Project acronym: NEST

Full title: Neurorehabilitation Ecosystem for Sustained Treatment "NEST".

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D3.3.1 Report on experimental observational study RGS-app

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Lay out

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1 Executive Summary

Scope of the document

Deliverable 3.3.1 reports on the work done to assess the movements provoked by the RGS app in comparison with therapy exercises. Additionally, the effect of different instructions (video vs. live instruction) were investigated.

Relevance of the work

The outcome of this work is relevant in the implementation of NEST. By assessing which games provoke specific movements, therapists can match the RGS app with the appropriate patient population, gaining insight into which games are effective and which may not work for certain individuals. In addition, the developer could adjust the RGS app protocols based on the outcome of this study. Lastly, the study provides valuable information on the amount and type of instruction needed for patients to play the RGS games correctly.

2 Introduction

Stroke has an major impact on healthcare. In 2020, almost 50.000 persons were admitted to the hospital in the Netherlands due to a stroke (Volksgezondheid en Zorg, 2022). Stroke can lead to a variety of impairments, such as hemiparesis, cognitive and visual impairments and aphasia (Intercollegiate Working Party for Stroke & Royal College of Physicians of London, n.d.). Fortunately, these consequences can improve with rehabilitation (Hatem et al., 2016). However, as the population ages, the incidence of stroke is expected to increase (Hilderink et al., 2020; Nielen et al., 2021). Furthermore, rehabilitation typically requires medical personnel, which, combined with the growing stroke population, will significantly raise healthcare costs. Home-based rehabilitation presents a potential solution to reduce these costs.

While home-based rehabilitation offers many benefits, one downside is the reduced supervision compared to in-clinic settings. Our focus group study (Deliverable 1.3) highlighted the importance of clear instructions and the possibility of initial training before starting the home-based rehabilitation program. Such instructions could minimize compensatory movements. However, the impact of different types of instructions on participant's actual movements remain unclear.

One technology used in home-based rehabilitation for upper limb function is virtual reality. Virtual reality (VR) has the advantage of a controlled environment which can be designed to mimic specific real life situations. Previous research that compared real life actions to the same action in VR, found that movement times and peak velocities were affected by virtual reality. However, trajectory curvature and joint range of motion were comparable (Arlati et al., 2022; Levin et al., 2015). This result makes VR a promising rehabilitation system (Levin et al., 2015). A more accessible kind of VR is augmented reality (AR) in which computed generated elements are added to the real world. An example of an AR system is the Rehabilitation Gaming System (RGS)-app, which can be used with only a smartphone, unlike VR which requires additional devices. This RGS-app includes gamified exercises for upper limb training. However, the kinematics of upper limb movements made while playing the RGS-app is unknown.

3 Overview of the ExoRGS study

Aim

The aim of this study was to gain insight into kinematics of movements provoked by the RGS-app and to compare these movements with movements made during therapy exercises.
The second aim of this study was to measure the effect of different instruction types: general video instruction compared to personalized live instruction.

Participants

So far, seven stroke survivors were included. They had to meet the following criteria: 1) suffered from a stroke at least 2 months ago, 2) were smartphone users, and 3) had a mild to moderate upper limb impairment, classified with a Medical Research Council scale for muscle strength equal or above three. Stroke survivors were excluded if they had severe cognitive impairments, visual impairments that could not be corrected with glasses or upper limb impairments not caused by the stroke. Characteristics can be found in table 1.

Sixteen healthy elderly were included if they were 60 years or older and were smartphone users. They were excluded if they had visual impairments that could not be corrected with glasses or currently had upper limb impairments that could affect smartphone use. Characteristics can be found in table 1.

Table 1: Characteristics of the study population

	Healthy elderly (16)	*Stroke survivor (7)*
Age, mean ± SD	67.2 ± 6.9	57.7 ± 16.9
Gender, male (%)	6 (37.5%)	4 (57.1%)
Dominant/unaffected arm, right (%)	15 (93.8%)	7 (100%)
Months since stroke, mean ± SD	-	51.9 ± 45.4
Screen time[a], mean ± SD	122.7 ± 69.4	130.7 ± 77.8
Phone proficiency[b], mean ± SD	6.2 ± 1.3	8.4 ± 1.3

a) screen time in minutes b) phone proficiency on a scale of 1-10

Study procedures

All participants were informed about the project orally and in writing by the investigator. Participants gave their informed consent before start of the data collection. This study was exempted for ethical review by the medical ethical committee Nijmegen/Arnhem (2023-16330).

<u>Measurements:</u>
IMUs were placed on the upper body, to record upper limb movements during the trials. A total of 11 IMUs were used, table 2 shows an overview of where the sensors were placed. For data analyses, the MVN-software of X-sens was used. This software is able to calculate range of motion, position, velocity and acceleration. For this software it is necessary that before the start of the measurement a calibration is executed. During the calibration, participants have to start by standing in a N-pose, which is the neutral standing position, and thereafter walk around.

