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A novel assistive therapy chair to improve trunk control during neurorehabilitation: Perceptions of physical therapists and patients

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ABSTRACT

A prototype assistive therapy chair (T-Chair) that induces exercise stimuli to improve trunk control and standing and walking early after stroke has been developed. The aim of this study was to assess its usability in a rehabilitation setting. Eleven physical therapists (PTs) integrated the T-Chair into the therapy programs of 15 patients post stroke. Each patient performed on average four individual therapy sessions on the T-Chair under the PTs' supervision. Usability was assessed using questionnaires, therapy diaries and focus group interviews with PTs'. Among PTs', 64% had generally a positive view on the T-Chair. Physical therapists recognized the potential for unsupervised therapy. Generally, patients reacted positively and enjoyed training. The T-Chair has the potential to become an adequate training tool for patients with an intermediate trunk control after stroke. Further development and usability testing are required to provide a therapeutic device allowing for an intensive therapy early post stroke.

1. Introduction

Stroke remains one of the leading causes of disease burden worldwide (Feiginet.al., 2015), (Milleret.al., 2010). In the coming years, rich and poor societies alike will face a further increase in the global burden of stroke, mainly due to the increase in the absolute number of disability-adjusted life years in developing countries and the ageing population in developed countries (Feiginet.al., 2015), (Bernhardtet.al., 2017), (Winters et al., 2018). Globally, around 16 million people per year experience a stroke for the first time, of which 5 million remain limited in their mobility (Strong et al., 2007). One cause of limited mobility early post stroke is impaired trunk control. This is the inability of the trunk muscles to maintain the body in an upright position, adjust weight-shift, or perform movements of the trunk. A loss thereof is clearly associated with limitations in breathing, speech, balance, gait, arm and hand function (Davies, 1990a). Moreover, sitting balance has been repeatedly identified as an important predictor of motor and functional recovery after stroke (Wade et al., 1983; Feigin et al., 1996; Kwakkel et al., 1996; Hsieh et al., 2002). Selective trunk control is an prerequisite to regain standing and walking (Kwakkel and Kollen, 2013), (Verheydenet.al., 2007), and a predictor for the total functional outcome of the rehabilitation, especially regarding standing and walking. The initial severity of disability and extent of improvement observed within the first weeks post stroke are substantial indicators of the outcome at six-months (Kwakkel and Kollen, 2013), (Kim et al., 2015), (Verheydenet.al., 2006). The largest improvements typically occur soon after a stroke, as most motor recovery is almost completed within ten weeks post stroke with only smaller improvements occurring in later phases (Kwakkel and Kollen, 2013).

Trunk exercises have a beneficial effect on trunk control, standing balance, and mobility after stroke. Patients post stroke whose trunk control improves faster are able to start earlier with gait and balance training (Saeys et al., 2012). Training of sitting balance while reaching beyond arm's length yields a positive effect on gait and mobility related functions and abilities (Veerbeeket.al., 2014), and trunk muscle strength is related to the Berg Balance Scale at discharge (Karatas et al., 2004). Despite these facts and while there is extensive research on rehabilitation of other functions, e.g. gait, there is sparse research and innovation

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on trunk control rehabilitation (Veerbeeket.al., 2014). Furthermore, traditional trunk control exercises are resource intensive for physical therapists (PTs) and therefore cannot be performed to the extent that it would be beneficial. Thus, resource-efficient interventions to augment conventional physiotherapy for trunk control in the early phase post stroke are needed. This may result in a higher dosage of trunk control training (e.g. high number of repetitions at an adequate level of challenge) (Winters et al., 2018), (Saeys et al., 2012), (Veerbeeket.al., 2014), (Johansson and Wild, 2011).

To overcome this gap a prototype of a robot assisted therapy chair (T-Chair) that induces exercise stimuli for trunk control training and standing and walking early post stroke has been developed. T-Chair is designed to allow many movement repetitions and potentially serve as an adequate training tool for unsupervised training. The development of the T-Chair followed a User Centered Design (UCD) approach (Sanders, 2003), which involves potential users from the outset of technology development. This is to ensure that the structure, content, and design of the technology is driven by the needs, expectations, and understanding of the users. The UCD approach can help developers to identify and fulfil user needs and requirements (Ghazali et al., 2014) at the prototyping stage of a technology (Ghazali et al., 2014).

The aim of this study was to analyze user needs and requirements based on the testing of a first prototype with PTs and patients early after stroke, with the results informing the development of future prototype generations.

