공학석사 학위논문

Evaluating the usability of sign language gestures for gesture-based human-machine interaction

- 제스처 기반의 인간-기계 인터렉션을 위한 수화동작의 사용성 평가 -

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지도교수 박 우 진

이 논문을 공학석사 학위논문으로 제출함
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ABSTRACT

Utilizing gestures of major sign languages (signs) for gesture-based interaction seems to be an appealing idea as it has some obvious advantages, including: reduced time and cost for gesture vocabulary design, immediate accommodation of existing sign language users and supporting universal design and equality by design. However, it is not well understood whether or not sign language gestures are indeed adequate for gesture-based interaction, especially in terms of usability. As an initial effort to enhance our understanding of the usability of sign language gestures, the current study evaluated Korean Sign Language (KSL) gestures employing three usability criteria: intuitiveness, preference and physical stress. A set of 18 commands for manipulating objects in virtual worlds was determined. Then, gestures for the commands were designed using two design methods: the sign language method and the user design method. The sign language method consisted of simply identifying the KSL gestures corresponding to the commands. The user design method involved having user representatives freely design gestures for the commands. A group of evaluators evaluated the resulting sign language and user-designed gestures in intuitiveness and preference through subjective ratings. Physical stresses of the gestures were quantified using an index developed based on Rapid Upper Limb Assessment. The usability scores of the KSL gestures were compared with those of the user-designed gestures for relative evaluation. Data analyses indicated that overall, the use of the KSL gestures cannot be regarded as an excellent design strategy when viewed strictly from a usability standpoint, and the user-design approach would likely produce more usable gestures than the sign language approach if design optimization is performed using a large set of user-designed gestures. Based on the study findings, some gesture vocabulary design strategies utilizing sign language gestures are discussed. The study findings may inform future gesture vocabulary design efforts.

Keywords : sign language, gesture, gesture-based interaction, gesture vocabulary, usability

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CONTENTS

TABLE LIST

FIGURE LIST

1. INTRODUCTION

1-1 Background

Gesture-based interaction has been actively researched in the human computer interaction (HCI) community as it has a potential to improve human-machine interaction (HMI) in various circumstances (Nielsen et al., 2003; Cabral et al., 2005; Bhuiyan et al., 2009; Wachs et al., 2011; Choi et al., 2012). Compared with other modalities of interaction, the use of gestures has many distinct advantages: first, gestures are the most basic means of human-to-human communication along with speech, and thus, may be useful for realizing natural, intuitive and comfortable interaction (Baudel and Beaudouin-Lafon, 1993). Second, human gestures are rich in expressions and can convey many different meanings and concepts as can be seen in the existing sign languages' extensive gesture vocabularies. Third, gesture-based interaction can be utilized in situations where the use of other interaction methods is inadequate. For example, covert military operations in battle fields would preclude the use of voice-based or keyboard and mouse-based interaction. Fourth, the use of touchless gestures would be ideal in environments that require absolute sanitation, such as operating rooms (Stern et al., 2008a; Wachs et al., 2011). Fifth, gestures may promote chunking, and therefore, may alleviate cognitive burden during human-computer interaction (Baudel and Beaudouin-Lafon, 1993; Buxton, 2013). Sixth, gesture can be combined easily with other input modalities, including voice, to enhance ease of use and expressiveness (Buxton, 2013). Finally, the use of the hands (or other body parts) as the input device eliminates the needs for intermediate transducers, and thereby, may help reduce physical stresses on the human body (Baudel and Beaudouin-Lafon, 1993).

One of the key research issues related to gesture-based interaction is the design of gestures. Typically, a gesture design problem is defined as determining the best set of gestures for representing a set of commands necessary for an application. Such set of gesture-command pairs is often referred to as a gesture vocabulary (GV) (Wachs et al., 2008; Stern et al., 2008a). Gesture design is important because whether or not gesture-based interaction achieves naturalness, intuitiveness and comfort largely depends on the qualities of designed gestures.

At this time, a dominant paradigm for gesture design seems to be to have humans ideate and create gestures from scratch. In the earlier days of gesture design research, the gesture recognition technology was limited; therefore, emphasis was placed upon creating gestures that are easily recognized by machines. Therefore, those who developed gesture recognition systems typically created gestures as well. As the gesture recognition technology evolved and became more reliable, the emphasis was shifted to the usability of interaction, and, users started actively participating in the design process. For example, in Stern et al. (2008a) and Wachs et al. (2008), candidate gestures for given commands were generated by computer programs and user representatives evaluated them so as to choose the optimal GV. In multiple studies, including Nielsen et al. (2003), Kela et al. (2006), Wobbrock et al. (2009), Henz et al. (2010), Morris et al. (2010), Fikkert et al. (2010), Kühnel et al. (2011), Vatavu (2012) and Piumsomboon et al. (2013), user representatives created gestures for given commands and the optimal GV was determined by selecting desirable ones from the user-designed gestures. This “user design” approach is a powerful design strategy as it directly incorporates users’ intuitions, preferences and creativity directly into the design of gestures. According to Wobbrock et al. (2009), “wisdom of crowds” could generate a better gesture set than a small number of HCI experts.

Despite the wide use, however, the “creating gestures from scratch” paradigm described above seems to have some drawbacks: first, GV design based on the paradigm can be costly and time-consuming especially when a large group of human designers or evaluators participate. All the steps involved in the design process, that is, recruitment of designers/evaluators, design and evaluation of candidate gestures and determination of the optimal GV, could require substantial time and cost. Second, the paradigm may not be suitable for developing a large GV or continually extending an existing GV as human designers would find it difficult to develop a large number of distinguishable gestures or invent additional gestures that can be clearly discerned from the existing ones. Third, a GV created from scratch would typically have no user base to start off with, and thus, additional efforts must be made to build one.

One possible alternative to the existing design paradigm is to borrow gestures from established gesture languages rather than create them from scratch. In particular, the gestures of major sign languages (signs) could be utilized for computer systems that process and recognize three-dimensional upper extremities gestures.

Utilizing sign language gestures for gesture-based interaction (hereafter, referred to as the sign language approach) seems to be an appealing idea as it offers some obvious advantages. Above all, it can significantly reduce design time and cost as a sign language is a complete human language rich in vocabulary and provides pre-designed gestures for numerous referents; therefore, a GV can be efficiently designed by simply identifying the existing signs corresponding to given commands. It is worth noting that this simple design method guarantees producing mutually distinguishable gestures regardless of the number of commands as all the signs of a sign language are already mutually distinguishable. Thus, creating large GVs or continually expanding existing GVs does not present any difficulties. Another notable advantage of the sign language approach is that a major sign language has a large existing user base, which includes the deaf and speech-impaired populations. The existing sign language users will be able to quickly adopt new gesture-based interaction systems with zero or minimal training if the systems are based on sign language gestures. Furthermore, such accommodation through design may greatly help many deaf and/or speech-impaired individuals gain access to new technology, which is undoubtedly a good thing. Also, the idea that everyone uses sign language gestures for interacting with machines seems to be in line with the notion of universal design.

Despite the aforementioned advantages, however, whether or not sign language gestures are indeed suitable for gesture-based interaction is uncertain, especially in terms of usability. To the authors' best knowledge, very few studies have evaluated the usability of sign language gestures, and consequently, little is known about it. This lack of knowledge makes it difficult to determine the applicability of sign language gestures for gesture-based interaction and further capitalize on their advantages mentioned earlier.

1-2 Objectives

As an initial effort towards addressing the problem stated above, the main objective of this study was to empirically evaluate sign language gestures employing three usability criteria: intuitiveness, preference and physical stress. In particular, this first study evaluated Korean Sign Language (KSL) gestures in comparison with user-designed gestures. Thus, the main research hypothesis of this study was that sign language gestures on average are not significantly inferior to user-designed (user-defined) gestures in intuitiveness, preference and physical stress metrics.

A set of 18 commands for performing object manipulation tasks in virtual worlds was determined. Then, gestures for the commands were designed using two different methods: the sign language and user design methods. The sign language method utilizes the existing Korean Sign Language gestures corresponding to given commands. The user design method requires gesture designers representative of the user population to design gestures for given commands. Eight gesture designers participated for user design. A group of user representatives, who had not participated in the user design sessions, subjectively evaluated both the sign language and user-designed command-gesture pairs in intuitiveness and preference. The physical stress level of each desgined gesture was quantified utilizing an evaluation scheme based on Rapid Upper Limb Assessment (RULA) (McAtamney and Corlett, 1993; Corlett, 1995). Statistical analyses were conducted to compare the sign language gestures and the user-designed gestures in each criterion considered.

In addition to the above comparisons, this study also investigated the following research questions that are relevant to gesture design:

- Do the sign language and user design methods produce identical gestures for some commands? What affects the probability that a user-designed gesture is identical to an existing sign language gesture?

- How is perceived intuitiveness of a command-gesture pair related to perceived preference of the gesture for the command? Also, how is physical stress of a gesture related to its perceived preference?

2. METHOD

This study employed a four-step procedure to accomplish the research objective: first, a set of commands necessary for performing object manipulation tasks in virtual environments were determined. Second, gestures for each command were obtained using the two gesture design methods: the sign language and user design methods. Third, the resulting gestures were evaluated in three usability evaluation criteria: intuitiveness, preference and physical stress. Finally, statistical analyses were conducted to compare the sign language gestures with the user-designed gestures in each usability criterion for the purpose of relative evaluation. Each step is detailed in what follows.