Table 2: Overview of the inertial measurement units and placement

Location	**Optimal position**
Pelvis	Flat on sacrum
Sternum	Flat, in the middle of the chest
Shoulder	Scapula (shoulder blades)
Upper arm	Lateral side above elbow
Fore arm	Lateral and flat side of the wrist
Hand	Backside of hand
Head	Any comfortable position

The study consisted of two parts. Participants started with performing therapy exercises, which will be referred to as '*therapy exercises*'. The second part consisted of playing the RGS-apps, which is referred to as '*RGS-games*'. For this part, participants were randomized into two conditions (video instruction or personal life instruction). Randomization was stratified into healthy elderly and people with stroke.

Part 1: Therapy exercises

All therapy exercises were chosen by a specialized upper limb physical therapist as they provoke similar movements as made with the RGS-games. These exercises were performed for 2 minutes.

The therapy exercises were:

- Sjoelen: this is a game where participants have to slide small pucks to the other side of the board into trays.
- Groceries: Groceries placed on shelves with different height. The participants have to pick up the groceries and place them on the table besides him.
- Tower of plastic cups: the participant has to make a tower with ten plastic cups by using their affected side. The tower need to be made by making a base of 4 cups, than place 3 cups on the base and so forth until all cups are used.
- Moving rings: participants have to slide rings. These rings are around a metal tube that is formed into half a circle, with a diameter of around 60 cm. This circle is standing upright and the rings have to go from one side of the circle to the other.

Part 2: RGS-games

All participants first received a detailed video instruction on how to play the RGS-games of the NEST system and which movements they had to perform. They then had practice time to familiarize themselves with the app. Following this, participants played the RGS-games for 2 minutes, and their movements were recorded using IMUs (measurement 1). After the initial 2 minutes, participants were randomly assigned to one of two groups. Group 1 received the video instructions again and played the game for an additional 2 minutes, with movements recorded once more (measurement 2). Group 2, on the other hand, received personalized live instructions from an instructor, followed by another 2-minute game session while their movements were recorded (measurement 2). An overview of the two conditions is shown in Figure 1.

This protocol was repeated for all four RGS-games, with participants remaining in the same condition troughout all games. During the measurement the order of games was randomized.

There are four games that were played during the measurement.

- Ice hockey: the player has to push the puck towards the goal. This exercise can be performed while resting the hand and phone on the table. Flexion and extension of the elbow are required.
- Shelves: during this task the player has to grab objects from shelves. This task needs to be performed with the arm in the air, therefore more muscle strength is required. Flexion and extension of the elbow are required.
- Ducks: the player has to angle ducks from a pool. Again, this task is performed while holding the arm in the air. Flexion and extension of the elbow is required, additionally trunk control and some shoulder rotation are necessary.
- Alphabet: during this game the player has to hit blue blocks that altogether make a letter. Muscle strength is required, since this task is performed in the air. Additionally shoulder rotation is necessary.

All therapy exercises were selected by a physical therapist based on its movements. The RGS-games are supposed to provoke similar movements as the therapy exercises, with the following combinations being made: sjoelen / ice hockey; groceries / shelves; cups / ducks; moving rings / alphabet.

Instructions

- Video instruction: the video instruction showed a person playing the RGS-game. A voice over explained the correct sitting posture and outlined which arm movements had to be performed and avoided (for example, keep the torso straight).

- The personalized instruction was tailored based on the participant's first session. The instructor had a checklist of correct movements and those to avoid. Using this list, the instructor provided real-time feedback to the participant (for example: your elbow stretch looks great, but try to relax your shoulder a bit more).

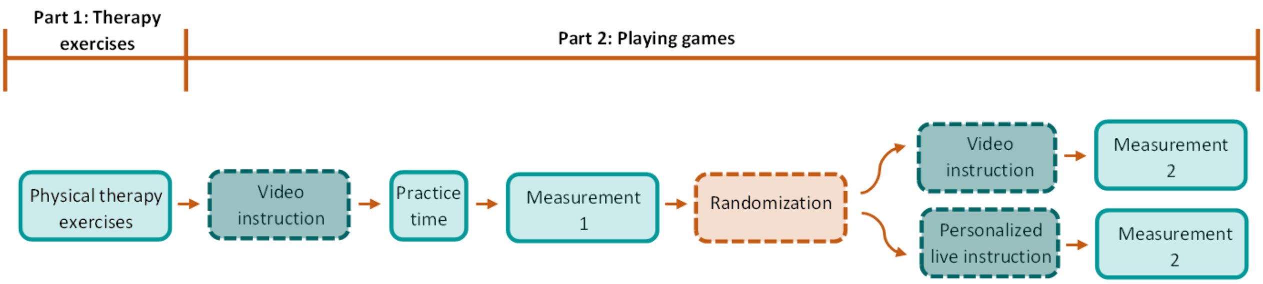

Figure 1 Overview of the study design. Participants will be randomized into one of the two conditions.