2. Materials/methods

2.1. Participants

Eleven PTs from the neurology department of a local rehabilitation clinic were recruited. Three of them were students who had completed their undergraduate studies and in their last clinical placement. For this study, the students were physical therapists and eligible to give their opinion on the usability of the device. The PTs recruited 15 patients with trunk control impairments early after stroke. Additional inclusion criteria for patients were age ≥18 years, being able to perform at least 2 h of rehabilitation training a day, a trunk impairment scale (TIS) (Verheyden et al., 2004) score between two and 19, being able to understand verbal instructions in German, and no previous injuries or disorders of the spine. The TIS spanned a wide range to cover the full spectrum of potential future T-Chair users.

2.2. Device

The T-Chair supports the following therapy goals within the International Classification of Health Intervention (ICHI) - Interventions on Body Systems and Functions – 10 Interventions on the Musculoskeletal System – Movement (ICHI 1-10-MV) domain (Hartet.al., 2019):

- MVD.PG.ZZ Assisting and leading exercise for control of voluntary movement functions
- MVF.PG.ZZ Assisting and leading exercise for involuntary movement
- MVD.PH.ZZ Training motor control.

The T-Chair is designed for patients with low TIS scores (≥2) early after stroke. The exercises difficulty level can be adapted to challenge patients with greater TIS scores (up to 19) by adapting the movement direction, range, and velocity. The T-Chair determines the exercises, but the latter are based on treatment recommendations for trunk control exercises (Edwards, 1996; Ryerson and Levit, 1997; Davies, 1990b).

The T-Chair's movable seat has either one or two degrees of freedom i.e. in medio-lateral and antero-posterior direction or a combination thereof. The seat is mounted on a U-shaped rail and, thus, rotates around a virtual axis located at the spine. This allows the upper torso to be kept in an upright, calm position during lateral and flexural motion of the lower spine and pelvis. The ergonomic design is explained in detail elsewhere (Bauer et al., 2018; Kuster et al., 2016, 2018, 2020). All necessary safety requirements (e.g. pinching of body parts, securing the patient) are implemented according to current technical standards (C and „C 80601-2-78:2019, 2019; O and „O 24496:2017“, 2449;:00–17:00 and „O 14971:200, 1497). The trunk and thighs of the patient may be secured on the T-Chair with a harness (Fig. 1 and Video).

Supplementary video related to this article can be found at https://doi.org/10.1016/j.apergo.2021.103390

The T-Chair can be used in two modes: A motorized to train the involuntary movement function, and a non-motorized one to train voluntary movement control. During the motorized mode, four exercises can be selected on the control panel: Flexion/Extension (anteroposterior seat motion), Lateral Flexion (mediolateral seat motion), Circle (circular motion in both direction), and Figure of Eight (motion in both direction in the form of an eight in transversal plane). The amplitude of the seat motion is variable up to ±50 mm for the medio-lateral and ±42 mm for the anteroposterior direction. This range of motion was derived from the physiologic motion pattern of the pelvis in healthy people (Bauer et al., 2018; Kuster et al., 2016, 2018). The speed of the exercises is variable up to 10 cm/s. In the non-motorized mode, patients must move the seat themselves according to the instructions of the PT. In both modes, the control panel shows the current location of the seat as visual feedback. Fig. 2 and video supplement 1 illustrate the therapy modes. Training intensity with the T-Chair is individually adapted to patients' trunk control ability. Patients with lower levels trunk control are trained 1) using the motorized mode, 2) their feet positioned wide apart 3) while performing unilateral trunk movements, 4) at low velocity and 5) a small range of movement. With higher trunk control ability motor task difficulty can be increased regarding these five parameters, for instance by switching into the non-motorized mode. In addition, patients can perform 6) arm reaching movements requiring 7) trunk and head rotation.

2.3. Procedure

The PTs received 3 h instruction by the investigators prior to the start of the study. In the rehabilitation setting, the PTs integrated the T-Chair into the usual therapy program, which had a total duration of 9.5 h per week. In addition to this, physical therapy training using the T-Chair, focusing on improving mobility and trunk control, took place for 5 h per week. Occupational therapy accounted for 3 h per week and focused on improving cognitive functions in daily activities, such as washing and dressing in the morning and household activities. Other treatments (1.5 h per week) were scheduled as needed based on the individual patient's needs. These included robotic and medical exercise training, neuropsychological training, counseling by a social worker, and recreational therapy. The same PT supervised all sessions of a patient and selected the number, type, mode, order, speed, amplitude, and duration of the exercises in each session. The duration of each therapy session was determined by the PT according to the patients' overall therapy goals and condition. If required, the PT assisted patients to transfer to and secure on the T-Chair.

2.4. Data collection

All data collection instruments are presented in the Appendix.