2-1 Determining a set of commands for virtual object manipulation (step 1)

The gestures to be created were for manipulating objects in three-dimensional virtual environments. Numerous tasks in virtual environments would require object manipulation. A total of 18 commands were chosen on the basis of user interviews (Table 1).

Table 1. The command set for virtual object manipulation

Command	Description
1. Grab	To take and hold with a hand
2. Put down	To place onto the floor or another surface
3. Push	To press against with force
4. Pull	To exert force upon so as to cause motion toward the force
5. Throw	To propel through the air in any manner
6. Reverse	To turn completely about in position or direction
7. Scale up	To increase the size of
8. Scale down	To decrease the size of
9. Undo	To nullify a previous action
10. Redo	To redo a previously nullified action
11. Show	To cause to be seen
12. Hide	To cause to be invisible
13. Select	To choose from a group
14. Rotate	To cause to turn about an axis or a center

15. Fetch	To bring near to the user
16. Return	To send back to the original position
17. Move	To move from one position to another
18. Stop	To stop an on-going action

2-2 Creating gestures for expressing the commands (step 2)

The sign language method and the user design method were utilized to generate gestures for expressing the commands determined in Step 1. The sign language method consisted of simply identifying the KSL gestures corresponding to the 18 commands – only the KSL was considered in this first study. The KSL is commonly used as a means of communication among those with hearing and speech impairments in Korea. The KSL gestures were found from an on-line resource provided by the National Institute of the Korean Language (The National Institute of the Korean Language, 2007). The user design method involved having a group of user representatives individually ideate and create gestures. Eight graduate students (4 males and 4 females) in their 20s and 30s participated as gesture designers. The gesture designers did not have any previous experience of gesture-based interaction. Also, they did not have any obvious musculoskeletal or neurological disorders. The gesture designers were asked to create three-dimensional, upper extremity gestures corresponding to the 18 commands. For each command, the experimenter provided the gesture designers with a written description of its effect in the context of a generic, three-dimensional virtual reality system. No other design references or cues for gesture design were provided to the gesture designers. The gesture designers were allowed to use as much time as needed. At the completion of the design of gestures, each gesture designer performed the resulting gestures while the performance was video-recorded. A three-camera video recording system was utilized to record body motions from three different angles.

The gesture designers signed an informed consent form prior to participating in the user design session. The user design session was approved by the Institutional Review Board, Seoul National University.

2-3 Evaluating gestures using usability measures (step 3)

The gestures designed in Step 2 were evaluated on the basis of three usability criteria: intuitiveness, preference and physical stress. Intuitiveness pertains to the cognitive association between a command and its physical gestural expression (Stern et al., 2008b). Preference refers to the subjective liking or disliking of a gesture presented as a physical expression of a command. Physical stress refers to the overall sum of stresses on individual body parts resulting from performing a gesture – this criterion becomes important if interaction involves frequent use of gestures for prolonged durations. Note that intuitiveness and preference pertain to a command-gesture pair and physical stress relates to a gesture.

For each of the command-gesture pairs from Step 2, its intuitiveness and preference levels were evaluated based on subjective ratings of human evaluators. A 10-point subjective rating scale was created for each criterion. The rating scales are shown in Figure 1. Ten graduate students in their 20s and 30s (8 males and 2 females) were recruited as gesture evaluators. The gesture evaluators had not participated in the user design session described in Step 2. For each of the command-gesture pairs from Step 2, the gesture evaluators watched video clips illustrating the gesture from different angles, made the gesture multiple times themselves and subjectively evaluated the command-gesture pair in terms of intuitiveness. Preference evaluation was conducted in a similar manner. For each gesture evaluator, intuitiveness and preference were evaluated separately in two evaluation sessions. The order of the two evaluation sessions varied across the gesture evaluators. Also, the order of the command-gesture pairs was randomized for each subject and each evaluation session.

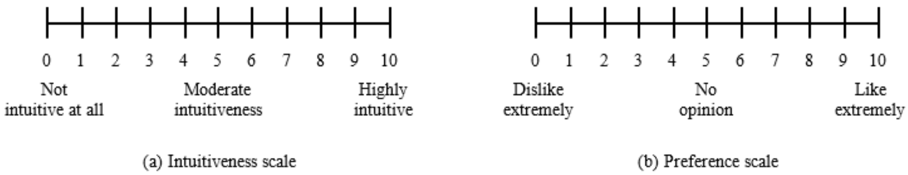


Figure 1. The 10-point subjective rating scales for assessing intuitiveness and preference levels of a command-gesture pair

The gesture evaluators signed an informed consent form prior to participating in the gesture evaluation session. The gesture evaluation experiment was approved by the Institutional Review Board, Seoul National University.

The physical stress levels of the designed gestures were evaluated utilizing a numerical index based on Rapid Upper Limb Assessment (RULA). RULA is a widely used posture analysis tool (McAtamney and Corlett, 1993; Corlett, 1995). When given a working posture observed from a manual task, RULA determines a score that represents its physical stress level using a predetermined posture classification and scoring system. RULA has shown good correlation with self-reported musculoskeletal discomfort and pain related to occupational work tasks (Hedge et al., 1995; Kilroy and Dockrell, 2000; Massaccessi, M., 2003) and its repeatability and reliability have been demonstrated (McAtamney and Corlett, 1993). RULA was considered as a general posture analysis tool that allows comparing postures in terms of physical stress.

The posture classification and scoring system of RULA divides the human body into two groups of body parts: Group A and Group B. Group A consists of the upper arm, lower arm and wrist. Group B includes the neck, trunk and leg. For each group, the corresponding body parts are analyzed separately. For each body part, its range of movement is divided into a few pre-determined joint angle intervals. Each interval has a numerical score representing the level of physical stress it imposes on the body part. Figure

2a shows the body part posture classification and scoring schemes for Group A (the upper arm, lower arm and wrist).

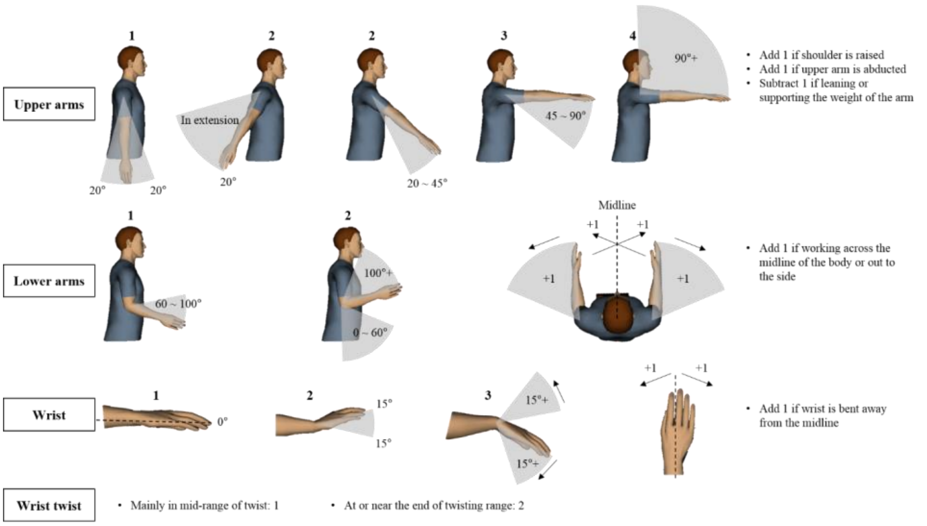
In analyzing a whole-body posture with RULA, a human analyst observes each body part's position and the interval that it belongs to; and, the corresponding body part posture score is determined. Then, for each group of body parts, the posture scores for the corresponding body parts are combined to produce a single overall score. Figure 2b presents the lookup table for determining the overall score for Group A from the individual body parts' scores. Finally, the overall scores of Group A and Group B are combined to produce the grand score.

In this study, only Group A and its overall score were considered as all the upper extremities gestures produced from Step 2 had identical neck, trunk and lower limb postures – for all of the designed gestures, no neck/trunk bending or twisting was involved, and the legs and feet were well supported and in an evenly balanced posture. Also, when using RULA, the left and right sides of the body are analyzed separately. Thus, two Group A overall scores (left and right) were considered in analyzing a posture.

A gesture is a dynamic motion, that is, a continuous time sequence of postures. To quantify the physical stress level of a gesture using RULA, a computation scheme was devised, which is described in Figure 3. The computation scheme produces a single physical stress score named the overall gestural stress score (OGSS). Note that the possible range of the OGSS is 4 through 36. An increase in the OGSS indicates increased physical stress.

As can be seen from the computation scheme, the OGSS considers only the two terminal postures of a gesture and the intermediate postures that connect the two are not considered. The underlying assumption was that the postural stress scores for the terminal postures are representative of the stress scores of all the intermediate postures between them. A preliminary study conducted by the authors showed that this assumption was indeed reasonable – a set of 20 randomly selected gestures was examined. For each gesture, the postural stress scores (the sum of the left and right Group A scores) of the terminal postures and those of several intermediate postures obtained from video recordings were determined. For each of the 20 gestures, the postural stress scores of the intermediate postures were found to be between those of the two terminal postures.

To illustrate the OGSS computation scheme, an example is provided in Figure 4. It shows how the OGSS of a gesture is determined.