Data analysis

Data analysis was conducted using custom-written Python (Python 3.10) scripts. The data was imported via Python scripts provided by Xsens, extracting trunk and elbow angles and the 3D position of the elbow and shoulder from the .mvnx files. The trunk was defined as the angle between the pelvis and a vertical reference line. For the elbow analysis, the flexion and extension was used. The shoulder was expressed in a scalar, with the shoulder as origin and a fixed point on the elbow as the direction. Using the dot product formula, the angle between two scalars was calculated. Thus, the shoulder data represents the change in angle between two samples ($\frac{d^{\circ}}{dt}$). The shoulder data was filtered with a low-pass filter to get rid of sharp peaking and prepare it for proper peak-detection.

To ensure data quality, the first 15 seconds of each dataset were removed due to the start-up phase of the exercise, and 1.5 minutes of gameplay were analysed. A peak-detection algorithm was applied to determine the number of movements made during a measurement. A movement was defined as a data segment between a local maximum and minimum (or vice versa).

Each movement was categorized based on angular change using the following ranges: 1-5°, 5-30°, 30-60°, 60-90°, 90-180°, and 1-180°. This classification aimed to evaluate the effect of the exercise on joint flexion. The 1-5° category represented minimal or near-zero movement, indicating stationarity rather than active motion. Additionally, for each movement, absolute angle (°) and absolute velocity (°/s) were calculated.

To compare the number of movements made between the stroke survivors and healthy elderly, and to compare the therapy exercises and RGS-games a two-way ANOVA was performed using Rstudio. With total movements between 5-180° degrees being the dependent variable, and group and RGS-game/exercise as factors. All RGS-games and all therapy exercises were taken together during this analysis. A p-value smaller than 0.05 was interpreted as significant.

4 Results

Total amount of movements

The total number of movements of all participants for each of the therapy exercises and RGS-games are shown in table 2. The therapy exercises had a larger number of movements than their RGS-game equivalent, especially in the elbow joint. Nevertheless, the therapy exercises and RGS-games provoked most movements in the elbow joint.

A two way ANOVA showed a significant interaction effect for the elbow movements between group and RGS-game/exercise ($F(1) = 6.99$, $p=0.008$), meaning that the healthy elderly showed more movements in the therapy exercises but not in the RGS-games. For the shoulder a significant main effect of both group ($F(1) = 5.94$, $p=0.016$) and RGS-game/exercise ($F(1) = 327.16$, $p <0.001$) was found, no interaction effect was found. This suggests that the shoulder showed more movements in the healthy elderly compared to the stroke survivors, and during therapy exercises compared to RGS-games. For the trunk only a significant main effect of RGS-game/exercise was found ($F(1) = 25.61$, $p <0.001$), no significant interaction effect or main effect for group were found. Therapy exercises showed more trunk movements compared to the RGS-games.

Table 3: Number of movements averaged per group performed per joint and each exercise

	Healthy elderly (n=16)			*Stroke (n=7)*		
	Elbow	Trunk	Shoulder	Elbow	Trunk	Shoulder
Cups	200 ± 39	7 ± 3	87 ± 21	126 ± 35	8 ± 2	55 ± 16
Ducks	**50 ± 18**	**10 ± 6**	**20 ± 13**	**41 ± 12**	**9 ± 5**	**15 ± 13**
Sjoelen	156 ± 28	11 ± 8	80 ± 14	127 ± 32	18 ± 11	80 ± 18
Ice hockey	**41 ± 11**	**18 ± 12**	**29 ± 12**	**29 ± 14**	**8 ± 5**	**25 ± 17**
Groceries	83 ± 23	21 ± 9	43 ± 15	75 ± 23	22 ± 10	42 ± 23
Shelves	**34 ± 8**	**9 ± 5**	**17 ± 11**	**34 ± 4**	**9 ± 5**	**15 ± 10**
Moving rings	150 ± 27	33 ± 19	79 ± 13	110 ± 31	35 ± 12	60 ± 21
Alphabet	**22 ± 8**	**6 ± 3**	**5 ± 7**	**16 ± 7**	**5 ± 2**	**5 ± 8**

RGS-games are in bold. Numbers expressed in mean ± standard deviation

Movements per degree category

The mean number of movements made per category range of the elbow are shown in Figure 2 for the healthy elderly and Figure 3 for the stroke survivors. It can clearly be seen that the movements provoked by all exercises are mainly within the 30 degrees ranges, where movements with ranges above 60 were barely provoked in healthy elderly and stroke population. Therapy exercises induce larger movements in the 5-30° and the 30-60° range than their RGS-game equivalent, whereas the 0-5° range are most provoked by the RGS-games. No clear differences were observed between healthy elderly and the stroke population.

