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Stroke Patients' Acceptance of a Smart Garment for Supporting Upper Extremity Rehabilitation

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ABSTRACT The objective is to evaluate to which extent that *Zishi* a garment equipped with sensors that can support posture monitoring can be used in upper extremity rehabilitation training of stroke patients. Seventeen stroke survivors (mean age: 55 years old, SD =13.5) were recruited in three hospitals in Shanghai. Patients performed 4 tasks (analytical shoulder flexion, functional shoulder flexion placing a cooking pot, analytical flexion in the scapular plane, and functional flexion in the scapular plane placing a bottle of water) with guided feedback on a tablet that was provided through inertial sensors embedded in the Zishi system at the scapula and the thoracic spine region. After performing the training tasks, patients completed four questionnaires for assessing their motivation, their acceptance of the system, its credibility, and usability. The study participants were highly motivated to train with Zishi and the system was rated high usability, while the subjects had moderate confidence with technology supported training in comparison with the training with therapists. The patients respond positively to using Zishi to support rehabilitation training in a clinical setting. Further developments need to address more on engaging and adaptive feedback. This paper paves the way for larger scale effectiveness studies.

INDEX TERMS Wearable system, stroke, rehabilitation, smart garment, compensatory movement.

I. INTRODUCTION

Stroke has a high incidence all over the world [1], including China where a recent study found that stroke is the leading cause of adult disabilities in China [2]. In 40 to 50% of stroke survivors, upper extremity function is affected, leading to a decreased quality of life [3], [4]. Often a long rehabilitation process is needed to regain function up to a level that varies from patient to patient, after which point patients are discharged. At that point and given resource limitations such as a limited number of rehabilitation hospitals and limited availability of therapists, it is hard for out-patients to continue their training program at home [5]. Advances in the Internet of things (Iot) technologies can maximize resource management and support extending the professional services from communities to homes [40], [41]. More specifically, technologies that can support patients continue to train independently are very promising to allow the continuation of training at home. When training at home, technology support may offer motivating feedback that guides towards optimal exercise performance. Training in a home setting is also a solution for cost reduction and improved quality of life outcomes [6].

Several task oriented training approaches have shown to improve arm hand skilled performance and decrease disability in stroke patients [7], [8]. However, it has been shown that stroke patients show compensatory anterior displacement of the trunk during upper extremity movements such as reaching [9] and grasping [10]. Such compromise the effectiveness of the training, and should be avoided or reduced. Also, De Baets *et al.* [11] have shown that stroke patients show reduced motor control at the shoulder complex during arm movements. It has also been shown that stabilization of the trunk [12]–[14] and shoulder complex [15] leads to improved arm hand performance, and should therefore be taken into account during the rehabilitation program. As intrinsic feedback mechanisms are impaired in stroke patients, extrinsic feedback is warranted during the learning process.

Recently, technology-assisted systems show great potential for supporting rehabilitation. For example, Human-machine Interface [37] may overcome problems of predicting human motion intention in advance and control the exoskeleton in real time. Internet of Things-based intelligent rehabilitation systems [38] may provide effective platform to interconnect various resources and achieve immediate communication. Cloud-computing-based mobile-health monitoring system [39] may support decentralised diagnosis, health data sharing and interoperation.

Wearable technologies have been widely used for health enhancement [36], there are also many wearable systems have been developed to support upper extremity rehabilitation [16]. The advantages that wearable systems can bring pertain to comfort, ease of use, low cost and accuracy and practical aspects such as not taking space [17]. Wearable technologies can be used on their own or they can be part of a larger system supporting rehabilitation training. For example, Beursgens *et al*. endowed a jacket with accelerometers for monitoring the posture of trunk and shoulder in stroke patients [18], providing to patients audio and vibrotactile notifications when the movement of trunk or shoulder would exceed a preset range. This preset was patient customized while they were playing a game for improving ''eating skills'' (handling knife and fork). A first evaluation showed that patients were motivated to use the jacket and found it credible as an assistive tool for rehabilitation. Wang *et al*. [19] (2014) developed this concept further, by integrating on a purpose made jacket two inertial sensors at the level of the thoracic spine (T1 and T5) and one at the level of the scapula (acromion). The sensorized garment was validated against a 3D motion tracking system [20] (Wang *et al*. 2015) and was found to be sufficiently reliable.

