

Biofeedback vs. Game Scores for Reducing Trunk Compensation after Stroke: A Randomized Crossover Trial

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Geolocation Information

Location where study was conducted: 49°15'40.5"N 123°14'56.2"W.

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Background: Compensatory movements are commonly employed by stroke survivors, and their use can have negative effects on motor recovery. Current practices to reduce them rely on strapping a person to a chair. The use of technology to substitute or supplement this methodology has not been thoroughly investigated.

Objective: To compare the use of Scores+Visual+Force and Visual+Force feedback for reducing trunk compensation.

Methods: Fourteen hemiparetic stroke survivors performed bimanual reaching movements while receiving feedback on trunk compensation. Participants held onto two robotic arms and performed movements in the anterior/posterior direction towards a target displayed on a monitor. A motion-tracking camera tracked trunk compensation; the robots provided force feedback; the monitor displayed the visual feedback and scores. Kinematic variables, a post-test questionnaire, and system usability were analyzed.

Results: Both conditions reduced trunk compensation from baseline: Scores+Visual+Force: 51.7% (40.8), $p=0.000$; Visual+Force: 55.2% (40.9), $p=0.000$. No statistically significant difference was found between modalities. Secondary outcome measures were not improved. Most participants would like to receive game scores to reduce trunk compensation, and the usability of the system was rated “Good”.

Conclusions: Multimodal feedback about stroke survivors’ trunk compensation levels resulted in reduced trunk displacement. No difference between feedback modalities was obtained. The positive effects of including game scores might not have been observed in a short-term

intervention. Longer studies should investigate if the use of game scores could result in trunk compensation improvements when compared to trunk restraint strategies.

Key Words: Feedback; hemiplegia; robotics; stroke rehabilitation; trunk compensation; upper extremity; virtual rehabilitation.

Introduction

Compensatory strategies are employed by stroke survivors to adapt to the loss of motor function. However, their long-term use can negatively impact recovery^{1,2,3}. It is suggested that compensatory strategies might be controlled by regions of the central nervous system that were less severely affected by the stroke; however, a clear understanding and distinction of the neural mechanisms driven by actual motor recovery versus compensation is still lacking⁴. In this study, we focus on reducing trunk compensation, a movement frequently observed when people with hemiparesis reach forward^{5,6}. As a result of the ubiquitous presence of trunk displacement in reaching patterns of stroke survivors, a reduction of this movement could be used to characterize “true” motor recovery at the body function/structure level¹, and serve as an assessment metric of the survivors’ progress in therapy.

Over the past few decades robotic devices, virtual environments, and serious games used in the context of rehabilitation have provided researchers and therapists with the opportunity to employ augmented feedback to promote changes in motor behavior^{7,8,9}. However, little attention^{10,11,12} has been given to the role of technology in the reduction of compensation. One current therapeutic approach to reduce trunk compensation relies on the use of physical restraints (straps/harnesses) to secure a person to a chair¹³. The training of arm movements while employing trunk restraints has led to improvements in reaching kinematic measurements². Thus, it seems that premorbid movement patterns may not be completely lost after stroke, but that they remain masked by the use of alternate compensatory strategies¹⁴. However, the feedback that a person receives when using trunk restraints is merely a physical movement constraint, which is continuously activated and precludes the opportunity to measure progress and change the level of restraint. Moreover, varying the frequency at which this information is given could also help to

prevent reliance on the feedback itself, making it more likely that improvements be maintained when the feedback is removed¹⁵. These observations open up a new set of possibilities for using computer and robotic technologies as a complement to or substitute for current trunk restraint strategies for providing extrinsic feedback to stroke survivors about their level of compensation^{10,11}.

In a previous study¹², we found that visual or force feedback was capable of promoting a reduction in trunk compensation. At the end of that intervention, a large proportion of participants expressed that they would like to receive both feedback conditions simultaneously, even though they only received each one alone during the trials. Some of the reasons participants provided were: it would be easier to perceive the feedback if it came from both sources, it would provide them with more information, and they understood both feedback conditions equally. These results, in addition to the current unanswered question of which type and characteristics of feedback are optimal for motor learning^{16,17}, guided the present work in which we combined Visual+Force feedback to investigate their effect on trunk compensation. Furthermore, as video games have shown promise as a strategy to improve health-related outcomes^{18,19}, we investigated if adding game scores to a virtual reaching task would provide any benefit when compared to just providing biofeedback about trunk compensation. As such, the overall objective of the study was to compare two multimodal augmented feedback conditions (Scores+Visual+Force and Visual+Force alone) to reduce trunk compensation.

The research questions we investigated were: Will the use of Scores+Visual+Force and the use of Visual+Force feedback reduce trunk compensation?; Will one of these feedback modalities be more effective than the other in reducing trunk compensation?

Methods

Participants

Fourteen participants (Table 1) were recruited from the community, stroke recovery groups, clinics, hospitals, and from a list of participants of a previous phase of this study¹². Inclusion and exclusion criteria are presented in Figure 1. The previous study was a single session conducted seven months before this work. Given the time that had passed, we were not expecting to find any long-term and/or memory effects that could affect the results of this intervention. This was confirmed by a statistical test ($t(8)=0.124$, $p=0.904$) of the baseline measurements of both phases (no difference), and by the fact that both feedback conditions reduced trunk compensation in our current study. The sample size was based on two previous short-term interventions that focused on strategies to reduce trunk compensation^{20,12}; these studies had sufficient power to observe significant changes. Participants provided written consent, and the study was approved by the university's Research Ethics Board.

Table 1. Participants' Demographic and Clinical Descriptive Information

Participant	Sex	Age (years)	Height (cm)	DHBS	Affected Side	Type of Stroke	TSS (months)	UE FMA (max. 66)	RPS (max. 36)
S-01	M	69	168	R	L	I	60	36	24
S-02	M	48	170	L	L	I	38	32	17
S-03	F	59	156	R	R	I	180	31	11
S-04	M	65	170	R	R	I	144	40	28
S-05	F	55	163	R	L	I	73	49	34
S-06	M	63	178	R	R	I	29	58	33
S-07	F	46	172	R	L	I	22	58	36
S-08	M	70	175	R	R	I	109	23	8
S-09	M	59	180	R	R	H	33	29	17
S-10	M	64	161	R	R	NP	6	14	1
S-11	F	36	150	R	L	I	301	29	18
S-12	F	53	156	R	L	I	73	35	25
S-13	F	65	152	R	L	I	72	16	7
S-14	M	59	168	R	R	H	44	21	10
Average		57.9	165.6				84.6	33.6	19.2
SD		9.6	9.5				78.8	13.8	11.1

DHBS: Dominant hand before stroke, F: Female, FMA: Fugl-Meyer Assessment, H: Hemorrhagic, I: Ischemic, L: Left, M: Male, NP: Not provided, R: Right, RPS: Reaching Performance Scale, TSS: Time since stroke, UE: Upper Extremity.