Figure 4 and 5 shows the number movements provoked in the shoulder for healthy elderly and stroke population, respectively. For the shoulder, almost all movements fell in the 5-30° range for both therapy exercises and RGS-games. Only the exercise moving rings provoked movement in the 30-60° range.

Number of movements per range for the trunk can be found in figures 6 and 7. Most trunk movements occur in the 1-5◦ range, with some in the 5-30◦ range, meaning that the trunk showed barely any substantial movement for both the therapy exercises and the RGS-games.

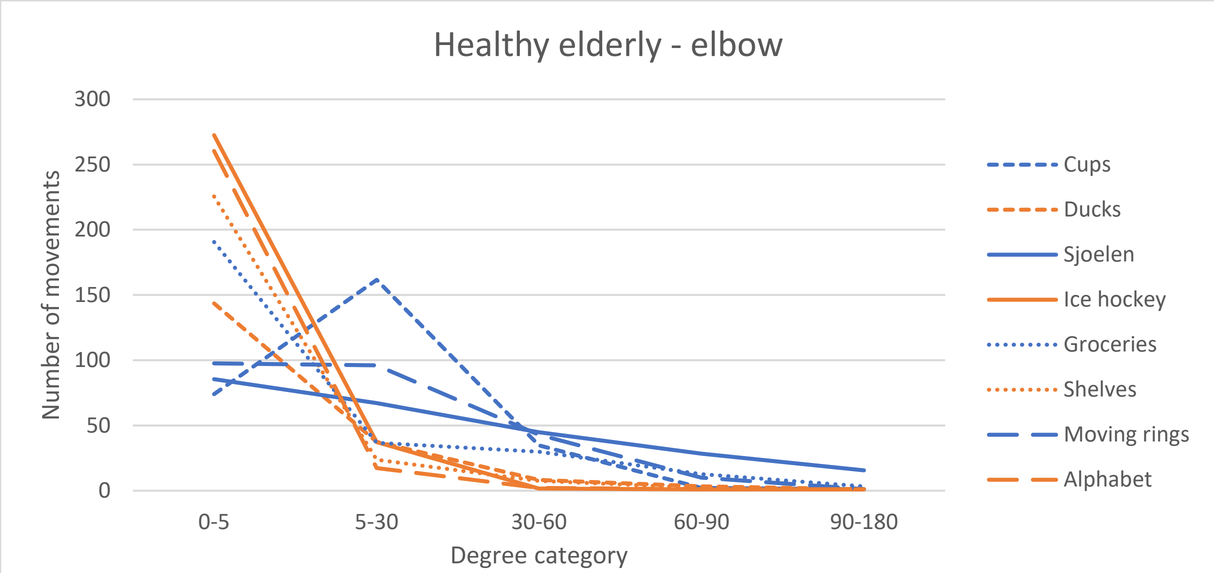

Figure 2 Number of movements of the elbow in each degree category. All therapy exercises are shown in blue and RGS-games in orange. The same line style represents a therapy exercise and game that should provoke similar movements.

