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Designing a tangible solution to encourage playful hand usage for children with cerebral palsy

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Abstract: Children with unilateral cerebral palsy (CCP) benefit from intensive training with the affected side. The SHArKi project strives for a motivational support system, using wristbands with inertial measurements units (IMU) to measure arm function, providing biofeedback as well as motivating stimuli. To consider finger and wrist movements as well, this paper covers concepts for a tangible solution and its first implementation including the gamification development. Finalizations of the demonstrator, an overall functional test as well as concluding feedback from CCP are pending.

Keywords: cerebral palsy; inertial measurement unit; motion tracking; motivation; rehabilitation; tangible device.

Introduction

Children with unilateral cerebral palsy (CCP) suffer from limited ability to use one body side. They benefit from intensive training with the affected side to (re-)establish motor function. The SHArKi project (Multimodal, sensor supported hand and arm training for children) compiles a support system based on playing and motivational aspects, using wristbands with inertial measurements units (IMU) to measure arm function and widen therapy into the child's home environment. Parents' general acceptance of such a system was confirmed [1]. Because CCP typically show a spastic hand posture, therapists underline the need to consider finger and wrist movements as well, on account of their necessity for gross motor development and

participation in daily life. Hence a supplemental tangible sensory device is being searched for.

To identify the most suitable system, the focus was set on encouraging enhanced movement through intrinsic, playful motivation, by thus avoiding known barriers to home-based training [2, 3]. Accuracy – very much needed for assessments – loses importance compared to practical applicability.

Multiple sensor systems such as 3D motion capture, flex sensors, LDR sensors, optical hand tracking, force myography sensors in form of gloves or other wearable solutions, are described in literature e.g. [1, 4–6] to measure hand function or to be used in therapeutic settings for various disease patterns. However, these rarely are applicable to child environs of everyday life nor without supervision. Also, the usage of gloves with spastic hands may be limited. Evading stationary gaming systems or technically elaborate solutions like augmented or virtual reality [7], this paper presents the development steps of a tangible solution that encourages playful hand usage of CCP in a user centred design approach.

Method

Therapeutic meaningful movements were analysed, categorized and selected according to therapeutic relevance for CCP, technical feasibility, and transferability into the child's everyday life as well as in game settings. Subsequently, the chosen movements were transformed into technical parameters and this selection led to concepts for the tangible device and game ideation. After feedback by experienced physio-therapists on geometry and gaming ideation, the functionality of the concepts was tested with healthy subjects.

Therapeutic relevance

Manifold sources were examined in the requirement analysis to identify therapeutic goals for wrist movements and hand functionality. Thorough literature research - including CP motor assessments and stroke rehabilitation - was followed by input of physiotherapeutic experts.

The clinical measurement tool Assisting Hand Assessment (AHA) examines the hand function of CCP in a playful setting. Video recorded test sessions are evaluated in six categories [8]. The items which refer to grasp/release movements complement the list of therapeutic needs.

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Other studies examine the grasp and release cycle in CCP;

Kanzler et al. [9] focus on arm and hand sensorimotor function and highlight the difference between grip strength (maximal force and maintain grip) and force control (force scaling and motor coordination); the presented parameters were considered in the technical concept (see Table 1).

Supplementary to studies on hand function and therapeutic goals in CCP, two workshops in the “Practice for Neurological Rehabilitation” were conducted. 13 physiotherapists discussed hand and arm exercises for fictive patients to identify and structure therapeutic goals and training movements with emphasis on the importance for the child’s daily life. The requirement analysis was completed with semi-structured interviews of physiotherapist and paediatric experts.

The movements with a high therapeutic need were examined regarding technical feasibility and the resulting aspects mapped in an order of increasing difficulty level.

Technical requirements

To be suitable for CCP, the training gadget must be robust, light-weight, easy to handle and suitable for different sizes of a child’s hand, installing the electronic safely inside the tangible. Haptic feedback to grip is desirable, also combinability with the SHArKi IMU system. To achieve this, movements with high therapeutic relevance were transformed into technical measurands. The selection of only few different sensors guarantees a robust and small construction.

