you can control it by moving your own body. See it? And at the bottom of the screen, you can also find your body skeleton while you are moving. Like a little match-man, huh? These two big cubes are for you to learn and practice. When you use your hand to swipe to either left or right, you may find that the left cube rotates and shows a wooden doll in a certain body posture. Move your body and adjust your own body posture to mimic the wooden doll's. You can adjust your body by comparing the avatar figure of yours, the match-man, and the wooden model in real-time. Once you think your posture is OK, stay still for a little while. You may notice that you will then trigger the cube on the right to rotate to a Chinese character, with some English explanation on top of it. Do you notice any connections between your own body posture and the character? Let's move to the next one by swiping your hand … (*Mouse version*) On this screen, you see two 3D cubes. Once you press the button here with your mouse, the two cubes will rotate simultaneously. The cube on the right shows you a Chinese character for you to learn. Don't worry. You will see an English translation of that character on the screen. And at the same time, the cube on the left offers you a visual clue that displays a wooden doll in some certain pose that may help you understand and memorize the Chinese character. There are ten characters in all and you may just click the button to move on.

Appendix B. Test Items and Answer Keys

Chinese Characters Test Items (pretest and posttest 1)

1. What does the character "火" represent?

    A. water
    B. a human
    C. fire or flame
    D. up or above

key: C

2. What does the character “下” represent?

A. down or below
B. a mountain or a hill
C. big or large
D. something to eat

key: A

3. The character that represents “a tree branch” is:

A. 吊
B. 口
C. 上
D. 丫

key: D

4. The character that represents “small or little” is:

A. 大
B. 小
C. 手
D. 中

key: B

5. What does the character “中” represent?

A. a hammer
B. big or large
C. to hang
D. between or in the middle

key: D

6. What does the character “人” represent?

A. a human
B. fire or flame
C. a mountain or a hill
D. to swim

key: A

7. The character that represents “big or large” is:

A. 下
B. 大
C. 丫
D. 气

key: B

8. The character that represents “a mountain or a hill” is:

A. 水
B. 吊
C. 山
D. 上

key: C

9. What does the character “吊” represent?

A. between or in the middle
B. to hang
C. a tree branch
D. to fly

key: B

10. The character that represents “up or above” is:

A. 小
B. 大
C. 上
D. 少

key: C

Chinese Characters Test Items (posttest 2)

1. The character that represents “fire or flame” is:

A. 水
B. 人
C. 火
D. 上

key: C

2. The character that represents “down or below” is:

A. 下
B. 山
C. 大
D. 尺

key: A

3. What does the character”丫”represent?

A. to hang
B. the mouth
C. up or above
D. a tree branch

key: D

4. What does the character”小”represent?:

A. big or large
B. small or little
C. hand
D. between or in the middle

key: B

5. The character that represents “between or in the middle” is:

A. 小
B. 大
C. 吊
D. 中

key: D

6. The character that represents “a human” is:

A. 人
B. 山
C. 吊
D. 手

key: A

7. What does the character “大” represent?

A. down or below
B. big or large
C. a tree branch
D. gas

key: B

8. What does the character”山”represent?

A. water
B. to hang
C. a mountain or a hill
D. up or above

key: C

9. The character that represents “to hang” is:

A. 中
B. 吊
C. 丫
D. 飞

key: B

10. What does the character “上” represent?

A. to fly
B. down or below

C. up or above
D. small or little

key: C

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