Wang [21] is an improved version of this sensorized garment which was designed with the aim to improve aesthetics and the fit of the scapula sensor. *Zishi* is designed to support various patient groups aiming to improve upper extremity function. The evaluation for its applicability for shoulder motor control training with shoulder pain patients in Jessa Hospital, Belgium has been reported in [22]. In this study, we focus on the stroke patients with limited upper extremity function. In order to find the determining factors of user acceptance and gain insights for further iterations, *Zishi* was evaluated in the terms of credibility, intrinsic motivation towards use, technology acceptance, and system usability.

II. METHODS

A. SYSTEM DESCRIPTION

Zishi is a wearable system that can detect compensatory movement of the trunk and shoulder complex (see Fig.1), providing real-time feedback to support the rehabilitation training. Zishi is a garment that resembles in appearance and comfort every day clothing while it is accurate in tracking posture and easy to use.

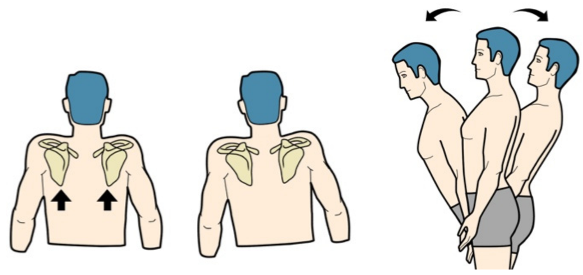


FIGURE 1. Compensation movement from shoulder girdle and torso.

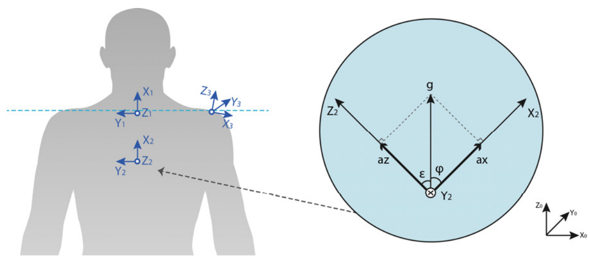


FIGURE 2. Calculation method.

1) COMPENSATORY MOVEMENT MONITORING

One IMU sensor locates on the acromion to register the vertical deviation of the acromion relative to the global coordinate. When the arm movements are below 60 degrees in the sagittal plane, the shoulder girdle should be stable. While patients with decreased motor function ability may achieve the training tasks thanks to the scapula elevation or depression or trunk lateral flexion. Sensor mounts on the acromion can capture these movement as acromion is the highest point in the shoulder girdle and following the ISB recommendations about the clavicle coordinate system [22]. Another two sensors locate on the T1 and T5 vertebras of the spine to monitor the trunk flexion and extension, previous iteration proved the accuracy and feasibility [20]. Regarding to the orientation angles, Fig.2 illustrates our approach that we assumed the target local coordinate frame is parallel with the world coordinate frames. In this way, the formulate for calculating the angle based on the accelerometer readings (ax, ay, az), as follows: $\varphi = \frac{\pi}{2} - \arccos|\frac{az}{g}|$.

2) HARDWARE DESCRIPTION

Zishi consists of 4 parts: 1) a flexible central node equipped with two sensors, Flora microcontroller, Bluetooth module and flexible circuit (see Fig.4) with conductive fabric (Shieldex® Super-tex) and conductive yarns; 2) sensor unit embedded in an elastic Velcro strip; 3) a garment embedded smart textiles and connection points, Fig. 3a shows the sensor position in blue dots; 4) an application that runs on an Android handheld device which supports calibration to fit the patient's body and training needs, real-time performance feedback, and knowledge of results feedback. All the sensors are sewable 9-DOF IMU sensor units (Adafruit® Flora-9 DOF) that integrates an accelerometer, gyroscope and a magnetometer. Coated conductive yarn (see Fig. 3c)

FIGURE 3. (a) Back view of the garment; (b) Adjustable design; (c) Sensor embedded in the strip.