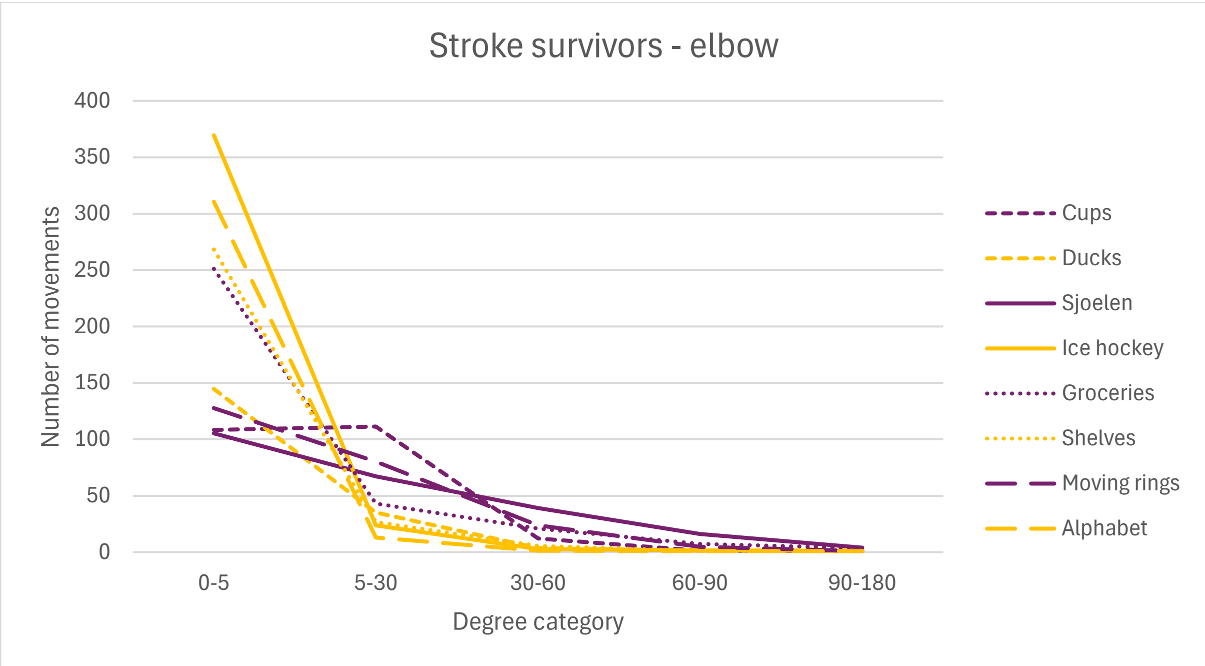

Figure 3 Number of movements of the elbow in stroke survivors in each degree category. All therapy exercises are shown in purple and RGS-games in yellow. The same line style represents a therapy exercise and game that should provoke similar movements

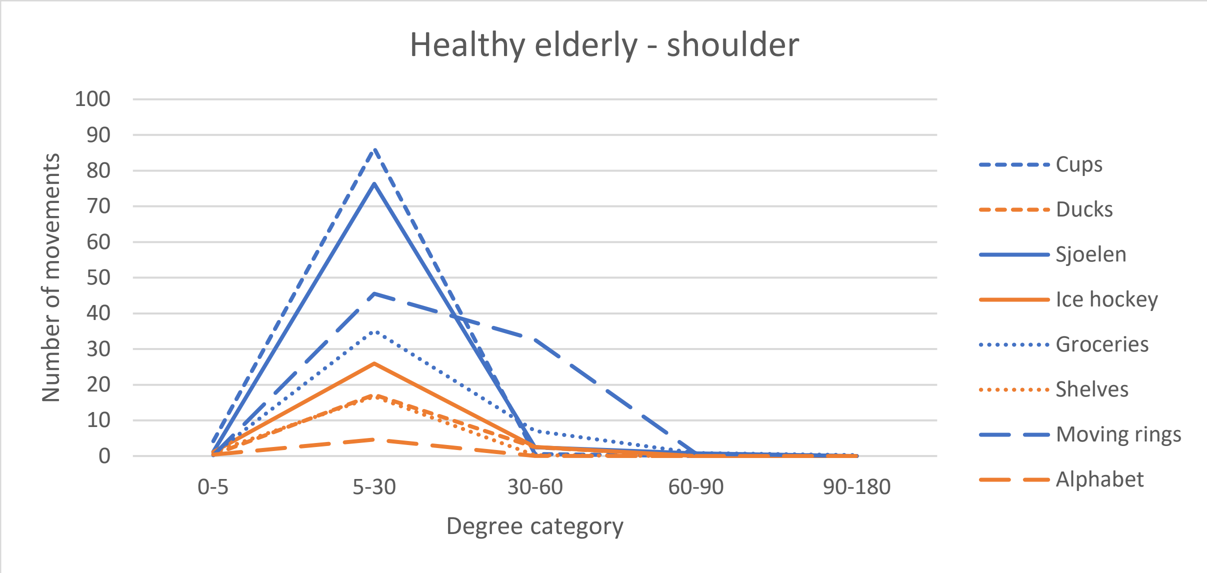

Figure 4 Number of movements of the shoulder in each degree category. All therapy exercises are shown in blue and RGS-games in orange. The same line style represents a therapy exercise and game that should provoke similar movements.