(a) The body part posture classification and scoring schemes for Group A

Upper arm	Lower arm	Wrist posture score							
		1		2		3		4	
		Wrist twist		Wrist twist		Wrist twist		Wrist twist	
		1	2	1	2	1	2	1	2
1	1	1	2	2	2	2	3	3	3
	2	2	2	2	2	3	3	3	3
	3	2	3	3	3	3	3	4	4
2	1	2	3	3	3	3	4	4	4
	2	3	3	3	3	3	4	4	4
	3	3	4	4	4	4	4	5	5
3	1	3	3	4	4	4	4	5	5
	2	3	4	4	4	4	4	5	5
	3	4	4	4	4	4	5	5	5
4	1	4	4	4	4	4	5	5	5

	2	4	4	4	4	4	5	5	5
	3	4	4	4	5	5	5	6	6
5	1	5	5	5	5	5	6	6	7
	2	5	6	6	6	6	7	7	7
	3	6	6	6	7	7	7	7	8
6	1	7	7	7	7	7	8	8	9
	2	8	8	8	8	8	9	9	9
	3	9	9	9	9	9	9	9	9

(b) The lookup table for determining the overall score for Group A

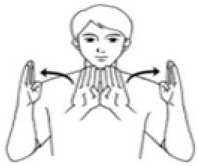
Figure 2. The RULA scoring system for Group A

① For the right side of the human body, the overall score for Group A is determined for each of the two terminal postures of the gesture: the initial and the final postures. The scores for the two terminal postures are then added together to determine the score for the right side.

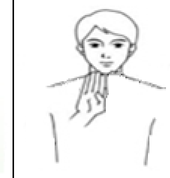
② Similarly, the score for the left side is determined.

③ Finally, the left and right side scores are added to produce the total score representing the physical stress level of the gesture. This total score was named the overall gestural stress score (OGSS). Its range of possible values is 4 to 36

Figure 3. The RULA-based computation scheme for quantifying the physical stress level of a gesture



Right



Initial posture

Body part	Score
Upper arm	1
Lower arm	3
Wrist	3
Wrist twist	1
Sum	3

Final posture

Body part	Score
Upper arm	1
Lower arm	2
Wrist	1
Wrist twist	1
Sum	2

Left

Initial posture

Body part	Score
Upper arm	1
Lower arm	3
Wrist	3
Wrist twist	1
Sum	3

Final posture

Body part	Score
Upper arm	1
Lower arm	2
Wrist	1
Wrist twist	1
Sum	2

Right		Left	
Initial posture	3	Initial posture	3
Final posture	2	Final posture	2
Sum	5	Sum	5
Overall gestural stress score (OGSS): 10			

Figure 4. An example illustrating the OGSS computation scheme

2-4 Data processing and analyses (step 4)

The main objective of the current study was to evaluate the usability of KSL gestures in the context of gesture-based interaction employing three usability criteria: intuitiveness, preference and physical stress. Especially, this study aimed to compare KSL gestures with user-designed gestures for relative evaluation. The following “null” hypotheses were tested via paired t-tests:

- The mean intuitiveness score of KSL gestures is not significantly different from that of user-designed gestures,
- The mean preference score of KSL gestures is not significantly different from that of user-designed gestures, and
- KSL gestures and user-designed gestures do not significantly differ in mean OGSS.

As for the testing of the first and second hypotheses, for each command, the mean intuitiveness and preference scores of the ten evaluators were computed for the KSL gesture; also, for each command, the mean intuitiveness and preference scores of all evaluator-gesture combinations were computed for the user-designed gestures. The paired t-tests were conducted on these mean scores data. Regarding the testing of the third hypothesis, for each command, the mean OGSS score of the user-designed gestures was computed; this mean value and the KSL gesture’s OGSS score were used for the paired t-test.

In addition to the comparative evaluation above, this study also investigated how gesture’s intuitiveness and physical stress are related to its preference. Scatter plots and correlation analyses were used.

SPSS 20.0 for Windows statistical package was used for all statistical analyses. The α-level was 0.05 for all statistical analyses.

3. RESULTS

The sign language method generated a total of 18 KSL gestures (one KSL gesture for each command). As for the user design method, the eight gesture designers produced a total of 144 user-designed gestures (144 gestures = 18 commands x 8 gesture designers). Visual examinations of the user-designed gestures revealed that for every command considered, multiple gesture designers produced identical gestures, and therefore, the total number of distinct (mutually distinguishable) gestures was less than eight. Figure 5 shows the number of distinct user-designed gestures for each command. The number of distinct user-designed gestures varied greatly across the commands, ranging from 2 to 7. The commands "push," "throw," "reverse," "scale down," and "return" respectively had only two distinct user-designed gestures indicating the lowest variety of user-designed gestures (in other words, the highest level of agreement among the designers). The largest variety was found for the "undo," "redo," "move," "stop" commands – seven distinct user-designed gestures were produced for these commands showing the highest level of disagreement.

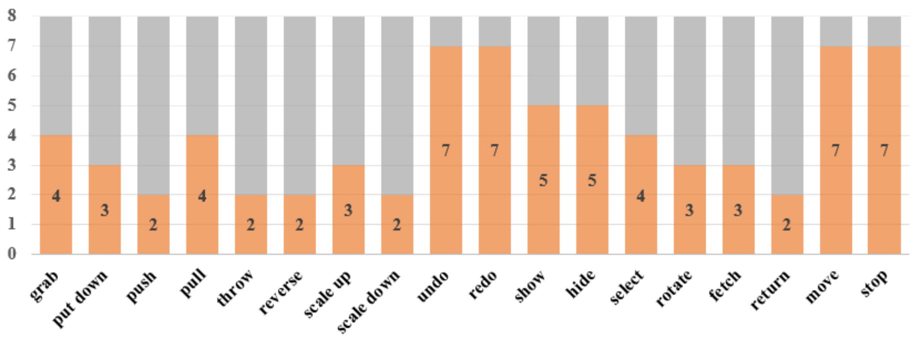


Figure 5. The number of distinct user-designed gestures produced for each command

The KSL and user-designed gestures for the command "grab" are graphically depicted in Figure 6 as examples of the gesture design results.

(a) Sign language

(b) User design

Figure 6. Gestures designed for the command “grab”

For each command, the eight gestures produced by the gesture designers were compared with the corresponding sign language gesture and the number of the gestures identical to the sign language gesture was determined. The result is summarized in Figure 7. The number varied greatly across the commands ranging from 0 to 7. Seven out of the eight gesture designers produced a gesture identical to the sign language gesture for the commands “push,” “throw,” and “reverse.” In contrast, for the commands “put down,” “undo,” “redo,” “select,” and “move,” there was no gesture identical to the sign language gesture for each command. Overall, 58 out of the 144 (40%) user-designed command-gesture pairs were found to be identical to the sign language command-gesture pair.

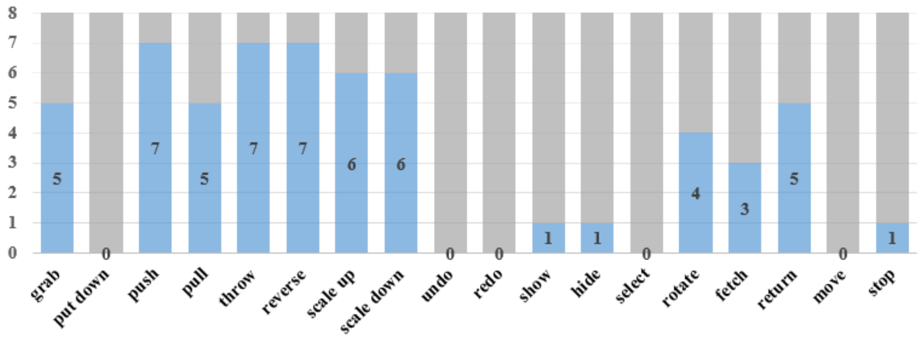


Figure 7. The number of user-designed gestures identical to the sign language gesture for each command

The relationship between the number of distinct user-designed gestures (per command) and that of user-designed gestures identical to the sign language gesture (per command) was examined. A negative relationship was found as depicted in Figure 8.

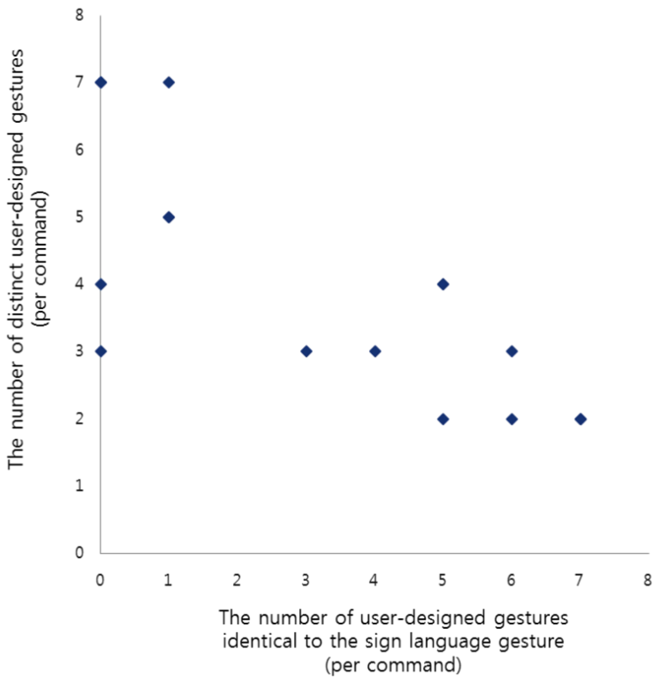


Figure 8. The relationship between the number of distinct user-designed gestures (per command) and the number of user-designed gestures identical to the sign language gesture (per command)

The results of the statistical analyses on the intuitiveness, preference and OGSS scores data are as follows:

- The intuitiveness scores of the sign language gestures and those of the user-designed gestures are summarized in Figure 9 using box-whisker plots. The grand mean of the intuitiveness scores for the KSL gestures was 4.24 while that for the user-designed gestures was 5.32. The paired t-test indicated that the mean difference of 1.08 was statistically significant (p-val=0.000).