Physical therapists: A mixed-method approach was used to explore the usability of the T-Chair, comprising of a diary, questionnaires, and focus group interviews. Before the first treatment session, the PT filled out a questionnaire detailing the sociodemographic data of the patients. After each therapy session, the PTs completed a diary, encompassing the preparation time, therapy time and content, and the problems that may arise. After the last therapy session, the PTs completed one questionnaire per patient regarding the preparation phase (eight items), the therapy (five items), safety (six items), and general aspects (two items).

Fig. 1. T-chair therapy setup with patient and physical therapist.

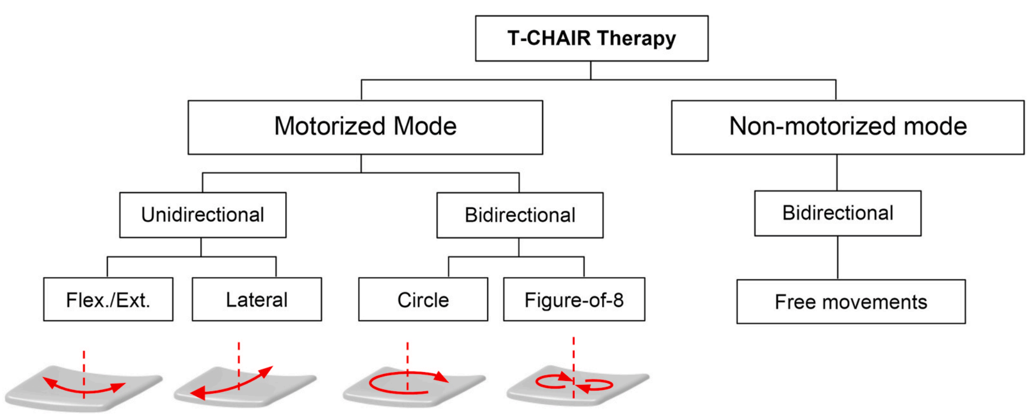

Fig. 2. T-CHAIR therapy modes: The motorized mode facilitates reactive trunk control. The patient is asked to keep the head and trunk stable while the motors induce unilateral or bilateral movements of the pelvis and lumbar spine, via the seat. The non motorized mode facilitates active trunk control by asking the patient to either keep the seat stable during exercised or by exploiding the seats range of motion actively.

To learn more about the personal and individual experiences of each PT regarding the T-Chair, two focus group interviews were conducted. The guideline for the focus group discussions covered the topics of "general remarks", "preparation", "handling/functionality", "therapy", "safety", and "concluding remarks".

Patients: Trunk control was measured at baseline with the TIS (Verheyden et al., 2004). Usability from the patient's perspective was recorded by various means: in a diary, by the rating of perceived exertion, and through a questionnaire. The details of the rating of perceived exertion and adverse events, a serious or non-serious event that might or might-not be related to the study (such as sudden exacerbation of pain or discomfort), were recorded in the diary. Perceived exertion of the trunk and lower extremities was measured using a Borg category-rating scale (CR10) with ratings from 0 (not at all) to 10 (extremely strong) (Borg, 1998). Due to the novelty of the T-Chair no prior hypothesis about a trend regarding perceived exertion was formulated. The diary and the CR10 were completed after every therapy session. After their last therapy session, the patients completed a customized questionnaire covering the preparation phase (seven items), the therapy (five items), safety (six items) and general aspects (one item). The items were formulated as in accordance with the physical therapists' questionnaire.

2.5. Data analyses

The results are presented as distribution of response frequencies to the questionnaires and diaries. The CR10 was evaluated descriptively. The focus group interviews were analyzed for emerging themes using summary content analysis (Mayring et al., 2019).

In order to obtain a multi-layered understanding of the T-Chairs usability, the concept of triangulation was chosen (Denzin, 2017), (Flick, 2020). Triangulation helps to consider and record diversity and contradictions of a research object. Different methodological procedures and different data are related (between-method) to each other to discover emerging themes. This complementary mixed methods approach enhances strengths and minimizes weaknesses of mono-method approaches (Greene et al., 2016). Feedback from patients and PTs were considered equally.

3. Results

3.1. Participants

Table 1 illustrates the PTs and patients' characteristics. Three PTs were apprentices at the time of the study. Of the other eight PTs, six worked for less than three years, one for five years and one for 30 years at the clinic. All the PTs had a workload of ≥32 h per week or ≥75%. Eight patients used the T-Chair during five therapy sessions, four patients for four therapy sessions, and the remaining three patients for one, two and respectively three sessions. Reasons for performing less than five sessions were: discharge from the hospital; too little challenge; concerns about the training for one patient with anxiety; and technical problems. No adverse events occurred.