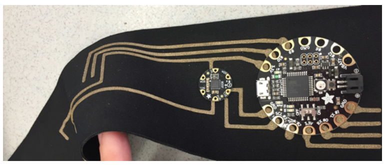


FIGURE 4. Flexible Circuit of the central node.

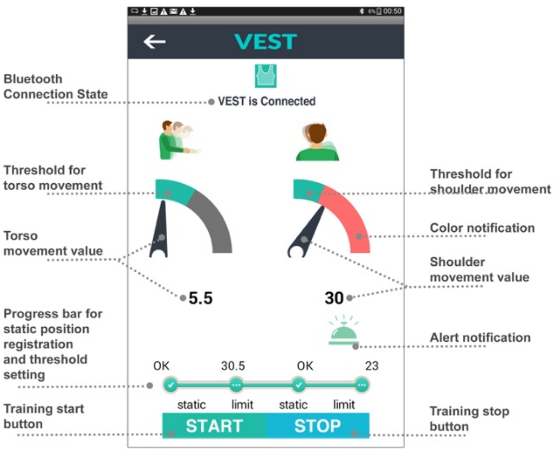


FIGURE 5. Interface elements.

is utilized to embed the sensor on the Velcro strip (shows in Fig. 3b) which allows adjustments to be made on the body for precise sensor position and comfort on different subjects.

3) FEEDBACK STRATEGY

Zishi provides concurrent feedback to users in multiple modalities including: a) visual display on smart device; b) sound alert and c) haptic feedback by vibrotactile notification. End-users could perceive awareness of their compensation movement during the training tasks. Feedback is given only when a movement error exceeds a pre-set threshold and is beneficial for personalized feedback to individual patients [16], [23]. This threshold is the allowed compensation level determined by therapists for each patient, as patients may be in different stages of rehabilitation and have different level of motor functions. Fig. 5 illustrates the elements in details about the interface design. The pointer rotation visualizes user's compensation movement in real-time as the KP (knowledge of performance) feedback, users are encouraged to keep the pointer straight and stay within the green part (threshold) of the dashboard by maintaining low compensation. For notification of exceeding the threshold, the dashboard turns into red color, producing a sound alert and a vibration. The left dashboard regards to the trunk and right one regards to the shoulder part. The target is to control the compensatory movement within the threshold while performing the training task.

B. SUBJECTS

Inclusion criteria were: 1) diagnosis of stroke, 2) age ≥18, 3) able to give informed consent of participation, 4) able to perform the tasks, 5) ability to read and understand Chinese. Exclusion criteria were: 1) surgery at the shoulder complex or cervical spine in last 6 weeks, 2) presence of aphasia, 3) cognitive disorder, MMSE score ≤17 [24], 4) Paresis or sensory problems of neurological origin or rheumatoid arthritis or other medically unstable disorders that would intrude the task performance.

C. MATERIALS

We standardized the materials and experiment setting for experiments including: two sets of *Zishi* garments in different sizes described in section 2.1; a Tablet with *Zishi* application installed; a bottle of water (0,5L); a cooking pot (weight 300g, size 6 inches) and an adjustable shelf. Each session took place in the normal training room of the participating hospitals.

D. PROTOCOL

The ethics clearance (No.251 (2014)) has been approved by the ethics boards of Huashan Hospital. The researcher would welcome the participant and gave a brief introduction of the working principle of the garment and explanation of the interface. After giving informed consent, each participant filled in a socio-demographic questionnaire. Also, each patient filled out the SPADI questionnaire [25] which gauges the pathologic condition of shoulder functioning. Then participants would put Zishi on; the researcher would provide assistance only when requested. The researcher would adjust the Velcro strip to mount the IMU sensor precisely on the acromion. Afterwards the patient was invited to perform a movement protocol, consisting of 4 standardized tasks: 1) analytical shoulder flexion; 2) placing a cooking pot on a shelf as functional shoulder flexion (as shown in Fig.6); 3) analytical elevation in the scapular plane; 4) functional elevation in the scapular plane.