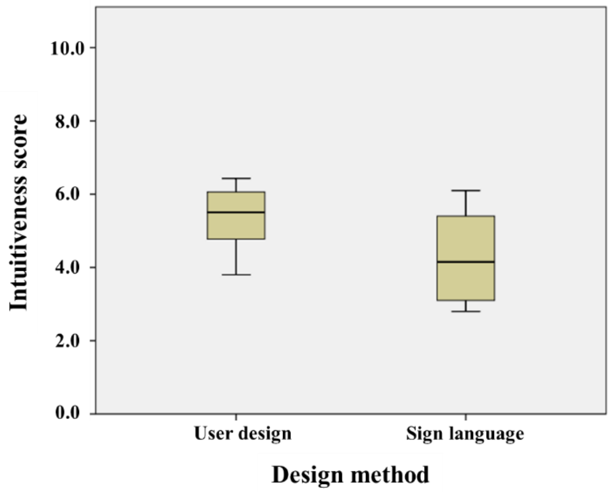


Figure 9. Intuitiveness score distributions for the two gesture design methods

- The preference scores of the sign language gestures and those of the user-designed gestures are summarized in Figure 10. The grand mean preference scores for the KSL and the user-designed gestures were 4.27 and 4.52 respectively. The means were not significantly different (p-val=0.356).

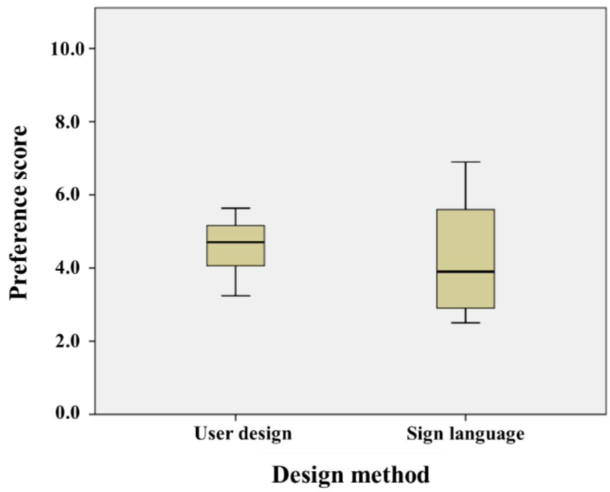


Figure 10. Preference score distributions for the two gesture design methods

- The OGSSs of the two groups of gestures are summarized in Figure 11. The grand mean OGSS scores for the KSL and the user-designed gestures were 9.72 and 10.29, respectively. The mean difference was not statistically significant (p-val=0.323).

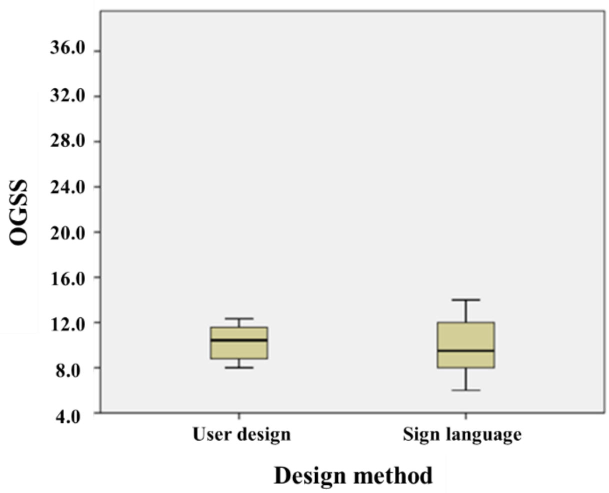


Figure 11. OGSS distributions for the two gesture design methods

Figure 12 shows the ratios (percentages) of the intuitiveness scores of the sign language command-gesture pairs to the top intuitiveness score of the 8 user-designed command-gesture pairs. If this ratio exceeds 100%, that is, for each command, the intuitiveness score of sign language command-gesture pair is higher than the top intuitiveness score of user-designed command-gesture pairs, it was considered as 100%.

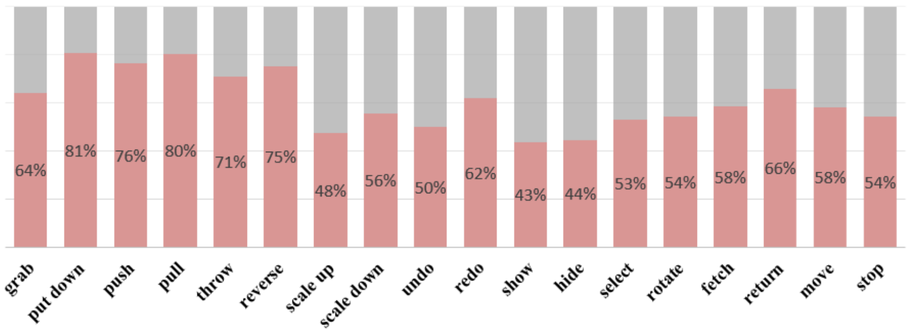


Figure 12. The ratios of the intuitiveness scores of the sign language command-gesture pairs to the top intuitiveness score of the user-designed command-gesture pairs

Overall, the average ratio of the intuitiveness scores of the sign language command-gesture pairs to the top intuitiveness score of the user-designed command-gesture pairs was about 60%. For the commands "put down,""push,""pull,""throw," and"reverse,"the ratio was higher than 70%. In contrast, for the commands "scale up,""show,"and"hide,"the ratio was even lower than 50%.

Similarly, the analysis for the preference measure was conducted as well, and the result is shown in Figure 13.

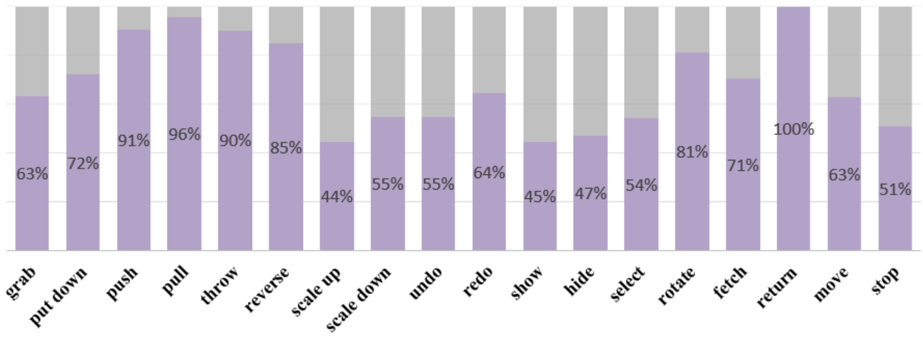


Figure 13. The ratios of the preference scores of the sign language command-gesture pairs to the top preference score of the user-designed command-gesture pairs

Overall, the average ratio of the preference scores of sign language command-gesture pair to the top preference score of user-designed command-gesture pairs was about 70%. For the commands“push,”“pull,”“throw,”and“return,”the ratio was higher than 90%. In contrast, for the commands “scale up,”“show,”and“hide,”the ratio was even lower than 50%.

Figure 14 shows the ratios (percentages) of the OGSSs of the sign language gestures to the lowest OGSS of the 8 user-designed gestures. If this ratio exceeds 100%, that is, for each command, the OGSS of sign language gesture is lower than the lowest OGSS of user-designed gestures, it was considered as 100%. For most commands, the OGSSs of sign language gestures were close to the lowest OGSS