3.1.1. Emerging themes

During the data triangulation process, the following major main themes emerged: 1) adequacy of challenges; 2) resources required for independent training; 3) motivation of the patient; and 4) safety. Suggested improvements within these themes were derived based on the conclusions of the patients and PTs.

In this article, only data related to the above major themes are presented and elaborated. The following study results are not elucidated: 1) ease and adjustment of the chest and tight belts, since neither had been used by 47% (chest belt) and 33% (tight belt) of the PTs; 2) The sound volume and the supplied instruction manual of the T-Chair, since they are not related to any of the major themes.

Table 1
Descriptive statistics of study population.

Patients (n = 15)	M ± SD; n (%)
Age (years)	69.7 ± 9.9; 43-82
Sex	
male	12 (80%)
female	3 (20%)
Retired	11 (73%)
Physiotherapists (n = 11)	M ± SD; n (%)
Sex	
male	1 (9%)
female	10 (91%)
Work experience at study site (years)	4.6 ± 10.3
Actual Employment Level	96% ± 6.9%

Abbreviations: M – mean; SD – standard deviation.

3.2. Adequacy of challenges

3.2.1. Physical therapists

Most PTs expressed a positive view of the T-Chair (64%) during the focus groups. Some particularly emphasized the benefit that patients could feel their own trunk movement. They recognized the T-Chair's potential to become an adequate training device for patients with an intermediate level of trunk control. The possibility of choosing either the non-motorized or motorized mode and to increase the number of movement repetitions were considered useful. However, the PTs regarded the current version as a prototype, with only 33% rather to strongly agreeing that the T-Chair is a useful rehabilitation device (Fig. 3a). This finding was related to, for example, reservations regarding the adequacy of challenges: The PTs had the impression that the patients were challenged by varying degrees while training with the T-Chair: 54% at least rather agreed that the choice of exercises corresponds to the patients' abilities (Fig. 3c). With regard to the adjustability of the T-Chair to the patients' needs, 66% of PTs rather to strongly agreed that the T-Chair's direction of movement (Figs. 3e), 54% that its range of motion (RoM) (Figs. 3f) and 47% that its speed of movement (Fig. 3g) were adequately adjustable. The PTs also, identified several themes to improve the adequacy of challenges: The level of assistance could be made more variable, by integrating an intermediate level of assistance between the motorized and non-motorized modes, and varying the levels of resistance of the seat against the patient's movement in the non-motorized mode. The exercises could be made more challenging by including games or feedback, randomized movements, increased range of motion of the seat, increased movement speed, a randomization of the range and movement speed within or between exercises, a vertical degree of freedom and more elastic guidance of the seat so that wobbling becomes possible during exercises.

3.2.2. Patients

Among patients, 47% rather to strongly agreed that the T-Chair is useful for their therapy (Figs. 3b) and 34% rather to strongly agreed that they experienced therapy with the current prototype as adequately challenging (Fig. 3d). They described the T-Chair as a good training device and a suitable supplement. They nevertheless expressed criticism regarding the level of challenge. For some patients, the training offered too little challenge. They reported a median level of perceived exertion of the lower extremities across all sessions and slightly stronger exertion of the trunk (Table 2).

3.3. Resources required for independent training

3.3.1. Physical therapists

PTs appreciate the potential for independent training offered by the T-Chair. Concerning the resources needed, the mean time required for preparation, installation and setup across all sessions was 3.8 min (Table 3). This included the time expenditure for transfer, securing the patient and starting the software. Forty % of PTs considered this an adequate set-up-time (Fig. 4a). That 'operating the software was self-explanatory' was rather to strongly agreed by 87% of PTs (Fig. 4c). Fifty-four % rather to strongly agreed that the adjustment of the armrests was easy, quick, and adequate (Fig. 4d). Only 33% thought that the adjustment of the backrest (Figs. 4f) and 7% that the adjustment of the seat height (Fig. 4h) were easy, quick, and adequate. The transfer of patients was rather to strongly agreed to be easy by 46% of the PTs (Fig. 4j). The PTs encountered difficulties during transfer of severely affected patients, while decoupling (changing between motorized and non-motorized modes) and adjustment of the seat height. Virtually no adjustment of these settings was possible with a patient sitting on the chair. The mechanical resistance when adjusting the seat height was regarded as too high, even when the patient was not sitting on the T-Chair.