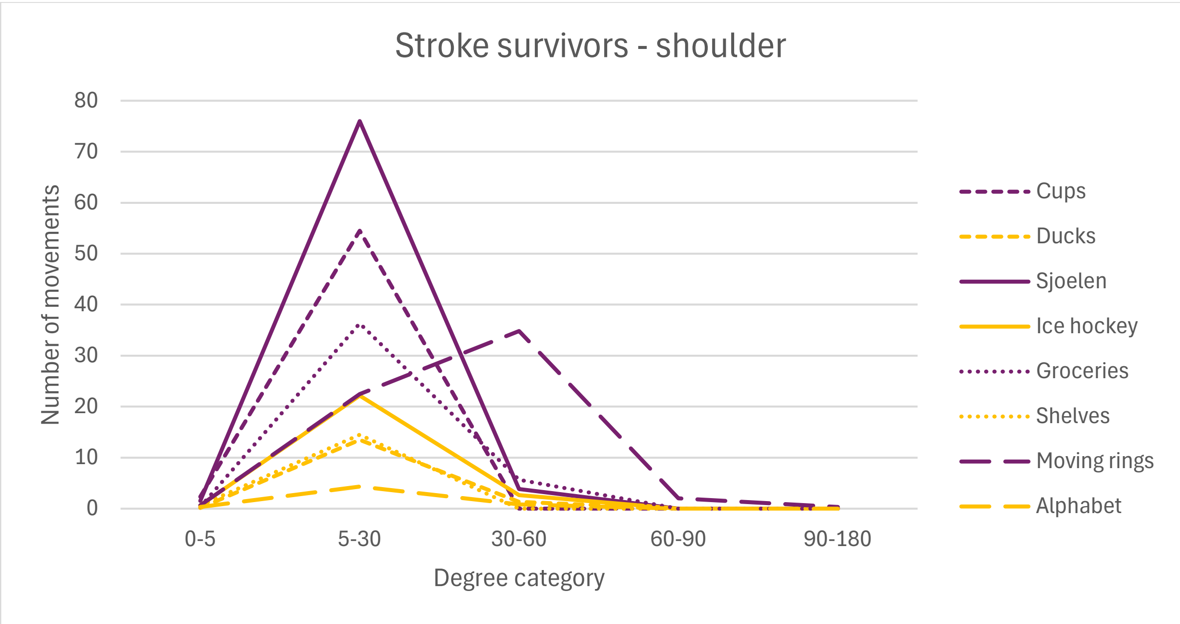

Figure 5 Number of movements of the shoulder in stroke survivors in each degree category. All therapy exercises are shown in purple and RGS-games in yellow. The same line style represents a therapy exercise and game that should provoke similar movements

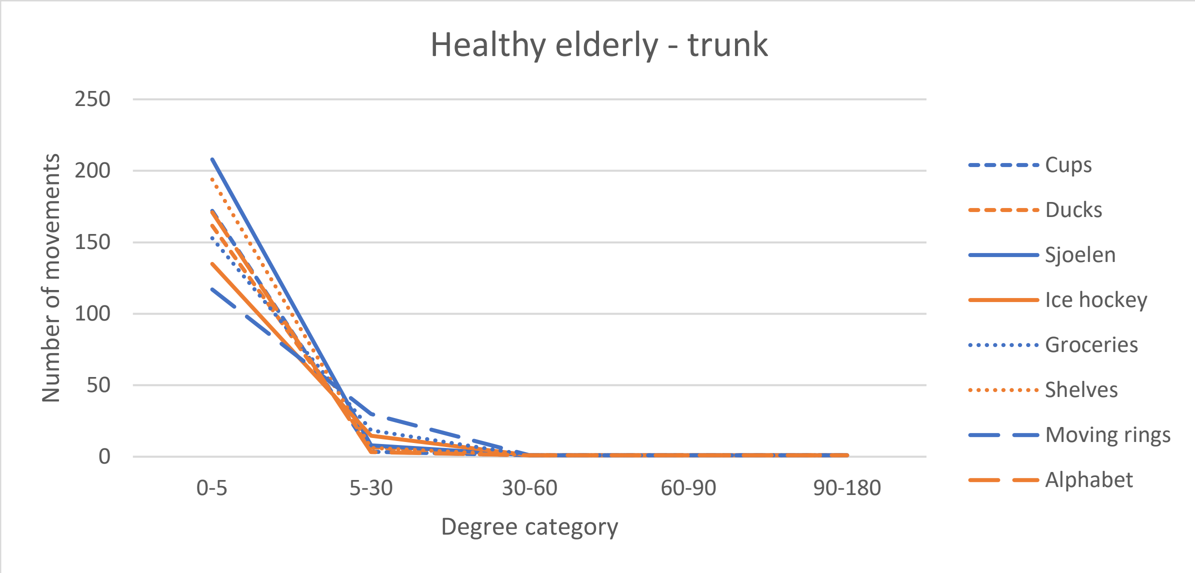

Figure 6 Number of movements of the trunk in healthy participants in each degree category. All therapy exercises are shown in blue and RGS-games in orange. The same line style represents a therapy exercise and game that should provoke similar movements