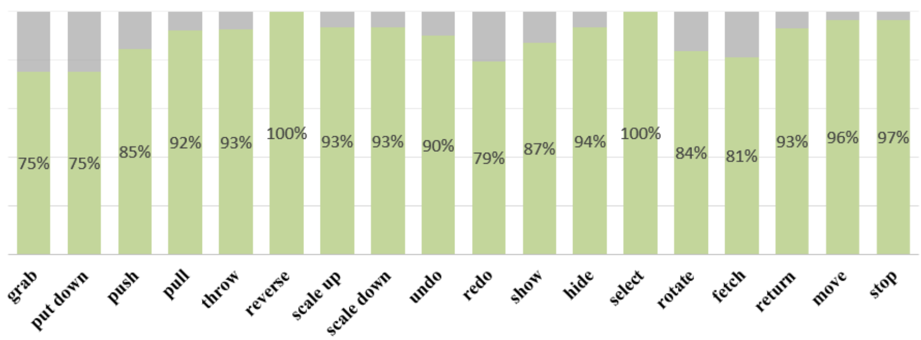
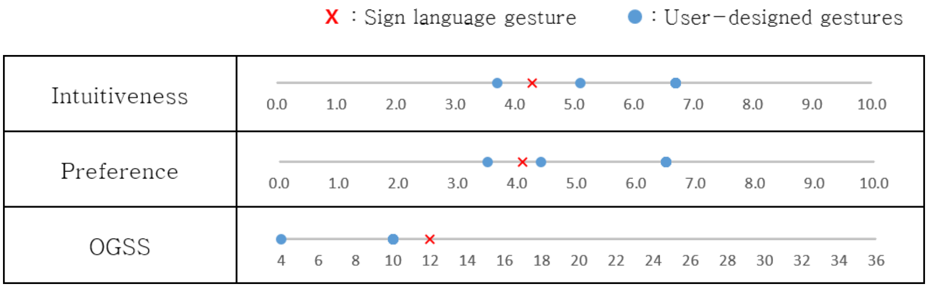
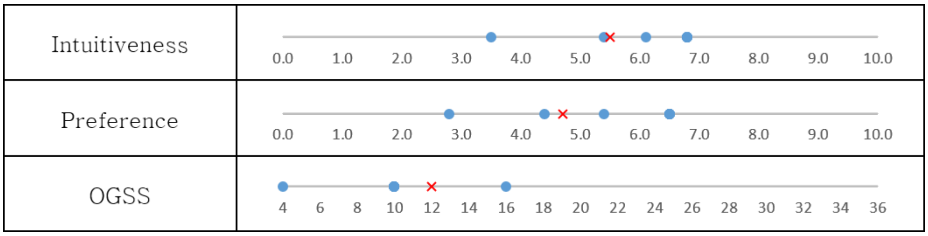


Figure 14. The ratios of the OGSSs of the sign language gestures to the lowest OGSS of the user-designed gestures

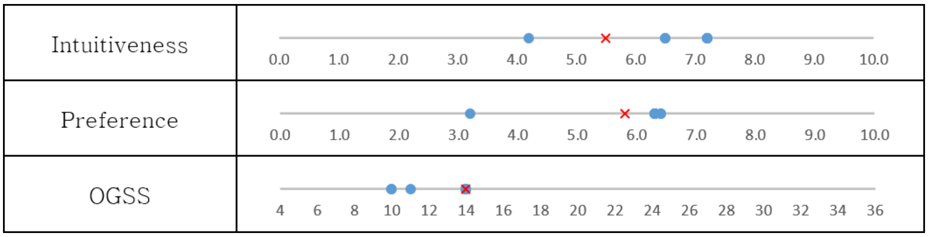
Figure 15 visually illustrates the distributions of the usability scores of the user-designed and sign language gestures for the 18 commands. Note that the X marks represent the scores for the sign language gestures and the dots, the scores for the user-designed gestures. For intuitiveness and preference, each X mark or dot represents the mean score of the ten evaluators for the corresponding gesture. For physical stress, each X mark or dot represents the OGSS of the corresponding gesture. For each usability criterion, the relative position of sign language gesture within score distribution varied substantially across the commands.