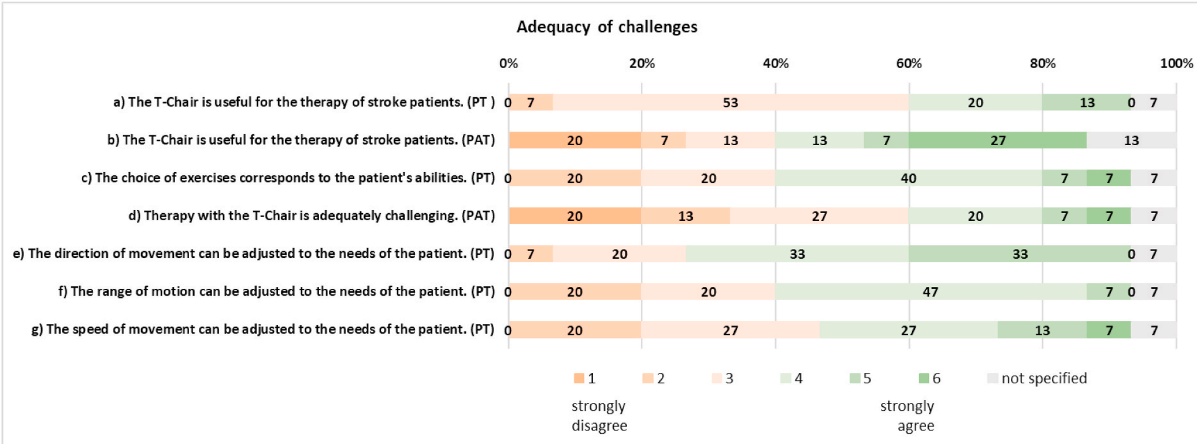

Fig. 3. Physical Therapists' (PT; n = 15) and patients' (PAT; n = 15) evaluation of items related to the adequacy of challenges offered by T-Chair.

Table 2
Level of perceived exertion reported by the patients.

Session					
	Session 1 (n = 15) n (%)	Session 2 (n = 14) n (%)	Session 3 (n = 13) n (%)	Session 4 (n = 12) n (%)	Session 5 (n = 8) n (%)
Perceived exertion trunk (0 = not strenuous at all, 10 = very strenuous)					
Median (Range)	4 (0–8)	3.5 (0–8)	4 (1–5)	4 (0–10)	3.5 (0–10)
Perceived exertion legs (0 = not strenuous at all, 10 = very strenuous)					
Median (Range)	3 (0–5)	2 (0–6)	4 (0–9)	3 (0–10)	2.5 (0–10)

Table 3
Time required for preparation, installation, and setup.

Sessions					
	Session 1 (n = 15) n (%)	Session 2 (n = 14) n (%)	Session 3 (n = 13) n (%)	Session 4 (n = 12) n (%)	Session 5 (n = 8) n (%)
Time required for preparation, installation, and setup (Minutes)					
mean ± SD	5.0 ± 4.3	3.4 ± 1.4	3.9 ± 1.8	3.5 ± 1.6	3.3 ± 2.8
<5 Minutes	6 (40%)	9 (64%)	5 (42%)	6 (55%)	4 (50%)
5 Minutes	8 (53%)	5 (36%)	6 (50%)	5 (46%)	3 (38%)
>5 Minutes	1 (7%) (20 Min.)	0	1 (8%) (7 Min.)	0	1 (13%) (10 Min.)

3.3.2. Patients

Among patients, 67% regarded the time for preparation as (rather) adequate (Fig. 4b). Some to strong agreement was expressed concerning the adjustment of the armrest and backrest to their needs by 80% of patients (Fig. 4e and g), and of the seat height by 53% (Fig. 4i). Seventy-two % of patients rather to strongly agreed that the transfer from wheelchair to the T-Chair was easy to perform (Fig. 4k).

3.4. Patients motivation

3.4.1. Physical therapists

The PTs were not inquired regarding the patient's motivation.