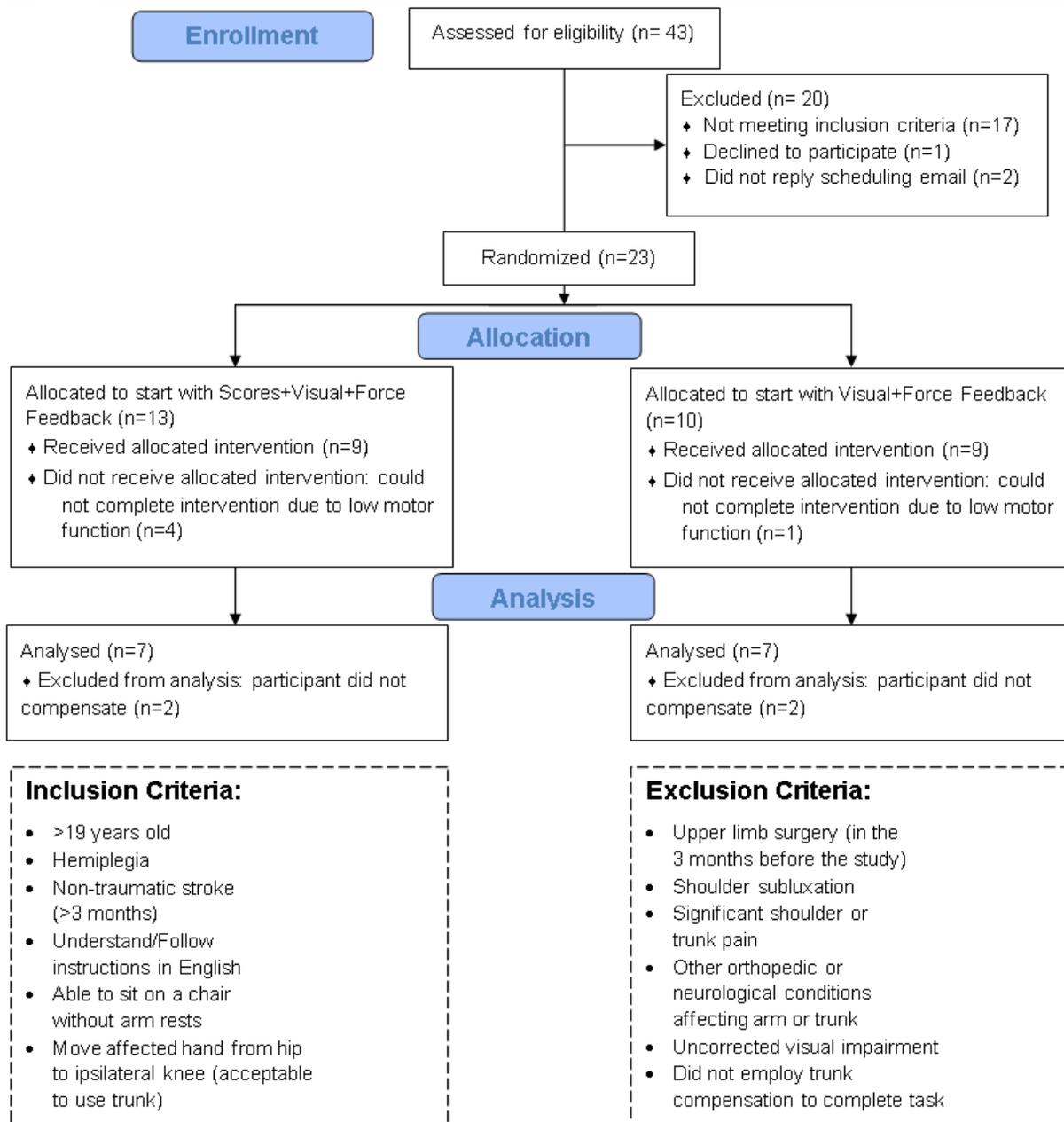


Figure 1. Allocation and randomization. Enrollment, randomization, and assignment to interventions were conducted by the first author. Trial was conducted from Sep. to Dec. 2016. A pseudo-random number generator (Sealed Envelope Ltd., London, UK) was used to generate the allocation sequence. Participants were not aware of their allocation until after the baseline trials were completed.

Clinical Evaluation

The Upper Extremity Fugl-Meyer Assessment²¹ (FMA) was administered to measure motor impairment, and the Reaching Performance Scale²² was employed to measure trunk compensation. Both scales were administered by registered occupational therapists at baseline (Table 1).

Trial Design

This study used a crossover design (Figure 2), in which all participants experienced both feedback conditions. Participants were stratified based on FMA scores (<50 moderate to severe; ≥ 50 mild, ^{23,24}) to ensure group balance, and blocked randomized approach (block size: 2) to start with one feedback condition or the other (Figure 2).

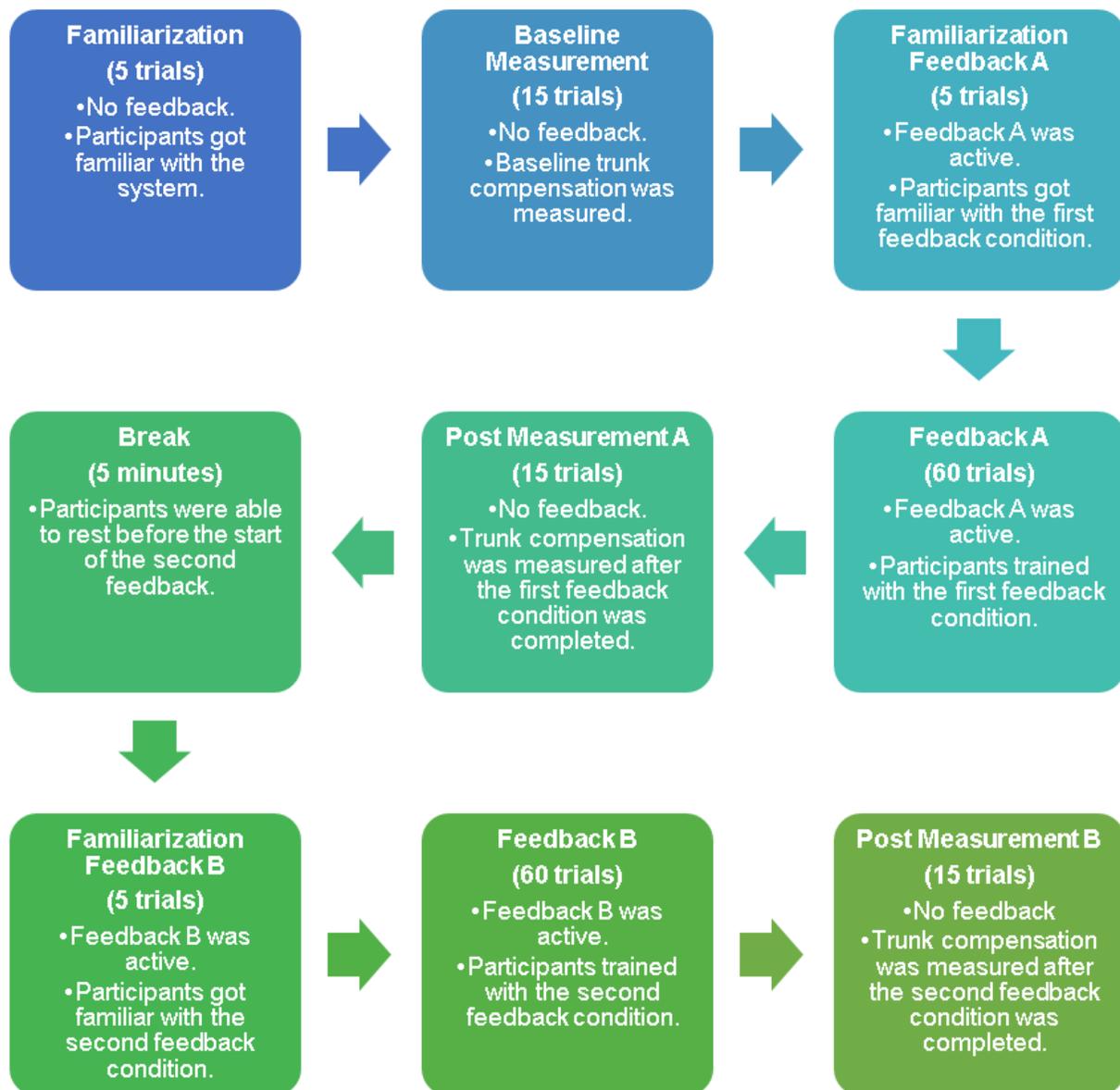


Figure 2. Trial design. After the baseline measurements, participants were randomized to start with either Scores+Visual+Force or Visual+Force feedback. This was a low-risk study, with fatigue being the only potential harm. To reduce fatigue, participants received a 1 minute rest every 15 trials. In addition, participants were allowed to take breaks when they requested. An average of 13 (10) minutes elapsed between the end of the first feedback condition and the start of the second one.

Experimental Setup

The system (Figure 3, left) included a Kinect v2 (Microsoft Corporation, Redmond, WA, USA) camera, and two Jaco v2 (Kinova Robotics, Boisbriand, QC, Canada) robotic arms. The devices were controlled by a computer running LabVIEW 2014 (National Instruments Corporation, Austin, TX, USA), which displayed the reaching task on a monitor. In addition, an extra monitor, only visible to the researchers, was used to supervise the system's inputs and outputs.