Several sensor configurations were considered and resulted in two final concepts, which were subjected to the following functional pre-tests with healthy probands.

- Functionality: three probands grasp the tangible hard three times and hold it for 5 s
- Long-term-stability: the tangible was installed in a screw clamp with medium pressure for 2 min
- Threshold detection: one healthy proband holds the tangible in light, middle and strong grip for 30 s.

Motivational aspects

Game design for this tangible solution means to meet the goal of encouraging playful hand usage for CCP. The children are supposed to play deliberately and be motivated by the game itself and not conceive

it as physiotherapeutic training. Therefore, the game must meet the individual’s preferences in game design, as of genre and core mechanic. In serious games, a balance between the serious goal and a game target is essential [10]. Flow theory - widely used for engagement in games - focuses on the balance between the player’s skills and the game challenge [11]. As cognitive and motoric skills are very diverse in the target group of CCP, the game concept has to be adaptable for motoric and cognitive levels.

A game ideation according to the outlined issues was exemplarily executed for a basic setting with the task of feeding crocodiles. Two experienced therapists sorted the level ideas by ascending motor difficulty. Different cognitive challenges were discussed. Future work shall adapt those principles in different designs like car race or fantasy, according to the wishes of CCP from a following workshop.

Results

The approaches above lead to an overall concept, described in detail as follows.

Therapeutic movements

The requirement analysis classified 24 movement elements to be trained for improving hand function. They were mapped in categories as range of motion (RoM), force, and functionality. Five important aspects and combinations of them were then sorted according to difficulty. E.g., starting with a simple grasp-release task, the next step is the wrist dorsal extension followed by a combination of the first two levels. The motoric challenges progress via radial deviation (w/o, then with grasp, followed by a combination of flexion/extension and abduction/adduction) up to the most difficult levels as maintain force, maximum force and force dosage. Force levels may finally be combined with a wrist movement.

For each motoric level certain basic and higher cognitive levels are developed. The basic level focuses on the movement itself, whereas in the first cognitive level the user has to decide if the movement shall be executed or not. In higher cognitive levels a decision must be made between different actions.

Table 1: Therapeutic needs and measured technical parameters.

Category	Therapeutic need	Technical parameter
RoM	Wrist dorsal extension	RoM from wrist and tangible IMU
	Wrist radial abduction	
Force	Force dosage	Detection of different pressure thresholds
	Maintain grip force/ holds	Duration of holding a pressure value
Functionality	Grasp-release	Pressure above threshold yes/no

Technical feasibility

The transformation into technical parameters resulted in five selected technical parameters (see Table 1).

The form of the tangible is based on the therapists’ experience, who formed preferred patterns from plasticine. The tangible was determined as cylindrical shape with an outer diameter of 240 mm for scholars resp. 360 mm for adolescents.

Figure 1: Tangible solution. A) Left: v01 with connector for the Kikuhime system B) Right: v02.

The RoM parameters (wrist flexion/extension and wrist abduction/adduction) shall be detected by an IMU consistent to the SHArKi wristband. Development and validation of an algorithm to measure wrist RoM using IMU in a cylindrical tangible device are described in Mittag et al. 2020 [12].

Different pressure sensors have been considered (capacitive sensors, force sensing resistor, air pressure or strain gauge). The advantage of air pressure is the independence of impacted area and force direction. Supplementary, an air-filled tube or bubble gives a direct haptic feedback. Two versions of air pressure sensors were tested in detail. In the first version (v01) a silicon tube was placed around a 3D-printed housing with grooves to prevent the tube from being completely squeezed (see Figure 1A). For the second version (v02), the cylindrical housing was enveloped with an air bubble (Kikuhime, Fa. TTMediTrade) (see Figure 1B). Both versions are covered with a layer of neoprene to distribute the pressure and an outer textile layer for haptic reasons. Air pressure was measured with an analogue HSC pressure sensor (Fa. Honeywell) and verified with the Kikuhime system. The overall coefficient of determination between the two systems was 0.93 during four grasp movements.