3.4.2. Patients

Thirty-four % agreed rather to strongly that therapy with the T-Chair

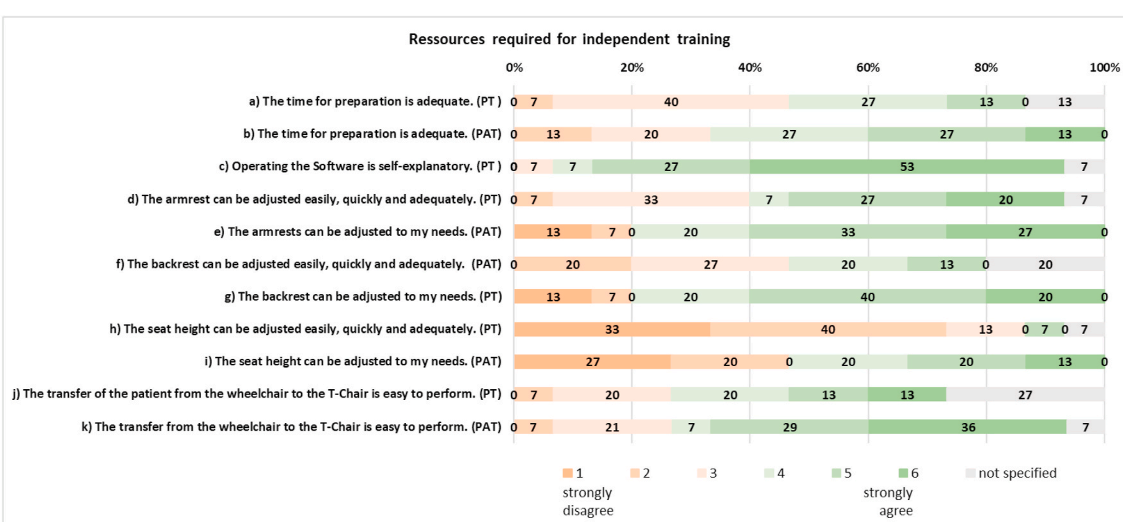

Fig. 4. Physical Therapists' (PT; n = 15) and patients' (PAT; n = 15) evaluation of items related to the resources that are required for independent training.

offered enough variation (Fig. 5a). Some patients at least rather agreed that the T-Chair's feedback function helped to perform the movement correctly (27%, Fig. 5b) and increased their motivation (3%, Fig. 5c).

3.5. Safety

3.5.1. Physical therapists

Sixty-six % rather to strongly agreed that adequate safety measures had been established (Fig. 6a). The majority at least rather agreed that the following security measures were sufficient: backrest (86%, Fig. 6c), armrests (53%, Fig. 6e), support aids (47%, Fig. 6g), thigh belt (73%, Fig. 6i) and chest belt (53%, Fig. 6k). Support aids had not been evaluated by 40% of PTs, thigh belt by 27% and chest belt by 40%. However, PTs recommended modifying the armrests to avoid interference during transfer.

3.5.2. Patients

Eighty-six % of the patients rather to strongly agreed that they felt safe during therapy (Fig. 6b). In particular, the majority rather to strongly agreed that they felt adequately supported by the backrest (93%, Fig. 6d), the armrests (74%, Fig. 6f), the support aid (53%, Fig. 6h), the tight belt (40%, Fig. 6j) and the chest belt (60%, Fig. 6l). Similarly, to the PTs, many patients (27–60%) did not evaluate the support aid, thigh belt and chest belt.

4. Discussion

This study used a user centered design to analyze the usability of the prototype T-Chair for the rehabilitation of trunk control early after stroke. Generally, the prototype T-Chair was found potentially to be a suitable device for the training of trunk control, with some limitations that are discussed below. Improvements in adequacy of challenges, resources required for independent training, motivation, and safety aspects are desired.

4.1. Adequacy of challenges

The exercises currently available may have been evaluated as not challenging enough due to insufficient demands on trunk control. To achieve an adequate training effect on trunk control, the exercises should be hard enough to trigger a training stimulus (Van Criekingeet. al., 2019)– (Van Criekinge et al., 2018). Further improvements regarding the level of challenges are needed. The level of challenge could become more modifiable through adaptations to the movement amplitude and speed. The movement speed of the seat could be increased by implementing more powerful motors. Increasing the movement amplitude would require a larger seat rail and, possibly, a re-evaluation of its geometry to ensure that the patient's lower back movement would still correspond to everyday movements (Bauer et al., 2018)– (Kuster et al., 2016). Both increased movement speed and amplitude might possibly require stronger damping mechanisms at the end range of motion. Concerning the motorized mode, more variable and stochastic movement patterns, in terms of movement speed and direction, might be warranted. This approach could facilitate more challenging trunk control exercises and perturbation training in sitting that include involuntary or reactive movements of the trunk (Van Criekingeet.al., 2019), (Dusane et al., 2019). The integration of an intermediate level of assistance between the motorized and non-motorized modes would be conceivable if the control of the motors were to be changed. Furthermore, it might then be possible to provide varying and adjustable levels of resistance to the seat by adding one additional mode, where T-Chair resists the patient's movement, to train voluntary movements and motor control (Haruyama et al., 2017), (Dorsch et al., 2018). In addition, it might be possible to make the guidance of the seat more elastic, to provide an unstable seat, thus further increasing the challenge for patients with higher levels of trunk control. These changes would add therapy options to intensify the training of voluntary movements, involuntary movements, and motor control (Hartet.al., 2019). A vertical degree of freedom to induce vertical perturbation and three-dimensional movement of the seat would require an additional motor and enable the training of motion patterns that would resemble movements such as walking more closely (Perry and Davids, 1992).