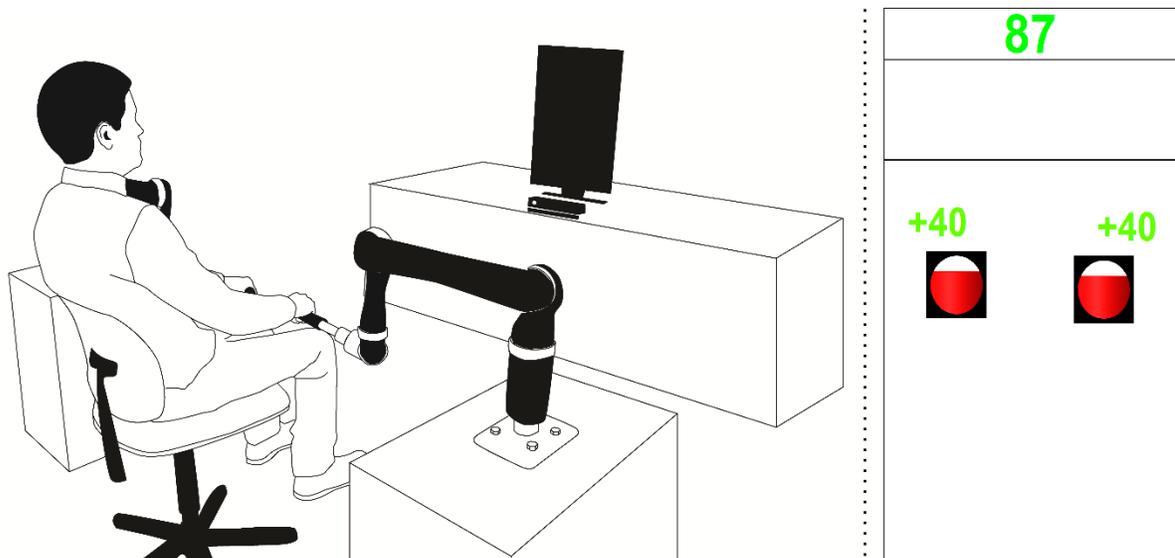


Figure 3. Experimental setup (left) and task (right).

Left Panel: Two robotic arms were used to interact with the system and to provide force feedback to participants. A computer monitor displayed the reaching task, visual feedback, and scores. A motion tracking camera captured the participants' trunk compensation.

Right Panel: The two lines at the top of the figure are the target boundaries. Each cursor represented one of the participants' hands. The fill level (visual feedback) inside the cursors represented the level of trunk compensation. The total score was displayed on top of the screen, added scores were shown on top of the cursors for one second.

Experimental Task

Participants held onto the handles of the robots, while seated on a chair (Figure 3, left) with a height-adjustable footrest (knees at 90°). Before the start of the trials, an initial position was calibrated, with participants seated in an upright position and their hands close to their hips. This position was used to ensure consistency of the starting point of all reaching movements. In addition, to set the required distance for the reaching task, participants were asked to move their unaffected arm from their hips to their ipsilateral knee.

The task required participants to perform bimanual reaching movements from their hips to their knees. The hands' forward/backward movements were translated to cursor movements on the screen (Figure 3, right). The instructions were to move the two cursors (one for each hand) past two target lines for one second. After each trial, a screen was presented to help participants move their hands back to the initial position. When the feedback was off or when participants were not compensating, the robotic devices were free to move and did not apply any resistance.

The level of all feedback conditions was proportional to the amount of trunk compensation captured by the motion tracking camera (Figure 4). For the first 30 mm of trunk compensation no feedback was activated, as these values were considered to be inside the threshold of “healthy” compensation⁶. Above that threshold, the feedback followed a linear relation with the amount of trunk compensation. The maximum feedback was set to be provided at 50% of the exhibited baseline trunk compensation. This desired improvement in trunk compensation was considered to be adequate for a short-term intervention¹². However, in longer

studies, this value could be adjusted after every session to accommodate for any continuous improvement/decline in participants' motor function.

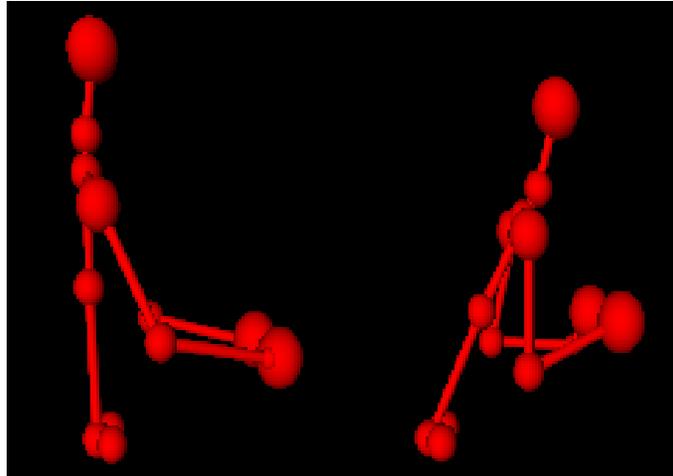


Figure 4. Skeleton captured by motion tracking camera. Participant reaching without using trunk compensation (left), and with compensation (right).

Visual feedback was represented by an increase in the cursors' fill level (Figure 3, right), with more “ink” present in the circles when more compensation was exhibited. This feedback was selected for its simplicity, and because participants were likely already familiar with this type of representation (e.g., fuel/battery indicators).

Force feedback was provided as an increase in the required minimum force to move the robots, which acted as a cue to make users aware of their compensation. When no compensation was present, the robots were free to move: as participants started compensating they would need to apply larger forces to move in the forward direction. The maximum feedback was set to the robots' torque limit (9.5 Nm). If required, the maximum value was reduced if participants were not capable of moving the robotic devices when exhibiting maximum compensation during the familiarization trials. This strategy ensured that all participants were capable of reaching the

target even when they compensated. During the familiarization trials, all participants confirmed that they could sense the change in force when compensating.

When the scores were active, participants gained points by moving both hands without trunk compensation. To ensure that participants were rewarded by exhibiting a positive behavior (no compensation) throughout the reaching task, they were able to collect points at four different stages when moving towards the target. At each stage they were able to collect a maximum of one hundred points. In addition, an extra one hundred points were awarded when participants completed the reaching movement (regardless of compensation) to avoid users getting zero points in any trial. These extra points were implemented to handle failure (not able to reduce compensation in a specific trial) in a positive way²⁵, which could reduce the chances of participants' discouragement and diminished motivation due to the lack of accumulated points, especially in individuals with lower motor function.

Data Analysis

The main outcome measure was trunk compensation: anterior displacement of the Kinect-measured shoulder-spine joint. Secondary outcome measures included: Trunk Rotation: angle between shoulder joints and frontal plane; Time: from target presentation to movement completion; Index of Curvature: ratio between hands' paths and a straight line; Root Mean Square (RMS) Error: measure of bimanual symmetry calculated by subtracting the distance between the hands' positions on every captured frame. All variables were measured at baseline and in post trials (Figure 2).

The motion data were filtered to remove inaccurate measured positions when any of the joints did not have a “tracked” state, as indicated by the Kinect’s motion log. In addition, the data were resampled at 20 Hz, and a 6 Hz low-pass Butterworth filter was applied.

A questionnaire was administered at the end of the intervention to investigate the usability of the system (System Usability Scale: SUS²⁶) and the participants’ experience with the devices and feedback.

Statistical Analysis

To compare if one feedback condition was superior to the other one, an Analysis of Covariance (ANCOVA) was employed with the baseline measurements as the covariate, a between-factor of group (which feedback was received first) and a within-factor of treatment (Scores+Visual+Force and Visual+Force Feedback). To investigate if either one of the feedback conditions improved the kinematic variables from baseline, a one-sample t-test was conducted on the percentage gains (changes from baseline to post measurements) against a mean value of 0 (no change). Holm-Bonferroni correction²⁷ was employed for the statistical tests. Cohen’s *d* was used as a measure of effect size²⁸. A 95% Confidence Interval was calculated for significant results. Where violations to statistical model assumptions occurred, less restrictive models were employed to corroborate the results (Mixed ANOVA, and non-parametric Mann-Whitney U Test and Sign Test). All statistical models’ assumptions and tests were conducted in SPSS Statistics v22.0 (IBM Corp., Armonk, NY, USA).