A therapist would demonstrate the tasks once for each participant. Each of the tasks was standardized as described in Wang *et al*. [22]. Before doing the training tasks, the therapist showed them how to stabilize the scapula on the thorax and avoid inappropriate torso flexion/extension or scapular elevation/depression. After completing tasks subjects would

FIGURE 6. A subject is instructed of performing task 2 in Huashan hospital.

complete the questionnaires to measure their attitudes (see infra).

E. OUTCOME MEASURES

Patients filled in the SPADI questionnaire [25] which gauges the pathologic condition of shoulder functioning. The analysis of its results generates a number between 0-100, reflecting the amount of disability of a person. Higher scores mean a higher degree of disability.

This study focuses on the evaluation of *Zishi* in terms of patient attitude regarding: intrinsic motivation, technology acceptance, credibility and usability. In this way, we examined the following aspects and all the questionnaires were translated from English to Chinese and adjusted lexically to fit the context of using *Zishi* while doing the training tasks.

1) INTRINSIC MOTIVATION

Intrinsic Motivation Inventory (IMI [26]) is a reliable and valid method to assess subjects' satisfaction and intrinsic motivation related to the target activity. Based on our research objective we selected 29 of its 45 questions distributed into the five subscales: '*interest/enjoyment*' (e.g. I thought participating the training was quite enjoyable), 'perceived competence' (e.g. I did pretty well during the training), '*effort/importance*' (e.g. I tried very hard on participating in the training), '*value/usefulness*' (e.g. I think this training is important because I can use my shoulder and arm-hand more and better), and '*pressure/tension*' (e.g. I was very relaxed during the training). The 'interest/enjoyment' subscale is considered as a self-report measure of intrinsic motivation. 'Perceived competence' subscale shows how capable the subjects feel and is considered to be a predictors of intrinsic motivation. The 'effort/importance' and 'pressure/tension' subscales respectively measure effort investment and pressure experienced. Subscale 'value/usefulness' embodies the idea that people internalize and develop more self-regulatory activities when experience is considered as valuable and useful for them. The subscale 'pressure/tension' is a negative predictor, scores were reversed together with other negatively formulated items in other subscales.

2) TECHNOLOGY ACCEPTANCE

Previous studies have validated Unified Theory of Acceptance and Use of Technology questionnaire (UTAUT [27]) as a robust model for understanding/assessing the users' acceptance of technology in various contexts including wearable technology [28], [29]. The original UTAUT model consists of 8 subscales of which 4 factors '*performance expectancy*' (e.g. I think the garment and the feedback are useful for my rehabilitation), '*effort expectancy*' (e.g. It is easy for me to become skillful at using the garment and the feedback), '*social influence*' (people who are important to me think that I should use mobile Internet), '*facilitating conditions*' (I have the necessary resources for the garment and feedback system) are considered as predictors of behavior intention and usage.

3) CREDIBILITY

The Credibility and Expectancy questionnaire (CEQ [30]) was used to evaluate the rationale credibility and improvement expectancy in the subjects' opinion. CEQ consists of 6 questions that ask the subjects to indicate what they think (e.g. How confident would you be in recommending this training to a friend who experience similar problems?) and feel (e.g. At this point, how much do you feel that the training will help you reduce your compensation movement?).

4) USABILITY

To evaluate the system usability, the Computer System Usability Questionnaire (CSUQ [31]) was applied which consists of 19 questions that are distributed in four groups: "*overall satisfaction*" (Q1-Q19, e.g. Overall, Overall, I am satisfied with this system), "*ease of use*" (Q1-Q8, e.g. It was easy to learn to use this system), "*information quality*" (Q9-Q15, e.g. The information provided for the system is easy to understand) and "*interface quality*" (Q16-Q18, e.g. The interface of this system is pleasant). The CSUQ was selected because CSUQ next to the satisfaction with usability it explicitly measures understanding (information and interface quality) of the system, which is essential for stroke patients facing cognitive impairments.

5) THERAPIST ATTITUDES

The therapists filled in the credibility component only of the CEQ questionnaire. Furthermore, to assess the general impression and usability, and to receive suggestions for improvement of the interface design, several open questions were asked (Q1-"What do you think about the design of the wearable system?";Q2 "What do you think about the arrow - was it clear? Should you replace it by an avatar? Or by an image of yourself?"