Both systems have a good stability over 2 min (see Table 2) and therefore pressure failure due to air leakage could be excluded. In the functionality tests v01 has measured a higher pressure than v02. Both versions showed the ability to distinguish between different pressure thresholds.

Both sensors (IMU (BMI160, Fa. Bosch Sensortec) and pressure sensor (HSC, Fa. Honeywell) as well as a Bluetooth capable microcontroller chip (e.g. Adafruit Bluefruit MO, Bluetooth Standard 4.0) are installed inside the cylindrical housing to form the final technical concept.

Game development

The game ideation defines the serious goal through the therapeutic needs. Sorting these by motoric and cognitive levels permit to increase the challenge. The game target was developed with narrative and surprise elements to motivate the children to play and repeat hand movements. Instant

Table 2: Pre-test results.

Pre-test	v01	v02
Functionality		
– Proband 1	168 ± 11 mmHg	53 ± 4 mmHg
– Proband 2	267 ± 2 mmHg	83 ± 5 mmHg
– Proband 3	322 ± 13 mmHg	155 ± 2 mmHg
Long-term stability	63 ± 4 mmHg	33 ± 1 mmHg
Threshold detection		
– Light	16 ± 1 mmHg	20 ± 1 mmHg
– Middle	55 ± 4 mmHg	32 ± 2 mmHg
– Strong	94 ± 17 mmHg	55 ± 6 mmHg

Figure 2: Game setup.

and long-term feedback is possible as well as creating rankings.

In the graphical user interface (Figure 2) of the game, the children's hand is represented by a crocodile's mouth. By grasping and releasing the tangible device, the crocodile's mouth can be closed and opened. The wrist movement controls the direction of the crocodile's head. The overall game target is to supply and nourish a crocodile's family with food. Diversification is implemented in different game targets such as reach or transport food, eat food of different degrees of hardness or feed a baby crocodile.

Up to three cognitive levels were developed for each motoric level. E.g. for the therapeutic aspect 'grasp release with wrist dorsal extension' in the basic level, the food appears at the middle and the top of the screen. The child has to move the wrist to reach the food and fulfill a grasp movement to eat it. The tangible device has to be released afterwards to open the mouth again. In the successive cognitive level only certain kinds of food are edible, other fruits should be ignored. In the highest cognitive challenge large apples should be eaten by grasping, small apples be fed to the baby crocodile by a wrist dorsal extension

movement. Similar visualizations were developed for all targeted therapeutic movements.

Discussion

The final concept addresses five therapeutic aspects of hand function. Different motoric and cognitive levels allow individual progress.

Pre-tests with prototypes and healthy subjects showed the general technical feasibility; the RoM can be determined with sufficient accuracy by inertial sensors at the wrist and inside a tangible device [12]. Absolute pressure value may not be useful for intra-patient comparability, being a function of grip strength and hand size, but the outcome is – in general – sufficient for controlling the game elements. Differences in repetition trials could result from the prototype setup or probands fatigue. The v01 showed higher pressure values during middle and strong grip. Further detailed functional tests are planned for the selection of the preferred solution.

The game concept was developed with regard to motivational aspects, allows multiple motoric and cognitive challenges and is adaptable to the child's abilities through pre-selection of motoric and cognitive levels by therapists. The child's approval needs to be tested in a user study.

Conclusion

The final concept is targeted on motivating children to conduct therapy movements at home. It adds hand movement detection to the wristband sensors of the SHArKi project, by thus satisfying all three main aspects: the therapeutic needs and technical possibilities combined with motivational aspects.

As next steps, the proposed gamification concept will be implemented, and the demonstrator finalized. The system will then be evaluated in trials with CCP.

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