In addition to examining the percentages of responses for each Likert item in the post-test questionnaire (appendix), Likert Scales (several questions examining the same underlying belief) were analyzed using a t-test against a neutral response (neither agree nor disagree).

Results

For the primary outcome measure, both feedback conditions were capable of reducing trunk compensation from baseline (Table 2, left). For both feedback conditions, a significantly ($p \leq .001$) large effect (Scores+Visual+Force:1.27, Visual+Force:1.35) was observed. Secondary outcome measures did not reach a statistically significant change.

Table 2. Feedback percentage change from baseline (left). Comparison between Scores+Visual+Force and Visual+Force Feedback (right).

	Percentage change from Baseline to Post measurements			Post SVF vs. Post VF		
	Post SVF	Post VF		Baseline	Post SVF	Post VF
Trunk Displacement (%)	-51.7 (40.8)*** <i>t(13)=-4.73</i> <i>p ≤ 001</i> <i>d=1.27</i> <i>Int: -75.2,-28.1</i>	-55.2 (40.9)*** <i>t(13)=-5.05</i> <i>p ≤ 001</i> <i>d=1.35</i> <i>Int: -78.8,-31.6</i>	Trunk Displacement (mm)	101.4 (70.2)	55.1 (73.8)	51.6 (71.4)
Trunk Rotation (%)	-2.4 [-28.1, 97.9]	13.6 [-13.0, 77.2]	Trunk Rotation (°)	0.97 (5.8)	-0.59 (6.6)	0.07 (6.3)
Time (%)	-4.7 (21.8)	-11.1 (18.1)	Time (s)	5.2 (1.3)	4.9 (1.7)	4.5 (0.99)
Index Curv. Left YZ (%)	0.83 [-5.1,5.3]	0.16 [-6.2,4.8]	Index Curv. Left YZ	1.1 (0.21)	1.0 (0.1)	1.0 (0.14)
Index Curv. Right YZ (%)	-0.83 [-4.98, 1.84]	-0.84 [-7.1, 1.7]	Index Curv. Right YZ	1.1 (0.33)	1.1 (0.13)	1.1 (0.13)
RMS Z (%)	-2.9 [-21.6, 31.6]	3.1 [-10.2, 24.4]	RMS Z (mm)	18 (9.0)	17.5 (7.6)	20.2 (12.3)
RMS Y (%)	20.4 [-34.5, 55.1]	14.5 [-21.8, 29.2]	RMS Y (mm)	35.6 (15.7)	40.2 (23.6)	41.2 (20.8)

d: Cohen's *d*. *Int.*: 95% Confidence Interval. *p*= *p* value. RMS: Root Mean Square. *t(degrees of freedom)*: *t* value. SVF: Scores+Visual+Force Feedback. VF: Visual+Force Feedback. Mean (SD). Median [1st and 3rd quartile]. Significant results are bolded (**p*<.05, ***p*<.01, ****p*<.001).

When comparing which feedback condition was superior to the other one (Table 2, right), we did not find any statistically significant difference between employing Scores+Visual+Force and Visual+Force Feedback.

Figure 5 presents a selection of questions from the post-test questionnaire; remaining questions are presented in the appendix. A mix of responses was obtained when participants were asked if they had moved their trunk to reach the targets (36% agree, 14% neutral, 50% disagree). When receiving either one of the feedback conditions, the majority (86%) of participants expressed that they reduced their trunk compensation. For almost all participants (93%), they would prefer to receive the Scores+Visual+Force feedback to reduce their trunk

movement, as scores provided them with: motivation, a game-like presentation of the task, encouragement to do better based on previous scores, and the ability to compete.



Figure 5. Post-test questionnaire selected results. Questionnaire was administered at the end of the intervention. The remaining questions are presented in the appendix.

Participants scored the usability of the system as “Good”. The average was 73 (SD: 15), according to the SUS.

Discussion

Based on the trunk displacement motion data, participants were capable of reducing their compensation when provided with either Scores+Visual+Force or Visual+Force feedback. In addition, in the post-test questionnaire, the majority (86%) of participants answered that they decreased their compensation when receiving either feedback condition. These results, in combination with our previous study¹² in which we found that force or visual feedback alone reduced trunk compensation, provide supporting evidence to the idea that regardless of the type of augmented feedback provided in a short-term intervention, participants are capable of modifying their movement strategies to reduce trunk compensation. As a result, it would appear that the information itself (real-time monitoring of trunk compensation) is more important than the medium employed to communicate it. However, this was only tested in a single-session, and longer studies would need to be conducted to confirm these results, as the source of feedback could have a different effect in long-term interventions. Our results reinforce the concept that stroke survivors might still have unexploited motor abilities that are masked by compensation¹⁴. If we focus on reducing these compensatory strategies, we might be able to unmask the “correct” movement patterns needed for recovery. Furthermore, the monitoring of movement quality could play an important role in stroke recovery rehabilitation, as sometimes improvements evaluated by clinical scales and brain imaging technologies can be the result of the use of compensatory movements and not of true recovery occurring at the neuronal level¹. Employing kinematic analyses as tools for rehabilitation professionals to obtain more detailed descriptions of the recovery process of their clients could be a significant complement to therapeutic practices that currently rely on qualitative ordinal scales²⁹. A similar short-term study²⁰, with the same number of training trials and participants per group, compared verbal instructions (directions not to move

the trunk) versus employing trunk restraints. In the study, the verbal instructions condition did not reach statistical significance; on the other hand, the trunk restraints did. When considering the average values of the trunk displacement's percent change, our numbers were larger than their verbal instruction condition and similar to the trunk restraint results. This is in agreement with the outcome of our previous study¹² in which only visual or force feedback was provided. Based on the aforementioned studies, it would appear that providing trunk compensation information as augmented feedback, which can track the performance of the user throughout the movement, could be an alternative to just providing verbal instructions to remind participants not to move their trunk, at least in a short-term intervention. In addition, the results support the idea that employing augmented feedback could serve as a complementary strategy to more restrictive trunk restraints. However, before making a recommendation to the rehabilitation community, longer studies with verbal-condition control groups and larger samples would need to be carried out to enable a clinical and statistical comparison of these feedback modalities.

One of the possible advantages of employing augmented feedback versus completely restraining trunk movement is that it would enable participants to be actively involved in the formulation of motion strategies and in the reception of afferent and efferent information derived from the movement, which are important factors for optimal motor learning³⁰. In addition, the schedule and frequency of the feedback strategies we propose can easily be modified (software parameters) to avoid a detrimental reliance on the feedback (guidance hypothesis³¹). On the other hand, trunk restraints are always active, unless a therapist completely removes the straps. Nevertheless, trunk restraint might be the only feasible option for participants with significant motor impairment and complete lack of upper body motor control, and for whom reaching

movements might be dangerous to perform without physical assistance. As these participants improve with time and training, they might be able to transfer to augmented feedback exercises.

When comparing if adding scores provided any advantage to just employing biofeedback, we did not find any statistically significant difference. A similar result was obtained by Alankus et al.¹¹, as they could not find any difference between biofeedback (showing lateral trunk tilt in a rehabilitation game) versus providing/deducting points based on compensation; however, in their study only the scores condition resulted in a reduction of compensation when compared to a no-feedback condition. The aforementioned results could suggest that in a short-term intervention, the positive effects that scores could have on participants' performance might not be greatly superior to just receiving biofeedback, at least for modifying trunk kinematic variables. Nonetheless, in the post-test questionnaire, 13/14 participants expressed that they would prefer to receive the scores together with biofeedback to reduce their trunk compensation. Some of the reasons mentioned were that the scores provided them with: motivation, encouragement to do better based on previous scores, a game-like presentation of the task, and the ability to compete. All of these elements might have a bigger role in long-term interventions where increased motivation and engagement become important factors to promote adherence to therapy programs³². In longer interventions, scores could be used to³³: show trends over several days or weeks and reward secondary actions (e.g., time playing the game, and improvement in other kinematic variables besides trunk compensation).