To receive therapists' opinions about the feedback strategy, we asked the questions: "Do you prefer feedback during or after the exercise? Do you prefer feedback about the manner of movement (knowledge of performance) or only on the result of movement (knowledge of results)?".

TABLE 1. Questionnaire scores list.

	Subjects	Factor	Median (IQR)	Sig
Intrinsic Motivation Inventory (IMI)	17/17	Interest/Enjoyment	5.14 (1.64)	0.003
		Perceived competence	5.6 (1)	0.000
		Effort /Importance	5.2 (1)	0.001
		Value/Usefulness	4.67 (1.29)	0.01
		Relatedness	4.8 (1.2)	0.006
		Pressure/Tension	1.2 (1.5)	0.000
Technology Acceptance (UTAUT)	10/17	Performance expectancy	4.5 (0.63)	0.031
		Effort expectancy	5.36 (1.94)	0.028
		Social Influence	4.5(1.125)	0.034
		Behavioural intention	3.67 (3.33)	0.635
		Facilitating conditions	4.58 (1.35)	0.012
		Anxiety	1.63(0.94)	0.005
		Attitude towards technology	4.8 (1.1)	0.037
		Self-Efficacy	5.5 (1.5)	0.05
Credibility/ Expectancy (CEQ)	11/17	Credibility	16(4)	0.153
		Expectancy	17.4(4)	0.07
Usability (CSUQ)	7/17	System overall	5.11(0.95)	0.018
		System usefulness	4.88(1)	0.018
		System information	5.83(1.67)	0.018
		System interface	5(1.5)	0.268

Abbreviations: IQR = Interquartile Range, Sig = Significance level of Wilcoxon Signed-Rank Test for One Sample, comparing to the neutral score of each scale.

F. DATA ANALYSIS

Data from the questionnaires were analyzed with group median scores, interquartile range and one sample Wilcoxon signed-rank test against the neutral point of the scale for each questionnaire using SPSS (SPSS Inc., Chicago, IL). All the subscales in the questionnaire were 7-point Likert rating scales except the CEQ which used a 9-point scale ranging from 1 to 9. We consider the median value of each scale as the neutral score, scores around the neutral score are moderate value, scores higher than neutral are positive, lower than neutral are negative. We applied one-sample Wilcoxon signed rank test to compare the Median score against the scale's neutral score (marked in redline in the Box plot) of each scale.

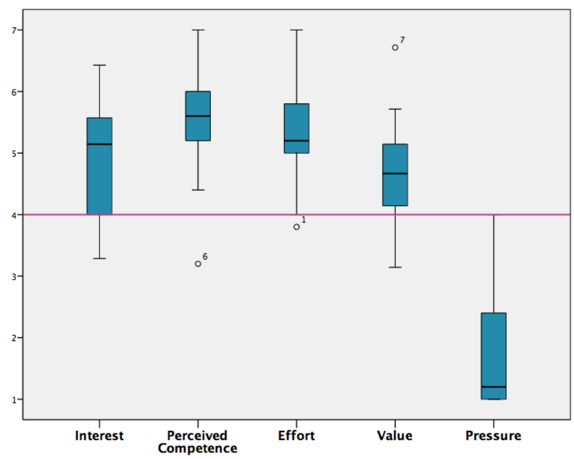


FIGURE 7. Boxplots for the IMI questionnaire subscales.