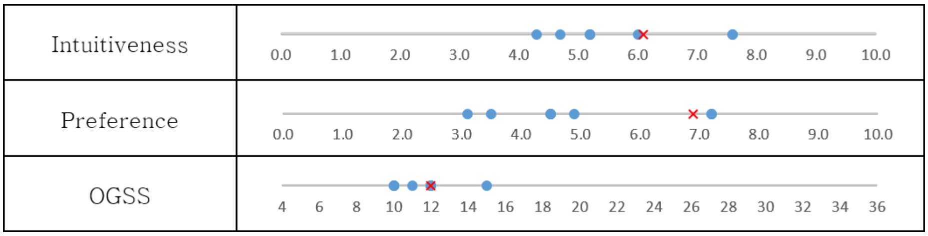
(a) grab



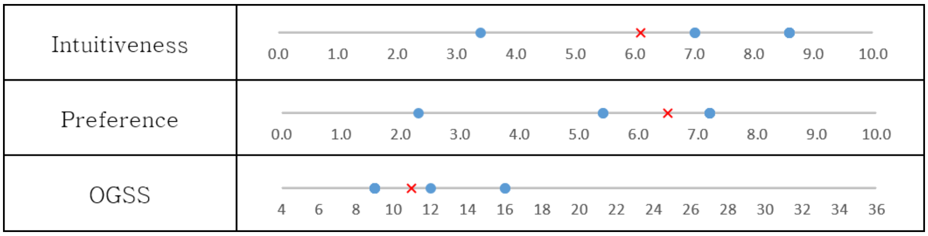
(b) put down



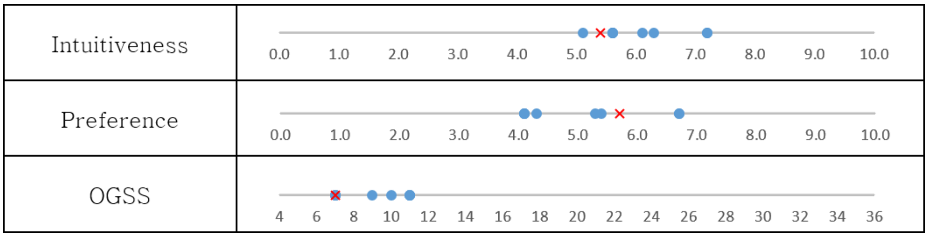
(c) push



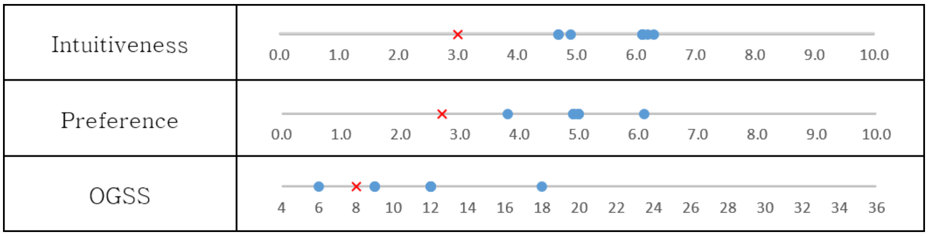
(d) pull



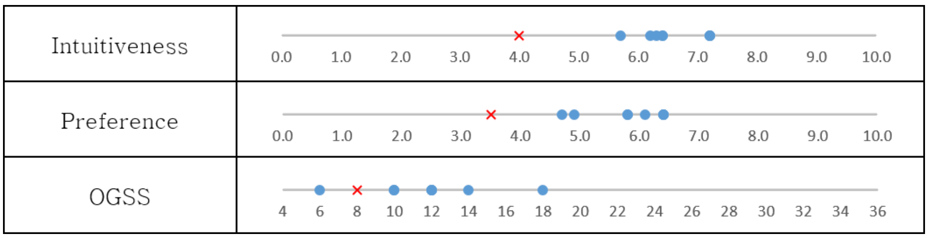
(e) throw



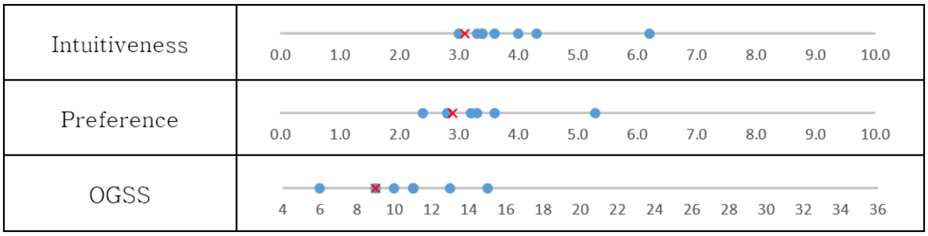
(f) reverse



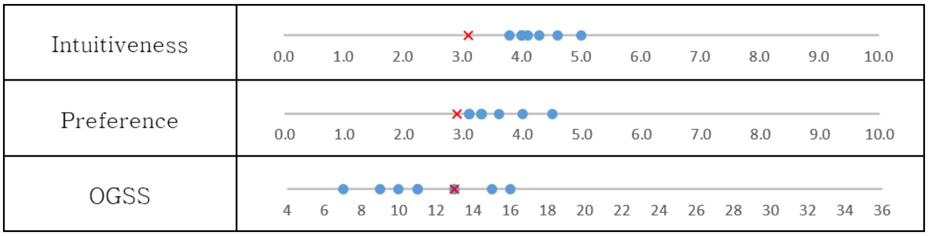
(g) scale up



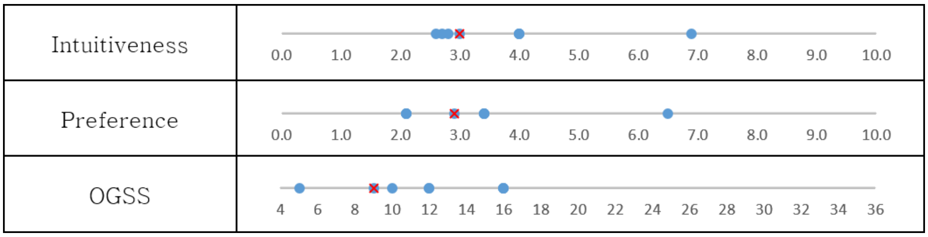
(h) scale down



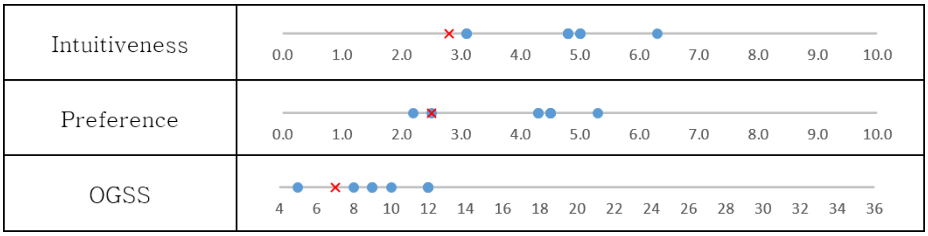
(i) undo



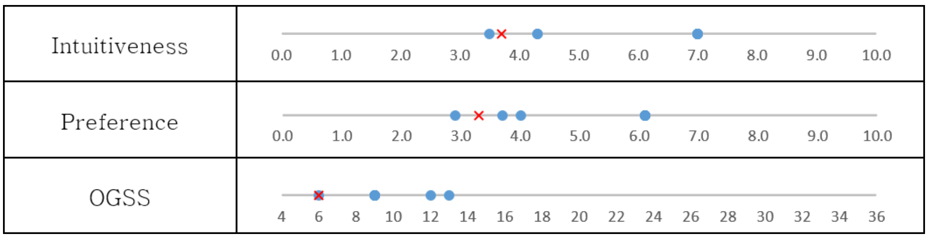
(j) redo



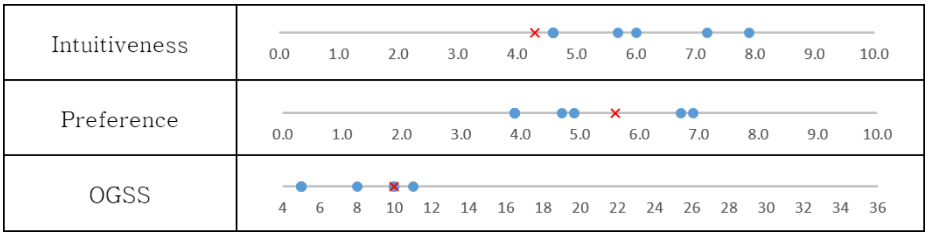
(k) show



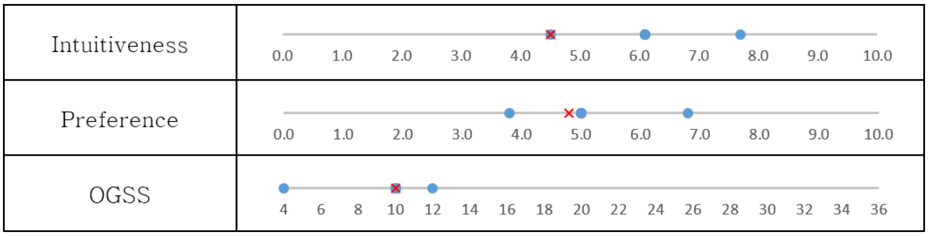
(l) hide



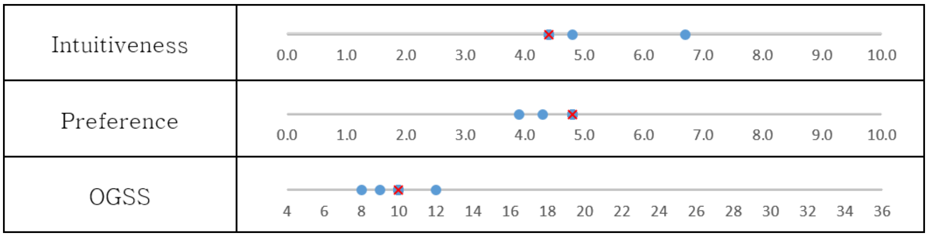
(m) select



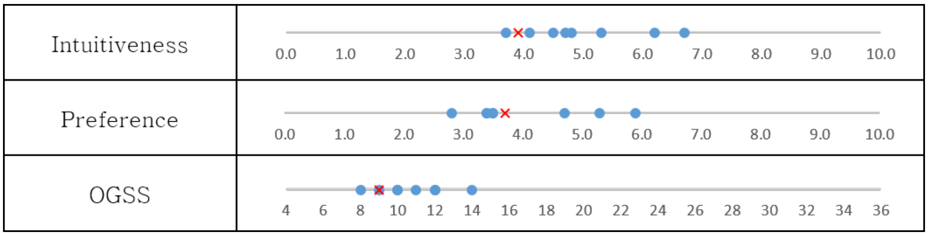
(n) rotate



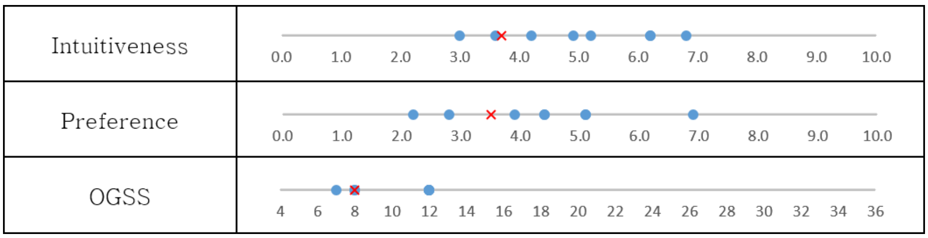
(o) fetch



(p) return



(q) move



(r) stop

Figure 15. The distributions of the usability scores of the user-designed and sign language gestures for the 18 commands

The relationship between gesture's preference and intuitiveness is provided in Figure 16. As can be seen in the scatter plot, a strong positive relationship was found. The correlation coefficient was 0.934 (p-value=0.000).

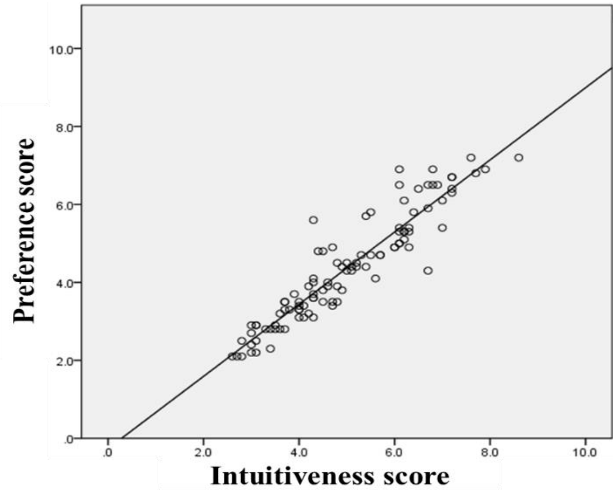


Figure 16. The relationship between preference and intuitiveness

The relationship between gesture's preference and physical stress (OGSS) is provided in Figure 17. A correlation analysis indicated that no significant relationship exists between the two quantities. The correlation coefficient value was -0.069 (p-value=0.488).

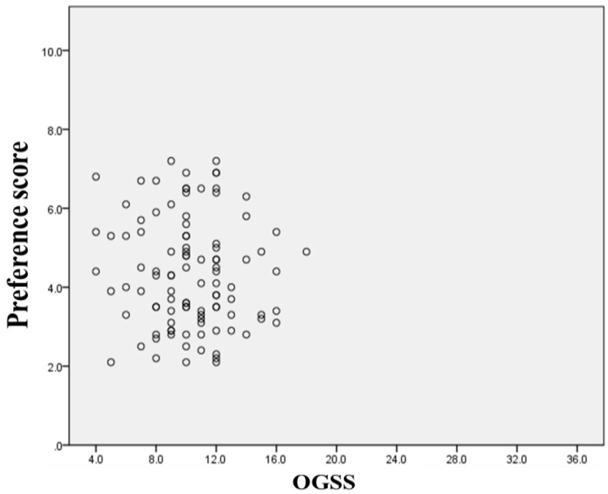


Figure 17. The relationship between preference and physical stress (OGSS)

4. DISCUSSION

Every command showed some level of agreement among the gesture designers – in other words, multiple gesture designers produced identical gestures for each command (Figure 5). The number of distinct user-designed gestures per command, which represents the level of disagreement among the gesture designers, varied substantially across the commands ranging from 2 to 7. This is consistent with the observation of Wobbrock et al. (2009) that some referents (commands) elicit high agreement while others do not. According to Wobbrock et al. (2009), commands that are low in conceptual complexity tend to result in high agreement among user designers. Such conceptually simpler commands also tend to be physical in nature and result in generation of "physical gestures," which are defined as gestures that physically act on objects (Wobbrock et al., 2009). The commands that elicited relatively high agreement among the user designers (only 2~3 distinct gestures) were: "put down," "push," "throw," "reverse," "scale up," "scale down," "rotate," "fetch" and "return" (Figure 5). These commands are associated with simple actions on objects and seem low in conceptual complexity. Visual examination of the user-designed gestures for these commands indeed revealed that they were mostly physical gestures involving simple actions on objects.

The commands that resulted in high disagreement (7 distinct gestures for a single command) were: "undo," "redo," "move," and "stop" (Figure 5). The "undo" and "redo" commands are not associated with simple physical actions on objects and seem conceptually more complex compared with other commands. The gestures produced for these two commands were mostly metaphorical or abstract according to the gesture classification scheme of Wobbrock et al. (2009).