One of the challenges in the design and provision of multimodal feedback is that the use of multiple sources of information could result in participants getting overwhelmed or confused³⁴. In our study, we did not find that employing multiple strategies together was detrimental for kinematic performance. The effect sizes obtained when combining feedback

types versus employing visual or force feedback alone¹² resulted in some small improvements: Scores+Visual+Force and Visual+Force were superior to providing only Visual feedback by +0.28 and +0.36, respectively, and when compared against Force feedback they were superior by +0.38 and +0.46. However, the motion of the virtual cursors was only in one plane, which was proportional to the movement of the participants' hands in the anterior/posterior direction, limiting task complexity. Future studies should allow participants to move their limbs in all directions and play more elaborate games to confirm if the increase in task complexity does not lead to a detrimental effect of employing multimodal feedback.

Given that most participants agreed that: the level of difficulty for the reaching task was adequate, the system was appropriate for performing rehabilitation exercises, the feedback types were easy to understand and perceive, and that the system was “Good” in terms of usability (SUS), it would appear that a similar system could be employed for long-term interventions. Based on the evidence found in this study and our previous phase, we would recommend that rehabilitation professionals employ a single feedback or a combination that works best for each client's preferences and motor abilities, as all tested conditions seem to be capable of promoting a reduction in trunk compensation. The results of our current and past studies could indicate that the use of larger robotic devices might not be completely necessary to obtain a reduction in trunk compensation (longer studies are needed to confirm this), which could be beneficial for participants, clinics, and hospitals with limited financial resources. We would recommend that future studies investigate if visual feedback combined with scores could obtain similar results to trunk restraints in a clinical environment over a period of several weeks. If superior or comparable results were to be obtained, an at-home rehabilitation program could be implemented at a low cost (Kinect camera and computer), which could provide participants with the

opportunity to perform the high number of repetitions needed to promote neuroplastic changes in the brain, instead of the low number currently being provided in clinical settings³⁵. In our study, participants with severe to mild motion impairment were capable of performing 180 upper-limb functional repetitions in one session.

Limitations

Longitudinal studies in which clinical scales (measuring function) are administered at different time points, in addition to kinematic variables, should be conducted to fully confirm the effectiveness of the proposed feedback strategies. In our study, we were not expecting to observe functional changes after a single session; however, after several weeks of training we would anticipate functional/impairment changes. Another limitation of the presented work was the small sample size. Larger samples of participants with different impairment levels should be included in future trials. This will ensure that researchers and rehabilitation professionals obtain a clearer picture of the role of feedback on participants with different functional levels.

In this study, we only investigated two multimodal feedback strategies to reduce trunk compensation, with a linear relationship between the level of compensation and feedback. Future studies could explore novel error augmenting methodologies³⁶, other feedback types (e.g., vibrotactile³⁷), and non-linear feedback relationships to reduce compensatory movements.

Researchers and clinicians lack a clear cutoff point to differentiate between stroke survivors whose only option would be to employ compensatory movements due to severe motor impairment, and those who can benefit from not using compensation⁴. As a result, future studies could focus on investigating this issue to obtain a better understanding of the limitations of

strategies aimed at reducing compensatory movements. Finally, investigating how brain activation patterns and cortical representations change as a result of compensatory reduction strategies might lead to a better understanding of the complex neuronal recovery process⁵.

Conclusions

In a short-term study, multimodal augmented feedback for stroke survivors' trunk compensation levels resulted in a reduction of trunk displacement. No statistically significant difference was found to support that one feedback was superior to the other. However, most participants responded that they would like to receive game scores for reducing their trunk compensation. As a result, the potentially superior positive effects of including game scores might not have been observed in a short-term intervention. Longer studies should investigate if the use of scores could result in trunk compensation improvements, especially when compared against trunk restraint strategies.

Conflict of Interest Statement

The authors report no conflicts of interest.

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Appendix

**BIOFEEDBACK VS. GAME SCORES FOR REDUCING TRUNK
COMPENSATION AFTER STROKE: A RANDOMIZED CROSSOVER
TRIAL**

POST-TEST QUESTIONNAIRE RESULTS

POST-TEST QUESTIONNAIRE PART A (REACHING TASK)

Part A of the Post- Test Questionnaire:

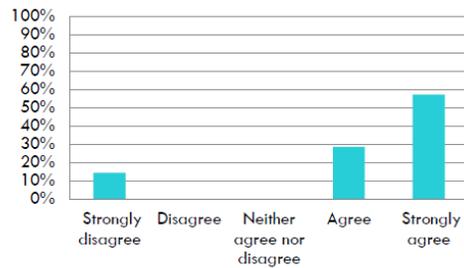
- Likert Scale comprised of 4 Likert-type questions (A.1-A.4)
- Examined the underlying belief that: “The level of difficulty of the reaching task was adequate for stroke survivors”

	Part A
Average	3.48
SD	0.73

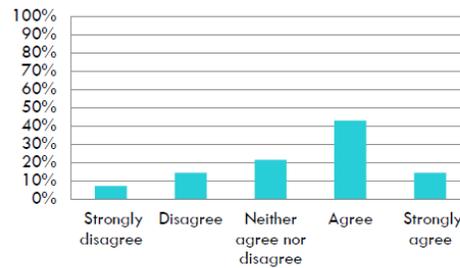
**On average people agreed that the level of difficulty of the reaching task was adequate for stroke survivors.
T-test against neutral response, $t(13)=2.47$, $p=0.028^*$, $d= 0.66$, 95%CI (3.06, 3.9)**

POST-TEST QUESTIONNAIRE PART A (REACHING TASK) A.1-A.4

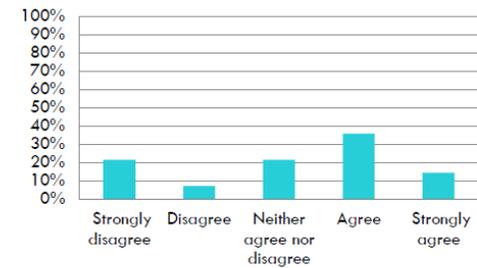
A.1 It was easy to control the cursor with my strong hand



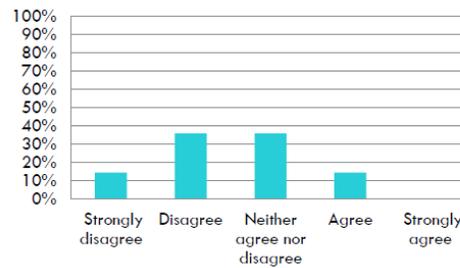
A.2 It was easy to control the cursor with my weak hand



A.3 I felt tired after completing the session

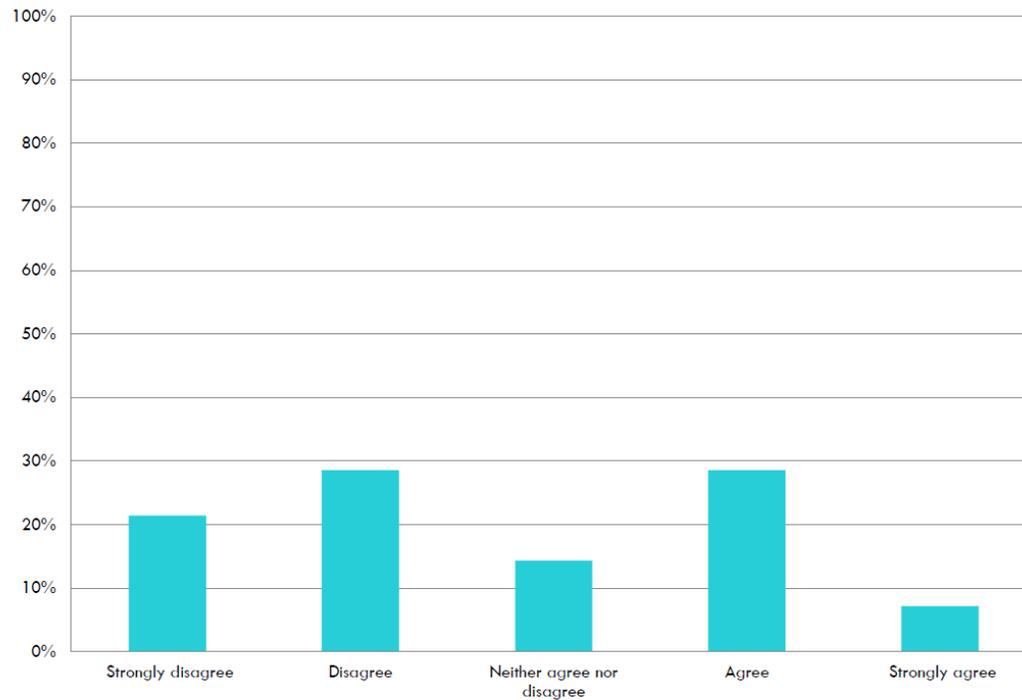


A.4 It was difficult to reach the targets



POST-TEST QUESTIONNAIRE PART A (REACHING TASK) A.5

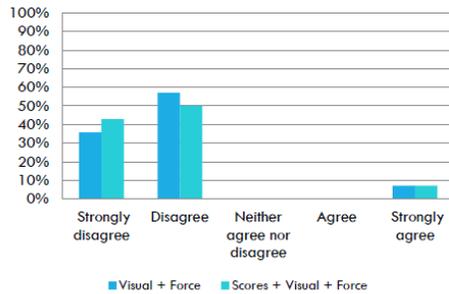
A.5 To be able to reach the targets, I had to move my trunk