III. RESULTS

A. RESULTS FROM THE PATIENTS

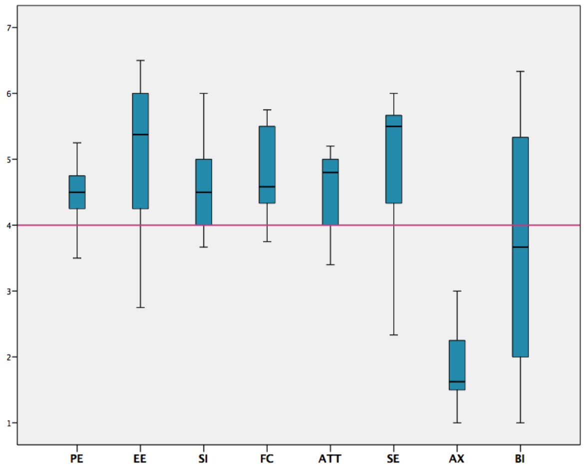
17 subjects after stroke were recruited from 3 rehabilitation centers: Huashan Hospital, the Tianshan Hospital, and First Rehabilitation Hospital in Shanghai (China). Their mean age was 55 years ($SD = 13.5$). However, patients from the First Rehabilitation Hospital were only available to participate in the experiment between their regular training sessions, therefore their questionnaires are only finished in part. The number of involved subjects for each questionnaire is listed in Table 1 together with the results of group Median and one-sample Wilcoxon signed rank test.

1) INTRINSIC MOTIVATION

All 17 subjects filled in the IMI questionnaire. The results (see Fig.7) on the '*interest/enjoyment*' subscale indicates that the subjects were positively ($MDN = 5.14$, $IQR = 1.64$) motivated to use the system during rehabilitation exercises. The '*perceived competence*' subscale obtained a high score ($MDN = 5.6$, $IQR = 1$), which suggests that patients considered themselves competent to use the system. The subscale '*value*' is scored moderate ($MDN = 4.67$, $IQR = 1.29$) suggest that patients thought training with *Zishi* was moderately important. Subscale 'effort/important' obtained a good score indicates they were willing to put effort. The subscale '*pressure*' is scored low and indicates that patients were executing the tasks without pressure.

2) TECHNOLOGY ACCEPTANCE AND SELF-EFFICACY

The UTAUT questionnaire (results see Fig.7) was filled in by 10 subjects. The subscale '*effort expectancy*' was rated



Abbreviations: PE=performance expectancy, EE=effort expectancy, SI=Social influence, FC=facilitating conditions, ATUT=attitude towards using technology, SE=self-efficacy, AX= anxiety, BI=behavioral Intention.

FIGURE 8. Boxplots for the UTAUT questionnaire subscales.

positively (*MDN* = 5.36, *IQR* = 1.94) and indicates that subjects expected little effort to use *Zishi*. Subscale 'performance expectancy' showed that subjects moderately (MDN = 4.5, *IQR* = 0.63) believed that *Zishi* would help to improve performance in the training. Also the subscales '*social influence*' resulted in a moderate score, indicating that subjects thought that "*important others*" would probably not use or recommend *Zishi*. *Zishi* does have the potential to be integrated in the current rehabilitation situation and has support on the subscale 'facilitating conditions' as this item was scored slightly higher than the neutral score. Although the above-mentioned four factors are strong predictors for behavioral intention (technology acceptance) in the traditional UTAUT model, the subscale 'behavior intention' (*MDN* = 3.67, *IQR* = 3.33) fluctuates a lot in the scale, reflecting a rather high dependence on personal intention. This score was influenced by 3 subjects who gave very low scores(one subject gave score one for each item in 'behavior intention'). However, subjects reported a high 'self-efficacy' score (*MDN* = 5.5, *IQR* = 1.5) and an acceptable score for 'attitude towards technology' (*MDN* = 4.8, *IQR* = 1.1).

3) CREDIBILITY AND EXPECTANCY

Eleven subjects answered the CEQ questionnaire. The credibility (*MDN* = 16, *IQR* = 4) was slightly higher than the sufficiency threshold (15 over 27), while the expectancy was positive (*MDN* = 17.4, *IQR* = 4). This indicates that Zishi was considered as a moderately credible system and patients were positive in respect to the expected effectiveness of the system for the improvement of upper extremity performance.