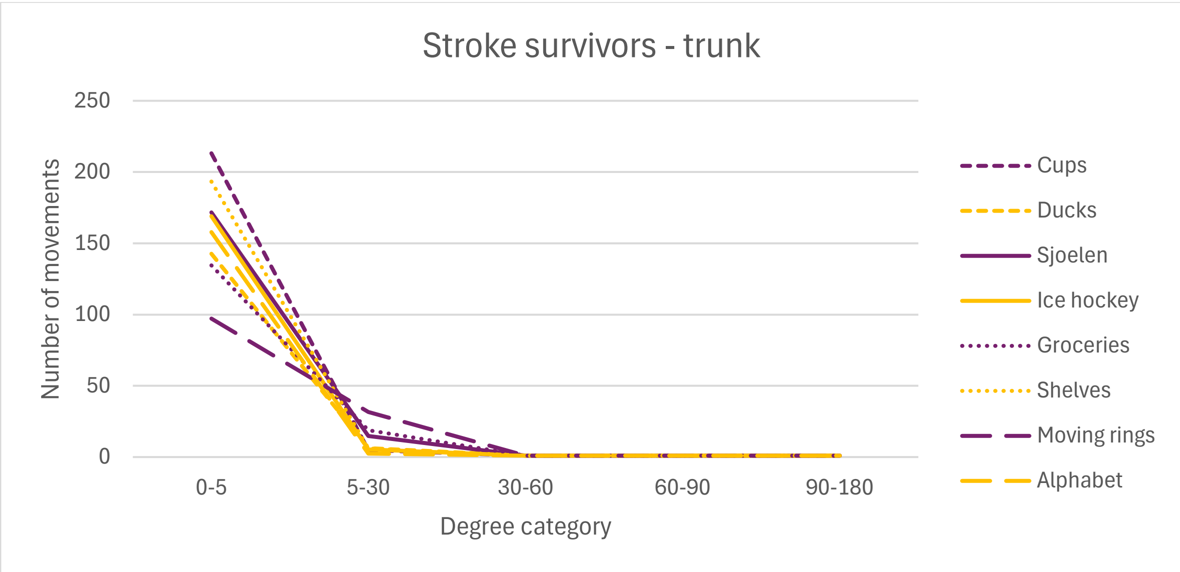

Figure 7 Number of movements of the trunk in stroke survivors in each degree category. All therapy exercises are shown in purple and RGS-games in yellow. The same line style represents a therapy exercise and game that should provoke similar movements

Effect of instruction

For the effect of instruction we looked at the difference in number of movements between the first and second round of game play, which can be found in figure 8 (stroke survivors) and figure 9 (healthy elderly). No noteworthy differences were found in number of movements between the first and second round, except for the 0-5 degree range. In addition there was no difference seen between the different instructions. For the 0-5 degree range, no clear effect of instructions can be seen. Since the 0-5 degree category cannot be seen as deliberate movements, these effects are not likely to be caused by learning or instructions.

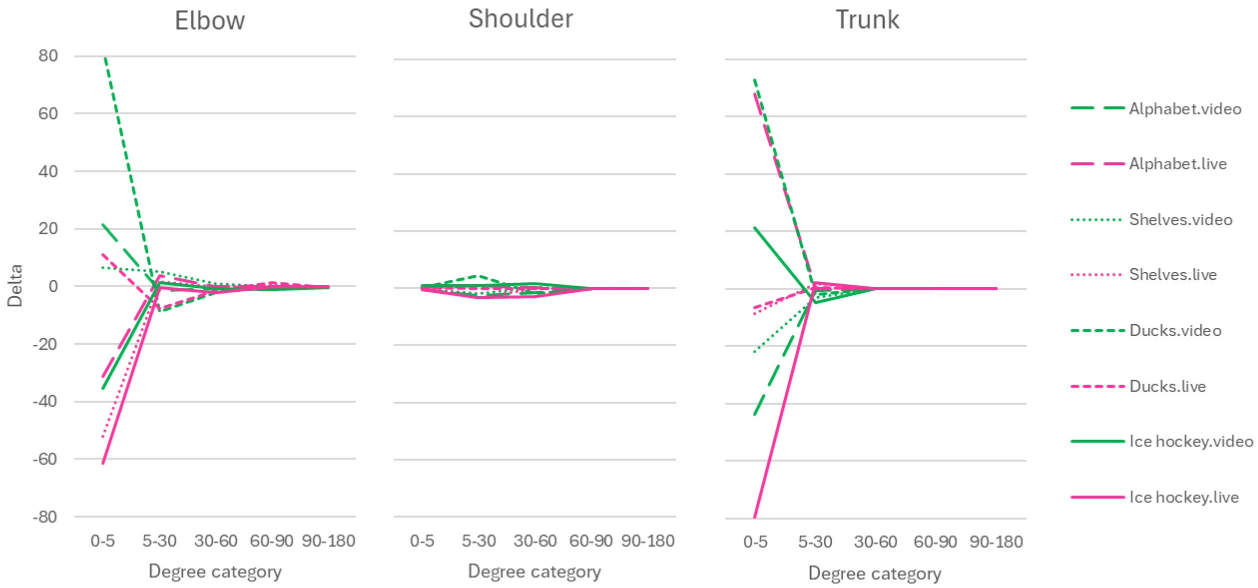

Figure 8 The effect of instructions in the stroke population on the elbow, shoulder and trunk movements. On the y-axis the delta between round 1 and round 2 is shown, meaning a positive delta represents more movements during the second round. The green coloured lines represent the group that got a video instructions twice. The pink lines represent the group that got a video instructions and personal live instruction.