The total number of the user-designed command-gesture pairs that are identical to the sign language command-gesture pair for each command was 58 accounting for 40% (58 out of 144) of the entire user-designed command-gesture set. The number of user-designed gestures identical to the sign language gesture per command varied substantially across the 18 commands as shown in Figure 7. Interestingly, the number of distinct user-designed gestures (the level of disagreement) and that of user-designed gestures identical to the sign language gesture per command were found to have a negative relationship (Figure 8). This negative relationship suggests that for a given command, an increase in the level of agreement among user designers is associated with an increase in the likelihood of a user-designed gesture being identical to an existing sign language gesture. In other words, if a user-designed gesture for a command achieves high agreement, it is likely to be a sign (a gesture) of an existing sign language for the referent. This interesting observation may be accounted for on the basis of the fact that sign languages are natural languages and their signs emerged as user-designed gestures and have evolved to their current forms through many individuals' contributions or consensus/agreement (Senghas et al., 2004; Stokoe, 2005). The negative relationship depicted in Figure 8 also allows a prediction that sign language gestures may be good design choices that many users find suitable when designing for conceptually simple commands. This is because conceptually simple referents tend to result in high agreement among user designers in the outcome of a user design process (Wobbrock et al., 2009). This hypothesis on the relationship between a referent's conceptual complexity and sign language gestures' perceived suitability is currently under our investigation.

The statistical analyses on the usability scores data indicated that the KSL gestures cannot be considered excellent in terms of intuitiveness and preference. The grand mean intuitiveness and preference scores for the KSL gestures were 4.24 and 4.27, respectively. These values were less than the midpoint of the rating scales and are considered to be in the "poor to fair" range. The mean OGSS score, however, was 9.72, which is thought to represent a low level of physical stress considering that the OGSS index has a range of 4 through 36. However, whether or not this level of physical stress is in the absolute sense acceptable for repetitive and/or prolonged gesture-based interaction tasks would need further investigations. The OGSS index should be regarded as allowing only comparative evaluation at this time.

The statistical comparisons with respect to the user-designed gestures further suggested that the KSL gestures are not necessarily a great design choice when viewed strictly from a usability standpoint. The grand mean intuitiveness score of the KSL gestures (4.24) was statistically significantly smaller than that of the user-designed gestures (5.32). This means that on average, KSL gestures are perceived as less intuitive than average user-designed gestures. The KSL and user-designed gestures did not exhibit statistically significant differences in the mean preference and physical stress scores. This indicates that on average, KSL gestures are comparable to average user-designed gestures in these criteria.

It should be noted that KSL gestures were found to be comparable not to the best or elite but to “average” user-designed gestures in the preference and physical stress criteria. Thus, optimal user-designed gestures chosen from multiple design candidates would likely outperform KSL gestures. This was indeed confirmed through an examination of the usability scores data – for 12 out of the 18 commands, one or more of the 8 user-designed gestures outperformed the KSL gesture in all three evaluation criteria considered in this study. In general, the user design approach is thought to be capable of producing more usable GVs than the sign language approach if many user designers participate to produce enough design candidates and some form of design optimization is performed.

In Figure 12 and 13, the ratios (percentages) of the intuitiveness (preference) scores of the sign language command-gesture pairs to the top intuitiveness (preference) score of the 8 user-designed command-gesture pairs were identified. These ratios varied substantially according to the characteristics of the commands. That is, for the commands that are associated with simple actions on objects and seem low in conceptual complexity such as “push,” “pull,” “throw,” and “reverse,” the ratio (percentage) of the intuitiveness (preference) scores of the sign language command-gesture pairs to the top intuitiveness (preference) score of the 8 user-designed command-gesture pairs was relatively high. In contrast, the commands that are not associated with simple physical actions on objects and seem conceptually complex such as “previous,” “next,” “appear,” and “hide,” the ratio was relatively low. Considering this outcome along with the results identified in Figure 8, conceptually simple referents tend to result in high agreement among user designers, and an increase in the level of agreement among user designers is associated with an increase in the likelihood of a user-designed gesture being identical to an existing sign language gesture. Therefore, the results that the intuitiveness (preference) scores of sign language command-gesture pairs for these commands were close to the top intuitiveness (preference) score of user-designed command-gesture pairs can be understood in the same context.

In Figure 14, the ratios (percentages) of the OGSSs of the sign language gestures to the lowest OGSS of the 8 user-designed gestures were identified. For most commands, the OGSSs of the sign language gestures were close to the lowest OGSS of the user-designed gestures. However, it should be noted that the OGSSs of both sign language gestures and user-designed gestures were lower than 16 points out of 36. Since the RULA-based computation scheme used in this study has some limitations such that it did not consider hand finger postures in evaluating physical stresses of upper extremity gestures, it needs some improvement.

For the 18 commands, the three usability score distributions of the gestures designed using the two design methods were identified in Figure 15. For the commands that are not associated with simple physical actions on objects and seem conceptually complex such as “scale up,” “scale down,” “undo,” and “redo,” the usability scores of the sign language gestures were in the lower ranks of the usability score ranges for the user-designed gestures. In contrast, for the commands that are associated with simple actions on objects and seem low in conceptual complexity such as “put down,” “push,” and “pull,” the usability scores of the sign language gestures were in the upper ranks of the usability score ranges for the user-designed gestures. These results were in accordance with the results in Figure 12, 13, and 14.

In addition to evaluating the usability of sign language gestures, the current study also investigated how gesture’s perceived intuitiveness and physical stress are related to its perceived preference. Interestingly, a strong positive relationship (correlation coefficient = 0.934) was found between preference and intuitiveness (Figure 16) while preference and physical stress score (OGSS) were found to have no significant relationship (Figure 17). These results seem to suggest that: 1) users do not or are not able to consider physical stress when subjectively evaluating a gesture in preference and 2) perceived intuitiveness is likely to be a good predictor of perceived preference. The results seem to have an important design implication that: gestures or GVs designed solely based on maximizing user preference or users’ agreement would not be optimal in terms of physical stress, and therefore, may not guarantee effectively protecting users from excessive physical stresses associated with gesture-based interaction. Physical stress may not be a critical issue if the duration of gesture interaction is short or the frequency of use is low. However, if a work task requires users to use gestures repetitively for long durations, it would likely become a design issue. Related to this, it is worth noting that sign language users have been reported to be at increased risks of upper extremity musculoskeletal disorders (Feuerstein et al., 1997; DeCaro et al., 1992; Meals et al., 1988). It is thought that physical stress must be considered in addition to other design criteria when designing GVs that are to be used in a repetitive or prolonged fashion. Stern et al. (2008a), Stern et al. (2008b) and Wachs et al. (2008)

developed a GV design methodology that considers the physical stress aspect along with other design criteria.

5. CONCLUSION

Utilizing gestures of major sign languages for gesture-based interaction seems to be an appealing idea as it has some obvious advantages, including: reduced time and cost for gesture vocabulary design, immediate accommodation of existing sign language users, helping deaf and speech-impaired individuals gain access to technology and supporting universal design and equality by design. However, very few research studies investigated whether or not sign language gestures are indeed adequate for gesture-based interaction, especially in terms of usability.

As an initial effort to enhance our understanding of the usability of sign language gestures, this study evaluated Korean Sign Language (KSL) gestures employing three usability criteria: intuitiveness, preference and physical stress. A set of 18 commands for manipulating objects in virtual worlds was determined. Then, gestures for the commands were designed using two design methods: the sign language method and the user design method. The sign language method consisted of simply identifying the KSL gestures corresponding to the commands. The user design method involved having user representatives freely design gestures for the commands. A group of evaluators evaluated the resulting gestures in intuitiveness and preference through subjective ratings. Physical stresses of the gestures were quantified using the OGSS index based on RULA. The usability scores of the KSL gestures were statistically compared with those of the user-designed gestures for relative evaluation.

Overall, the current study findings suggest that the sign language approach would not result in GVs excellent in usability and the user-design approach would be a better choice if the focus is on optimizing usability. However, as mentioned earlier, the sign language approach provides multiple advantages that are lacking in the user design and other approaches based on the "creating gestures from scratch" paradigm. This must be taken into account when designing GVs. Ultimately, the choice between design approaches should be guided by an understanding of the target application.

Given the relative strengths and weaknesses of the sign language approach, some design strategies utilizing sign language gestures may be suggested:

- In situations where universal access or accommodation of existing sign language users is critical, the sign language approach would be desirable,
- If design time and cost reduction is critical, the sign language approach may be a possibility. In fact, sign language gestures could help reduce design time and cost even if the sign language approach is not employed; a possible strategy for design time and cost reduction is to use existing sign language gestures to create an initial GV and improve the GV through agile redesign based on user feedback. Only the sign language gestures with low usability scores need to be replaced with new designs. This strategy may have an additional benefit that the resulting GV will exhibit a certain level of similarity to an existing sign language, which may be well received by the sign language user community.
- Another possibly effective design strategy would be to develop interaction systems such that they understand multiple GVs. Such multiple GVs that the systems understand must include a sign-language GV and a user-designed GV that is optimal in terms of usability. When interacting with such "multi-lingual" or "multi-GV" systems, the users shall select from the available GVs. This type of gesture-based interaction systems will provide immediate accommodation to the existing sign language users, and, at the same time, offer a highly usable GV to non-sign language users. The downside of this design approach, however, is that it still requires costly and time-consuming user design.