Combined categories:
36% Agree
14% Neutral
50% Disagree

POST-TEST QUESTIONNAIRE PART B & C (FEEDBACK)

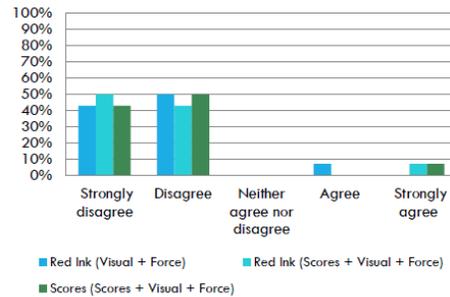
B.1 & C.1 It was difficult to understand the feedback



Mode		
Visual + Force	2	Disagree
Scores + Visual + Force	2	Disagree

Feedbacks not difficult to understand.

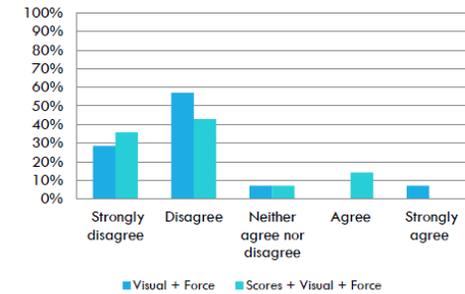
B.2, C.2 & C.3 It was difficult to see the visual feedback



Mode		
Visual + Force (Red ink)	2	Disagree
Scores + Visual + Force (Red ink)	1	Strongly Disagree
Scores + Visual + Force (Scores)	2	Disagree

Visual feedback (red ink) and Scores not difficult to perceive.

B.3 & C.4 It was difficult to feel the force feedback

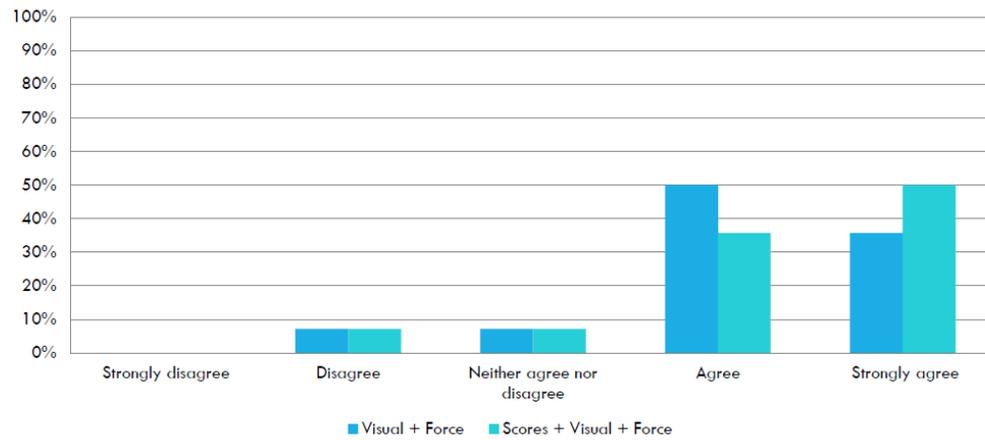


Mode		
Visual + Force	2	Disagree
Scores + Visual + Force	2	Disagree

Force feedback not difficult to perceive.

POST-TEST QUESTIONNAIRE PART B & C (FEEDBACK)

B.4 & C.5 When I received the feedback I reduced how much I was moving my trunk

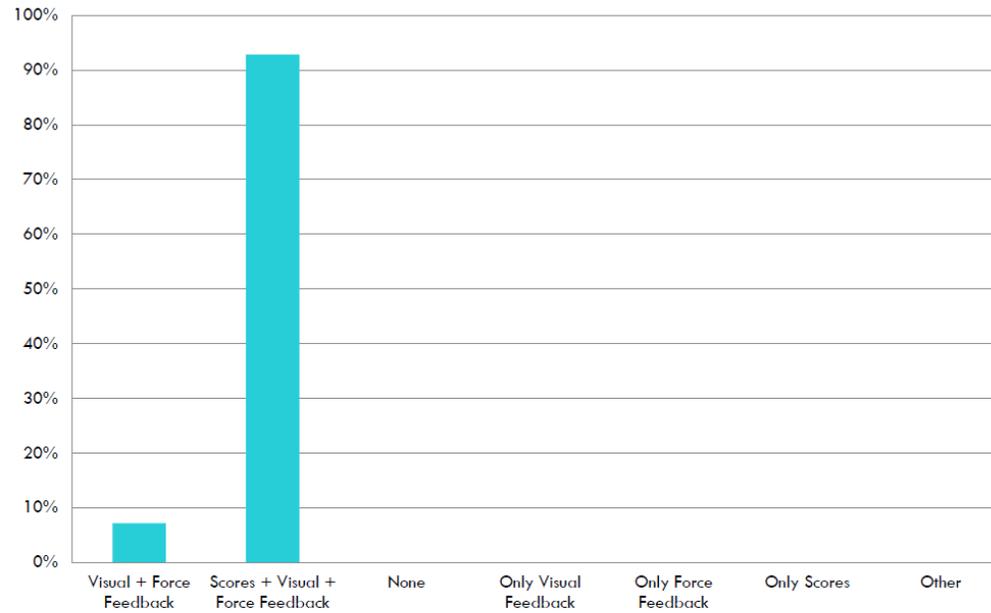


Both feedback conditions reduced compensation

Mode		
Visual + Force	4	Agree
Scores + Visual + Force	5	Strongly Agree

POST-TEST QUESTIONNAIRE PART D (FEEDBACK COMPARISON)

D.1.1 To reduce my trunk movements I would prefer to receive



POST-TEST QUESTIONNAIRE PART D (FEEDBACK COMPARISON)

For the ones that answered “Scores + Visual + Force”:

- *“Easy to figure out how it worked”*
- *“It is important to receive all feedback conditions to do a better job in the task”*
- *“I can see the monitor (scores and red ink)”*
- *“Very encouraging, helps you concentrate, competition is good”*
- *“It helps to get feedback on my movements because I don’t always realize that I am doing something. It helps me improve the next time when I get feedback”*
- *“Felt like you were playing a game helps want to achieve a higher score”*
- *“Easy to understand. Good to keep track with scores”*
- *“It is normal and is easy to understand”*
- *“See your movement”*
- *“Like scores, more motivated”*
- *“Motivates you to get better scores”*
- *“I can see my improvement based on the red ink+force+scores. Scores gives me encouragement to do well”*
- *“Easy to see”*

For the one that answered “Visual + Force”:

- *“Because I got the feedback in the direction I was moving”*

POST-TEST QUESTIONNAIRE PART E (SYSTEM DESIGN) E.1-E.7

Part E of the Post- Test Questionnaire:

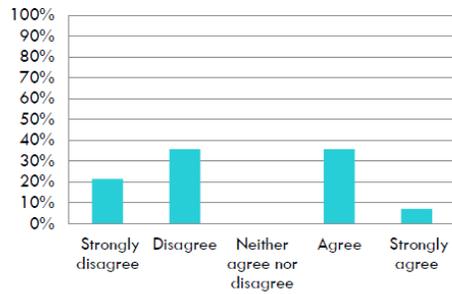
- Likert Scale comprised of 7 Likert-type questions (E.1-E.7)
- Examined the underlying belief that: “the system’s design is appropriate for performing reaching movements for rehabilitation”