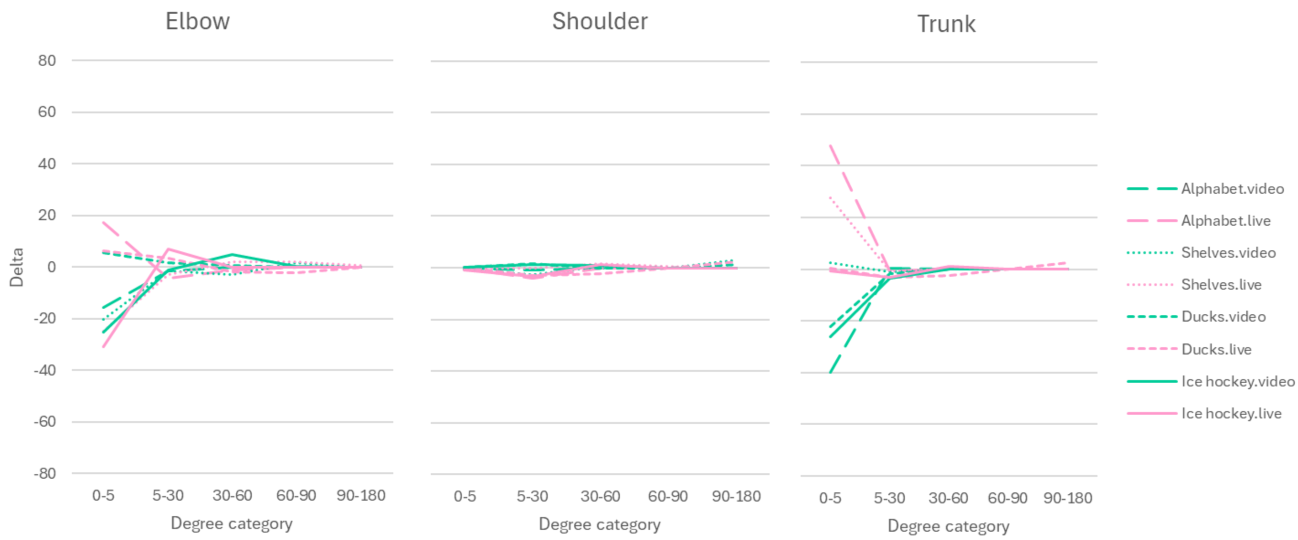

Figure 9 The effect of instructions in the healthy elderly on the elbow, shoulder and trunk movements. On the y-axis the delta between round 1 and round 2 is shown, meaning a positive delta represents more movements during the second round. The green coloured lines represent the group that got a video instructions twice. The pink lines represent the group that got a video instructions and personal live instruction.

5 Conclusion

The aim of this study was to analyse the movements provoked by the RGS-games and determine their comparability to therapy exercises. Additionally, the study investigated the impact of different instructional methods (video vs. personalized live instruction). Findings revealed that the RGS-games elicited fewer movements than traditional therapy exercises, with most elbow and shoulder movements below the 30 degree range. While therapy exercises also exhibited more movements in 5-30 degree range, they also had elbow and shoulder movements in the 30-60 degree range. Trunk movement was minimal for both RGS-games and therapy exercises, with angular changes of only 1-5 degrees, which do not qualify as significant motion.

The therapy exercises were matched to the RGS-games based on movement similarities as determined by a therapist. Although the RGS-games elicited less number of movements and smaller movements compared to the therapy exercises, they provoked movements similar to therapy exercises. Implementing a calibration step to establish maximum reach could potentially increase movement in the higher degree categories when playing the RGS-games. Additionally, the RGS-games may place greater emphasis on stabilizing and coordinating movements rather than solely increasing range of motion. While this approach may not generate large movements, it is still essential for improving functional use in daily activities. Ultimately, the results of the feasibility study will determine whether the RGS app enhances arm function and whether it primarily targets different aspects of upper limb rehabilitation beyond range of motion.

The different instructions did not show any effect on number and size of movements. This might be beneficial for home-based rehabilitation. Since the personal instruction does not improve performance, the RGS-app can be handed out without the feedback from a therapist. In addition, this study showed only minor movements of the trunk, meaning no compensation movements were performed. In the future the RGS-games can be implemented without specific instructions on movements from a therapist.

Finally, some participants required an adjustment period to familiarize themselves with the RGS games. Although they were given a practice round before the actual measurements, they may not have reached their optimal performance level. Future research could explore whether participants who have used the RGS app for a longer period demonstrate improved performance over time.

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