4) SYSTEM USABILITY

Seven subjects completed the CSUQ questionnaire (results see Fig.9). The system was considered of good usability

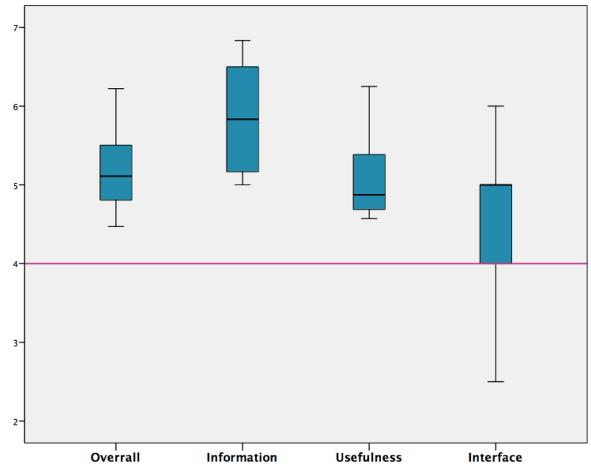


FIGURE 9. Boxplots for the CSUQ questionnaire subscales.

as the system overall satisfaction score was rated positively (*MDN* = 5.11, *IQR* = 0.95). The information on the screen was also perceived to be really easy to understand as subjects rated it very high for the questions addressing the information presented (*MDN* = 5.83, *IQR* = 1.67). System usefulness and interface design was rated above the sufficiency threshold (4 over 7).

B. RESULTS FROM THE THERAPISTS

The four therapists who provided instruction for the participating patients answered the 3 questions addressing Credibility in the CEQ questionnaire. Therapists gave a high score with regard to treatment credibility (*MDN* = 20.5, *IQR* = 6.75), which suggests that they find ZISHI a credible addition to task training.

Regarding to the open questions, two therapists mentioned that the garment was **easy to put on and take off** (T4). One therapist thought the grey color of the garment is suitable for the hospital while two therapists preferred **multiple color** choices. Three therapists thought the pointer design for feedback was **clear**, while one mentioned the pointer and dashboard on the screen could be even bigger. Two therapists proposed replacing the pointer by animation or by a 3D avatar and one of them suggested VR game integration for enhancing the delectation, this point was confirmed as two of the therapists mentioned the preference of **gamification**. Zishi was considered as **convenient and useful**: *"It's an intuitive visualization of compensatory movement, convenient and efficient"* (T1), *"Convenient, practically to use and can be widely popularized"* (T2). T3 mentioned that the **audio feedback** was quite helpful for the patients who cannot control their shoulder movement very well. Besides, therapists pointed out their concerns and suggestions: *"Tightness and compactness of the garment need improvement, the interface is a bit plain, more functions such as arm-hand training programs with animation tutorials and remote progress dashboards that could be accessed by therapists are needed for home rehabilitation"* (T1); *"The requirements for the* *patient's cognitive level is a bit high."*(T2) and *"Not applicable for controlling shoulder movement with patients who are still facing serious obstacles regarding to functional motor ability"* (T3).

IV. DISCUSSION AND FUTURE WORK

The purpose of this study has been to evaluate the patients' motivation, technology acceptance, credibility and expectancy and usability with regard to the *Zishi* garment for stroke patients and their therapists. Patients reported high motivation to use *Zishi* and rated its usability favorably, but they expressed moderate confidence in towards using it independently for home rehabilitation.

A. HIGH MOTIVATION WITH SMART GARMENTS SUPPORTED TRAINING

This study demonstrated high motivation for a wearable system supported training. Stroke patients gave positive scores in terms of 'interest' on the IMI, similarly for the subscale 'attitude towards technology' of UTAUT. These results are compatible with previous findings [8], [32], [33] that patients can be intrinsically motivated towards wearable technology in rehabilitation. Further our results indicated that participants appreciated that the system provides real-time compensation feedback.

B. USABILITY ANALYSIS

Respondents found both *Zishi* the garment and the application usable, easily to operate by oneself. One major concern for wearability is how easy it is to put the garment on and take it off, which were both appreciated by our participants. *Zishi* fulfilled the requirement that patients are willing to invest little effort for learning a new system. In order to minimize the subject's cognitive load required for information processing, we tried to make the interface simple and only show the essential information. The questionnaire results also reflected this point regarding to the high scores from factors 'perceived competence' from IMI, 'self-efficacy' from UTAUT and 'system information' from CSUQ.