	Part E
Average	4.07
SD	0.49

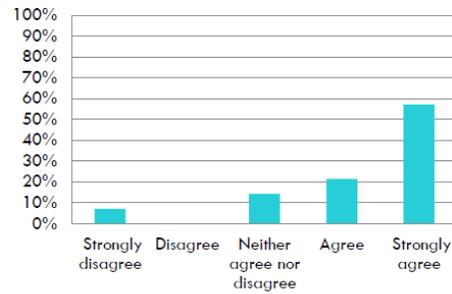
**On average people agreed that system was appropriate for performing reaching movements for rehabilitation.
T-test against neutral response, $t(13)=8.17$, $p =0.000^{***}$, $d=2.18$, 95%CI (3.79, 4.35)**

POST-TEST QUESTIONNAIRE PART E (SYSTEM DESIGN) E.1-E.3

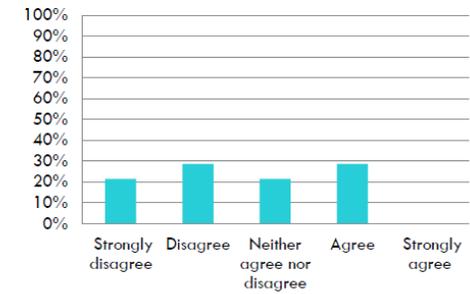
E.1 The robotic devices limited my reaching movements



E.2 I felt comfortable grasping the robotic devices

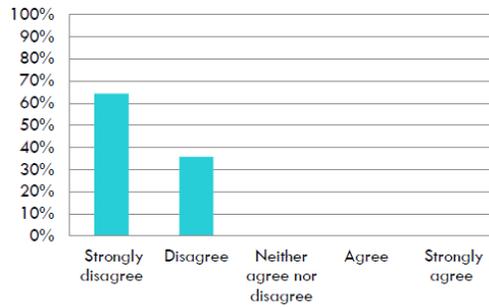


E.3 The robotic devices felt heavy in my hands

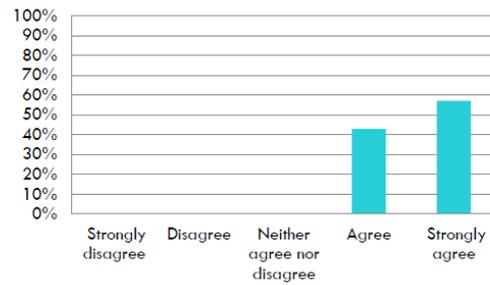


POST-TEST QUESTIONNAIRE PART E (SYSTEM DESIGN) E.4-E.7

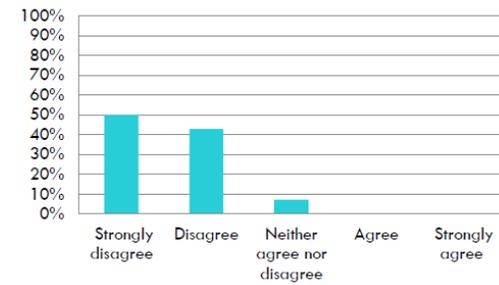
E.4 I felt unsafe using the robotic devices



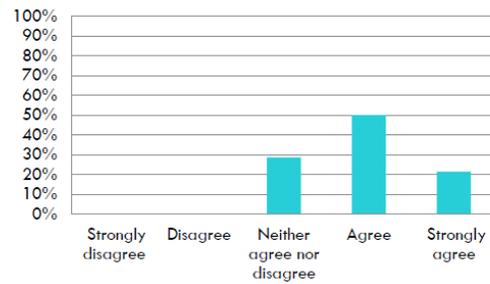
E.5 I would use these robotic devices for rehabilitation



E.6 It was hard for me to see the targets and cursor on the computer's monitor



E.7 I felt comfortable maintaining a proper seated posture



POST-TEST QUESTIONNAIRE PART F (SUS) F.1-F.10

System Usability Scale (SUS): “A reliable, low-cost usability scale that can be used for global assessments of systems usability”.¹

- It consists of a 10 item questionnaire with five response options for respondents
- **A value above 68 is considered above average. Though the scores are 0-100, these are not percentages.**
- Adjective ratings are²: “Worst Imaginable”, “Awful”, “Poor”, “OK”, “Good”, “Excellent”, and “Best Imaginable”.

	SUS Score
Average	73
SD	15

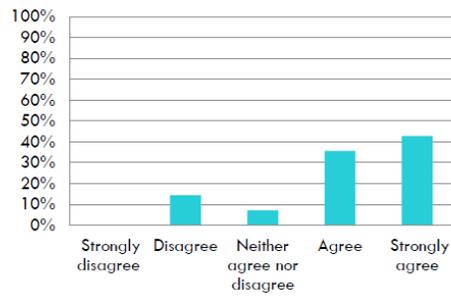
On average system can be considered “Good”

¹ Brooke J. SUS-A quick and dirty usability scale. In: Usability evaluation in industry. 1996. p. 4–7.

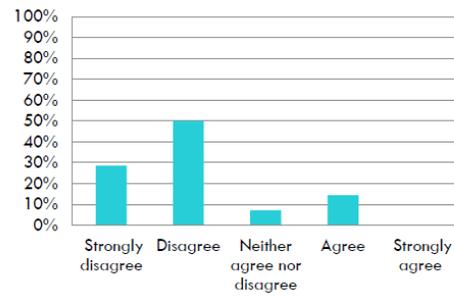
² Bangor A, Kortum P, Miller J. Determining what individual SUS scores mean: Adding an adjective rating scale. Journal of usability studies. 2009;4(3):114–123.

POST-TEST QUESTIONNAIRE PART F (SUS) F.1-F.3

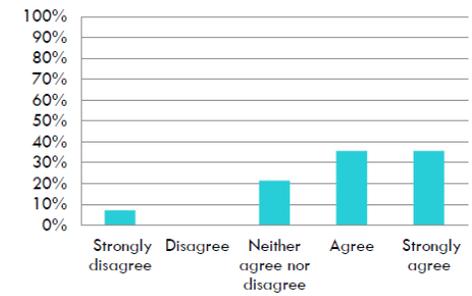
F.1 I think that I would like to use this system frequently



F.2 I found the system unnecessarily complex

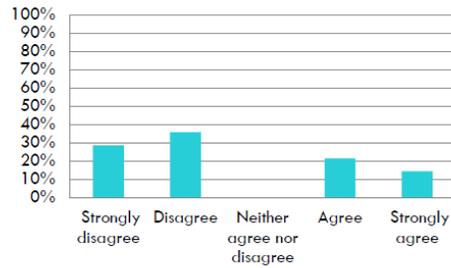


F.3 I thought the system was easy to use

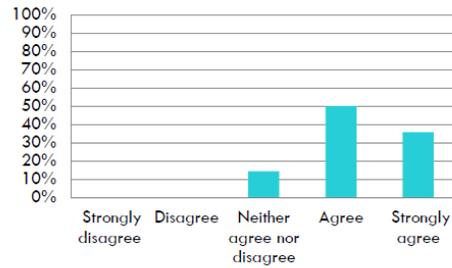


POST-TEST QUESTIONNAIRE PART F (SUS) F.4-F.6

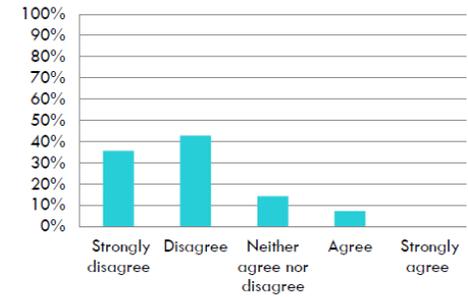
F.4 I think that I would need the support of a technical person to be able to use this system