4.2. Resources required for independent training

It was relatively cumbersome to set up the T-Chair. This reduces the possibilities and the time to offer the patients an independent, intensive, and adequate training. Since intensive training after stroke is important, it is essential to achieve improvements in this area (Langhorne et al., 2011). The most important features in need of improvement are the mechanical aspects regarding seat height adjustment and the armrests: patient transfer should not be restricted by the armrests, and chair set-up should be possible with a patient sitting on the chair. This requires problem-free decoupling between the operating modes, foldable armrests, and simplified adjustment of seat height. Problem-free decoupling can be achieved by a redesign of the coupling mechanism beneath the seat. This would enable switching between the two therapy modes and make the T-Chair more versatile by supporting the patient in training voluntary movement and motor control within one session, (Haruyama et al., 2017), (Dorsch et al., 2018). More available therapy modes within one session might also promote the motivation of patients (Thilarajahet. al., 2020). To facilitate transfer, the armrests need to be redesigned, possibly with rotating or folding swivel joints. Doing this would make the transfer from a standard wheelchair to the T-Chair, with a 45° or 90° angle between the two chairs, possible (Marras et al., 1999), (Garg et al., 1991). Mechanical assists, such as a pivot device or total lift, could be used to safely transfer patients who are more dependent from the wheelchair to the T-Chair. Adjusting the T-Chair's seat height required the patient to get out of the T-Chair. Readjustment of the seat height was time consuming, but unavoidable because the optimal seat height for the patient was unknown before the patient sat on the T-Chair for the first time. A hydraulic, pneumatic, or electrical mechanism might allow for a smoother and more time efficient adjustment of the seat height.

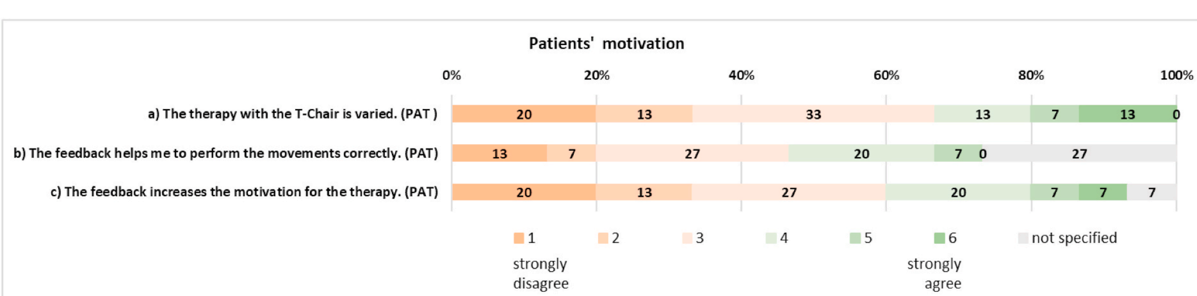

Fig. 5. Physical Therapists' (PT; n = 15) and patients' (PAT; n = 15) evaluation of items related to the patients' motivation.