C. MODERATE CONFIDENCE WITH TECHNOLOGY IN DOMESTIC ENVIRONMENT

The subscales '*value'* from IMI, subscale '*performance expectancy*' from UTAUT, subscale '*credibility*' from CEQ and '*system usefulness'* from CSUQ resulted in unfavourable scores which also explains the mild score of '*Behavioral Intention*'. It appeared to us that they perceived the system as a potential substitute for therapist supervision and thus reacted retiscently. Based on the feedback from the therapists, this may because of the following context reasons: "*Our patients are not used to do the rehabilitation at home since most of them are inpatients. They are used to train under the supervision of the therapist. Patients relied on therapists in the hospital and were taken good care by their family members or nursing workers at home*" (P3); Further, installation at home may be perceived as a barrier. Fore example, a recent experimental study requiring participants to use a wearable system for Fugl-Meyer assessment succeeded to recruit 24 patients for using it in a clinical setting, while only 5 participants agreed to join the experiment in a home setting; the reason for this low number was the complexity of the installation and lack of awareness of the importance of home rehabilitation. Besides, two subjects appeared to cast what is research prototypes developed for scientific research with a commercial product, and were worried about being drawn into promotional campaigns, "*I gave score* 1 *as I thought maybe your agency will call me for product promotion*" (S6). However, therapists gave high score of credibility and good comments of usability for *Zishi*. This indicates that *Zishi* has good potential to be used in the current therapy while to improve the perceptions of usefulness one would need first improve awareness regarding the value of home rehabilitation. Finally, future studies aiming to assess patient attitudes could reduce the role of the researcher in the experiment, letting the whole interaction take place between the therapist and the patient as would be the case for the actual deployment of the technology in therapy.

V. FUTURE WORK

Both therapists and patients seemed to need more engaging feedback, asking for example that feedback should be made more playful with the introduction of gaming elements. This also suggest that further developments in feedback should be more adaptable, providing more options for advanced users, such as simple rewards and punishments. We will conduct a further study to examine the preference, acceptance, usability of different feedback modalities to different users and contexts. While adding such gamification features is straightforward, future research would still need to demonstrate that they enhance the effectiveness of the system in treating stroke.

This study used validated instruments measuring attitudes towards the system that are key to its successful implementation in clinical practice. More extensive studies could try to validate potential relations between these variables in order to understand how different aspects of the system, such as enjoyment, usefulness and usability contribute to the intention to use such wearable posture correction technology. More importantly, behavioural measures regarding adherence to training and the posture during training may be taken to assess the effectiveness of the device, which may be tested extensively in randomized clinical trials.

The evidence presented in this study suggest that Zishi is promising as a technology to support rehabilitation training by helping patients maintain a good posture. This can be useful for several patient groups. So far, the Zishi garment has been evaluated for training with musculoskeletal shoulder pain (ref, under review) and stroke patients (current paper). Potential future applications include arm-hand training for other patient groups, such as multiple sclerosis patients or spinal cord injury patients, in combination with interactive applications that support exercise programs, as for example The Zishi garment may be also of great value to monitor compensatory movements in combination with interactive tabletops such as the application used by Timmermans *et al*. [34], or in combination with tablet applications as in Beursgens *et al*. [18] or special purpose training devices such ast TagTrainer [35].

VI. CONCLUSION

Wearable technologies for posture monitoring and posture correction are emerging as a way to support and enhance physical therapy treatment, while related research has been primarily concerned with demonstrating the required accuracy and clinical validity of measurements, less attention focused on the requirements of aesthetics, wearability, ease of use and motivation. Therefore, the work presented in this study developed a garment for interactive posture correction to be used in rehabilitation, in particular, we focused on the applicability of stroke patients with limited upper extremity function. To our knowledge, *Zishi* (named as Smart Rehabilitation Garment in earlier studies [2]) was the first interactive garment system that supports shoulder complex and trunk motor control training by monitoring compensatory movement and providing tailored real-time feedback. The results of this study demonstrate that stroke patients are motivated to use *Zishi* during rehabilitation and they consider the system usable. Patients are hesitant to use the device independently compared to training with therapists. At this moment *Zishi* is preferred of being used in collaboration with other rehabilitation tasks in a clinical setting. Based on the positive results, we are currently further developing the system, especially taking into account the suggestions about the feedback design for long-term using and potential context of home rehabilitation.

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