Some limitations of the current study are acknowledged along with future research ideas: first, this study considered only KSL gestures. Sign languages have emerged and evolved in many communities and countries; and, currently, numerous sign languages are known to be in use - the Ethnologue database (Lewis, 2009) provides a list of 121 different sign languages. Other major sign languages need to be investigated in future studies. Some sign languages may turn out to be better than the KSL and indeed highly acceptable in terms of usability in the context of gesture-based interaction. Second, this first study considered intuitiveness, preference and physical stress among various usability criteria. Our on-going work is currently evaluating gestures employing other usability criteria, such as guessability, learnability and memorability.

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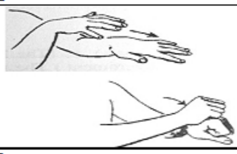
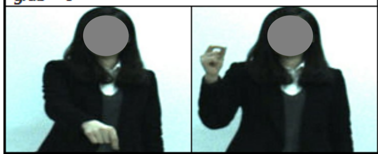
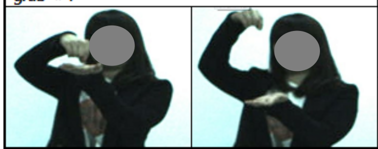
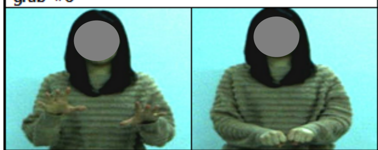
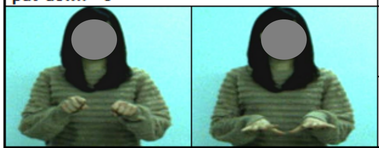
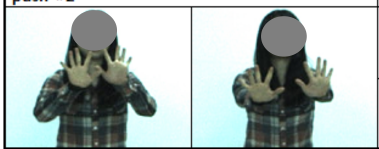
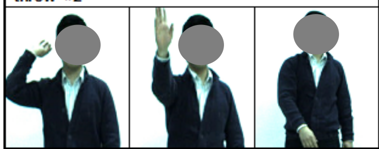
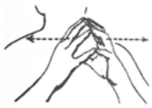
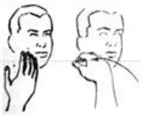
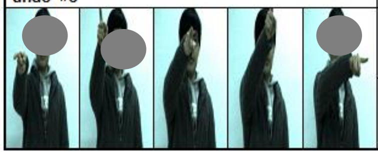
APPENDIX : Usability evaluation form

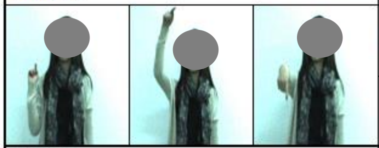
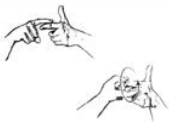
grab #1	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
grab #2	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
grab #3	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
grab #4	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
grab #5	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
grab #6	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
put down #1	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
put down #2	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10

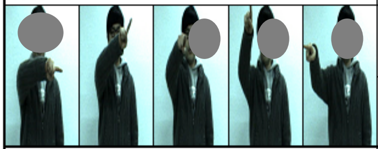
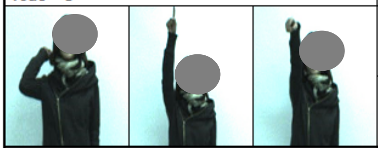
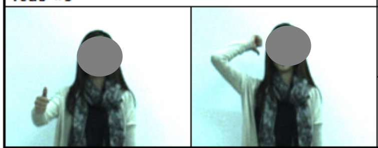
put down #3	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
put down #4	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
put down #5	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
push #1	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
push #2	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
push #3	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
pull #1	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
pull #2	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10

pull #3	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
pull #4	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
pull #5	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
throw #1	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
throw #2	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
throw #3	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
reverse #1	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
reverse #2	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10

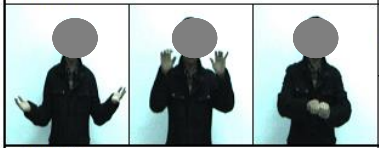
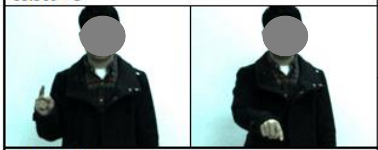
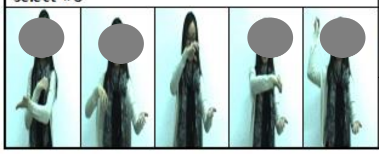
reverse #3	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
Scale up #1	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
Scale up #2	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
scale up #3	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
scale up #4	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
scale up #5	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
Scale down #1	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
Scale down #2	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10

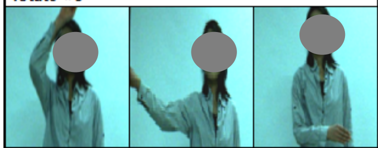
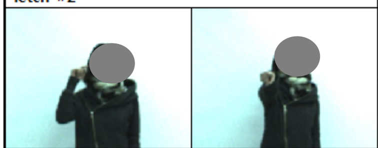
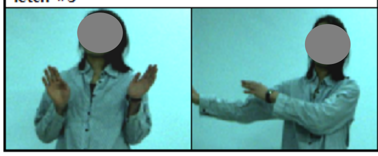
Scale down #3	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
Scale down #4	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
undo #1	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
undo #2	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
undo #3	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
undo #4	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
undo #5	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
undo #6	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10

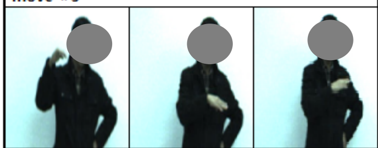
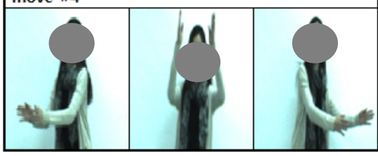
undo #7	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
undo #8	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
undo #9	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
redo #1	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
redo #2	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
redo #3	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
redo #4	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
redo #5	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10

redo #6	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
redo #7	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
redo #8	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
redo #9	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
show #1	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
show #2	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
show #3	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
show #4	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10

show #5	문항	Borg's CR10 Scale										
 	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
show #6	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
show #7	문항	Borg's CR10 Scale										
 	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
hide #1	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
hide #2	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
hide #3	문항	Borg's CR10 Scale										
 	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
hide #4	문항	Borg's CR10 Scale										
 	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
hide #5	문항	Borg's CR10 Scale										
 	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10

hide #6	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
hide #7	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
select #1	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
select #2	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
select #3	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
select #4	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
select #5	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
select #6	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10

rotate #1	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
rotate #2	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
rotate #3	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
rotate #4	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
rotate #5	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
fetch #1	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
fetch #2	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
fetch #3	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10

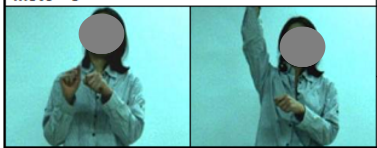
fetch #4	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
return #1	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
return #2	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
return #3	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
move #1	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
move #2	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
move #3	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
move #4	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10

move #5	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10

move #6	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10

move #7	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10

move #8	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10

move #9	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10

stop #1	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10

stop #2	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10

stop #3	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10

stop #4	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
stop #5	문항	Borg's CR10 Scale										
 	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
stop #6	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
stop #7	문항	Borg's CR10 Scale										
 	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10
stop #8	문항	Borg's CR10 Scale										
	Intuitiveness	0	1	2	3	4	5	6	7	8	9	10
	Preference	0	1	2	3	4	5	6	7	8	9	10

ABSTRACT

Evaluating the usability of sign language gestures for gesture-based human-machine interaction

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Utilizing gestures of major sign languages (signs) for gesture-based interaction seems to be an appealing idea as it has some obvious advantages, including: reduced time and cost for gesture vocabulary design, immediate accommodation of existing sign language users and supporting universal design and equality by design. However, it is not well understood whether or not sign language gestures are indeed adequate for gesture-based interaction, especially in terms of usability. As an initial effort to enhance our understanding of the usability of sign language gestures, the current study evaluated Korean Sign Language (KSL) gestures employing three usability criteria: intuitiveness, preference and physical stress. A set of 18 commands for manipulating objects in virtual worlds was determined. Then, gestures for the commands were designed using two design methods: the sign language method and the user design method. The sign language method consisted of simply identifying the KSL gestures corresponding to the commands. The user design method involved having user representatives freely design gestures for the commands. A group of evaluators evaluated the resulting sign language and user-designed gestures in intuitiveness and preference through subjective ratings. Physical stresses of the gestures were quantified using an index developed based on Rapid Upper Limb Assessment. The usability scores of the KSL gestures were compared with those of the user-designed gestures for relative evaluation. Data analyses indicated that overall, the use of the KSL gestures cannot be regarded as an excellent design strategy when viewed strictly from a usability standpoint, and the user-design approach would likely produce more usable gestures than the sign language approach if design optimization is performed using a large set of user-designed gestures. Based on the study findings, some gesture vocabulary design strategies utilizing sign language gestures are discussed. The study findings may inform future gesture vocabulary design efforts.

Keywords : sign language, gesture, gesture-based interaction, gesture vocabulary, usability

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