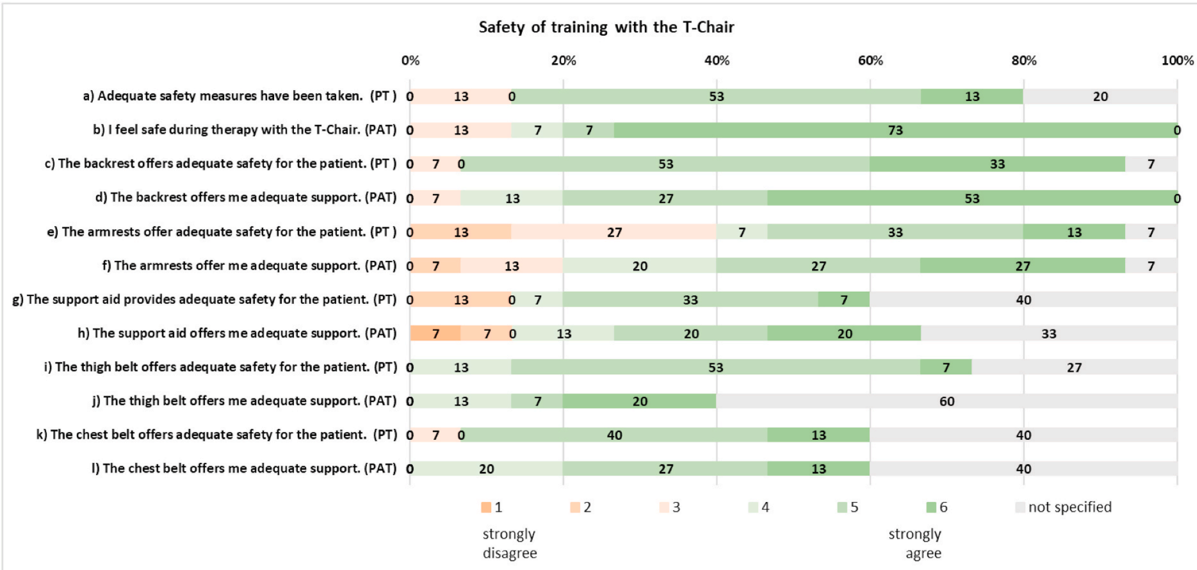

Fig. 6. Physical Therapists' (PT; n = 15) and patients' (PAT; n = 15) evaluation of items related to the safety of the training with the T-Chair.

4.3. Patients motivation

Some patients reacted very positively and enjoyed training with the T-Chair, while others found the training not challenging enough, too complicated, or felt anxious. Additional feedback might help to increase the treatment contrast between the T-Chair and conventional therapy, because feedback may constitute a motivating training supplement in stroke rehabilitation (Brunneret.al., 2017). Visual feedback methods, such as virtual or augmented reality (AR) provided by a head mounted display, or tactile feedback methods could be added (Gorman and Gustafsson, 2020), (Sheehyet.al., 2020). AR feedback has the potential to provide additional stimuli relevant to daily life and thus train a stroke patient's voluntary and involuntary movements and motor control in scenarios of daily living (Bank et al., 2018)– (Rohrbachet.al., 2019). Future research should address what type of feedback should be provided, and when to assure that it is not perceived as overwhelming or distracting but beneficial for the transfer to daily living situations (Rohrbach et al., 2019). Possible applications could be balance, transfer, reaching, or other functional exercises; potentially by controlling two degree of freedoms and corresponding movement directions independently (Davies, 2000). Generally, it needs to be investigated under which situations the T-Chair should provide real time feedback of a patient's performance, or when it should provide summary feedback after an exercise is completed. For example, if warnings (e.g. when a patient approaches his or her limits of stability, or end of movement range) are provided too extensively this might trigger unwanted protective behavior. Furthermore, it needs to be investigated whether other types of exercises in combination with feedback modalities and the moving seat, such as reaching exercises, should be integrated (Valdes et al., 2017).

4.4. Outlook

The use of UCD has shown that involving potential users in the design and testing is useful in increasing the functionality and usability of the technology. This can help to promote the intended health outcomes (Dabbset.al., 2009). The identified limitations are currently improved for a next iteration of the T-Chair. The new iteration will be re-evaluated with potential users, following the user centered design approach (Sanders, 2003). Future research on this novel therapy approach should also address which subgroup of patients after stroke would benefit most from assisted trunk exercises. This subgrouping could be based upon functional outcomes, such as the TIS, or non-invasive biomarkers such as imaging techniques to assess function changes in the brain (Winters et al., 2018), (Boydet.al., 2017). This approach might also assist to determine how therapy programs for assisted trunk therapy should be designed to match an individual patient's level of trunk control, to maximize benefit for an individual patient, both in terms of functional activities and neuroplasticity, possibly resulting in a wider spectrum of patients that are enabled to train their trunk control more specific (Winters et al., 2018), (Calabroet.al., 2018). It would have been interesting not only to use the CR10 generally, but to describe the intensity of the specific task performance, e.g. transfer to the device, autonomous modes administered for training. The T-Chair could become an adequate training tool for patients post stroke at an intermediate trunk control level. The T-Chair could also become a therapeutic device to train trunk control with many repetitions early post stroke, and thus help patients to regain balance and mobility.

5. Conclusions

The T-Chair is a unique therapy device aiming to train trunk control early post stroke. It might become an adequate device at an intermediate trunk control level, between exoskeletons and manual exercises. Improvements regarding adequacy of challenges, resources required for independent training, and motivation are desired.

Ethical approval and consent to participate

All participants were informed orally and in writing about the purpose and procedures of the study and signed a written informed consent before inclusion. The ethics committee of Eastern Switzerland, St. Gallen, Switzerland, approved this study (2017-00866). All participants gave their written informed consent for their data to be published (2017-00866).

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Declaration of competing interest

Prof. Dr. Daniel Baumgartner is the owner of rotavis AG (Winterthur, Switzerland) developing the T-Chair. Besides, the authors declare no competing interests.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.apergo.2021.103390.

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