F.5 I found the various functions in this system were well integrated

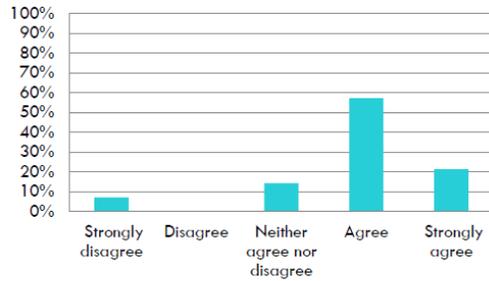


F.6 I thought there was too much inconsistency in this system

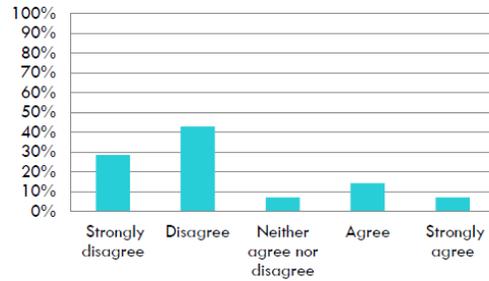


POST-TEST QUESTIONNAIRE PART F (SUS) F.7-F.10

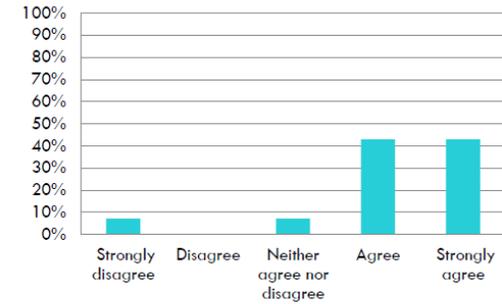
F.7 I would imagine that most people would learn to use this system very quickly



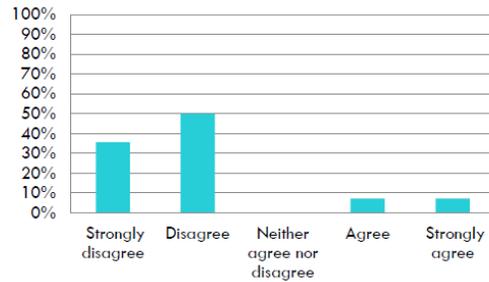
F.8 I found the system very cumbersome to use



F.9 I felt very confident using the system



F.10 I needed to learn a lot of things before I could get going with this system



POST-TEST QUESTIONNAIRE PART G (SYSTEM'S FEATURES) G.1-G.3

G.1 My favorite features:

- "Hitting the targets"
- "Getting feedback about compensation with scores + force + visual"
- "I liked the scores"
- "Instructor"
- "It makes exercising easy + fun. It helps me think about moving in a productive way"
- "The colors and scoring ability. The feeling of achievement when completing task"
- "Achieving the goal at the end of the line. Red ink is good to see; help me control trunk movement"
- "The game in the screen"
- "All of it is pretty good"
- "The cursor movement"
- "The scoring system, cumulative scores. Improve, motivated, and more fun"
- "The use of robotic device helps encourage reaching further. Helpful to prevent trunk movement (encourage arm use)"
- "The robotic arms because it forces me to use my left (affected) arm"
- "Scores, easy to see"

G.2 My least favorite features:

- Nothing
- "When you take out the feedback"
- Nothing
- None
- "I can't use it daily!"
- "Long trial"
- None
- "It was hard for my hand"
- "Pretty fine with the entire system (none)"
- "Sometimes it was hard to control"
- "Getting back into original position. Time consuming and really difficult"
- "Didn't like using the strap"
- No
- Nothing

G.3 Anything that you would change:

- Nothing
- "Improve the handle on the weak side because it can get uncomfortable with the straps and tape"
- Nothing
- No
- "Make it cheap and portable"
- "Try to get more people involved"
- Nothing
- "Something to help the affected hand move the robot"
- "This system is normal. You can't tell and pretty much fine"
- Nothing
- "Make it more fun, more animation like ping pong make it exciting"
- "Make the strap flexible softer. Would like to operate the system from her chair by herself (remote operation)"
- Nothing
- "Strap make it better"



CONSORT 2010 checklist of information to include when reporting a randomised trial*

Section/Topic	Item No	Checklist item	Reported on page No
Title and abstract	1a	Identification as a randomised trial in the title	Title
	1b	Structured summary of trial design, methods, results, and conclusions (for specific guidance see CONSORT for abstracts)	Abstract
Introduction Background and objectives	2a	Scientific background and explanation of rationale	Introduction Section
	2b	Specific objectives or hypotheses	Introduction Section
Methods Trial design	3a	Description of trial design (such as parallel, factorial) including allocation ratio	Trial Design Section, Figure 1 and 2
	3b	Important changes to methods after trial commencement (such as eligibility criteria), with reasons	N/A
Participants	4a	Eligibility criteria for participants	Figure 1
	4b	Settings and locations where the data were collected	Title Page (submitted separately)
Interventions	5	The interventions for each group with sufficient details to allow replication, including how and when they were actually administered	Experimental Task Section and Figures 1,2, and 3.
Outcomes	6a	Completely defined pre-specified primary and secondary outcome measures, including how and when they were assessed	Data Analysis

		Section	
	6b	Any changes to trial outcomes after the trial commenced, with reasons	N/A
Sample size	7a	How sample size was determined	Participants Section
	7b	When applicable, explanation of any interim analyses and stopping guidelines	N/A
Randomisation:			
Sequence generation	8a	Method used to generate the random allocation sequence	Figure 2 Caption
	8b	Type of randomisation; details of any restriction (such as blocking and block size)	Trial Design Section
Allocation concealment mechanism	9	Mechanism used to implement the random allocation sequence (such as sequentially numbered containers), describing any steps taken to conceal the sequence until interventions were assigned	Figure 1 Caption
Implementation	10	Who generated the random allocation sequence, who enrolled participants, and who assigned participants to interventions	Figure 1 Caption
Blinding	11a	If done, who was blinded after assignment to interventions (for example, participants, care providers, those assessing outcomes) and how	N/A
	11b	If relevant, description of the similarity of interventions	Participants Section
Statistical methods	12a	Statistical methods used to compare groups for primary and secondary outcomes	Statistical Analysis Section

	12b	Methods for additional analyses, such as subgroup analyses and adjusted analyses	Statistical Analysis Section
Results			
Participant flow (a diagram is strongly recommended)	13a	For each group, the numbers of participants who were randomly assigned, received intended treatment, and were analysed for the primary outcome	Figure 1
	13b	For each group, losses and exclusions after randomisation, together with reasons	Figure 1
Recruitment	14a	Dates defining the periods of recruitment and follow-up	Figure 1 Caption
	14b	Why the trial ended or was stopped	N/A
Baseline data	15	A table showing baseline demographic and clinical characteristics for each group	Table 1
Numbers analysed	16	For each group, number of participants (denominator) included in each analysis and whether the analysis was by original assigned groups	Figure 1
Outcomes and estimation	17a	For each primary and secondary outcome, results for each group, and the estimated effect size and its precision (such as 95% confidence interval)	Results Section and Table 2
	17b	For binary outcomes, presentation of both absolute and relative effect sizes is recommended	N/A
Ancillary analyses	18	Results of any other analyses performed, including subgroup analyses and adjusted analyses, distinguishing pre-specified from exploratory	N/A
Harms	19	All important harms or unintended effects in each group (for specific guidance see CONSORT for harms)	Figure 2 caption
Discussion			
Limitations	20	Trial limitations, addressing sources of potential bias, imprecision, and, if relevant, multiplicity of analyses	Discussion Section
Generalisability	21	Generalisability (external validity, applicability) of the trial findings	Discussion Section

Interpretation	22	Interpretation consistent with results, balancing benefits and harms, and considering other relevant evidence	Discussion Section
Other information			
Registration	23	Registration number and name of trial registry	Title Page (submitted separately)
Protocol	24	Where the full trial protocol can be accessed, if available	Title Page (submitted separately)
Funding	25	Sources of funding and other support (such as supply of drugs), role of funders	Title Page (submitted separately)

*We strongly recommend reading this statement in conjunction with the CONSORT 2010 Explanation and Elaboration for important clarifications on all the items. If relevant, we also recommend reading CONSORT extensions for cluster randomised trials, non-inferiority and equivalence trials, non-pharmacological treatments, herbal interventions, and pragmatic trials. Additional extensions are forthcoming: for those and for up to date references relevant to this checklist, see www.consort-statement.org.

CONSORT 2010 Flow Diagram

