Ergonomics Assessment for Wearable Elbow Exoskeleton Prototype

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Abstract

This study aims at assessing ergonomics and usability variables in wearable elbow exoskeleton prototype. Ergonomics testing is conducted in three level of iteration. Usability testing is performed based on Nielsen approach. The results of ergonomics testing in the third iteration of observation show that the product has met all the existing checklists and is ready to be tested directly on the patient. In terms of medical and therapeutic stages, the product can withstand the load, the repetition speed is good and the delay between reps is also not long. The respondents agreed that the stroke therapy aids were easy to understand and acceptable (80%). Respondents chose neutral level of memorability (70.83%). It means stroke therapy aids can help them make it easier for them to undergo therapy. Respondents chose neutral regarding the level of efficiency (80.83%) of the stroke therapy aid. There was an error while undergoing therapy with a stroke therapy aid, but felt comfortable undergoing therapy with the help of a stroke therapy aid. Respondents feel happy, satisfy and comfortable (83%) undergoing therapy with stroke therapy aids and are able to adjust to the differences.

Keywords
Ergonomics, Assessment, Wearable, Elbow, and Exoskeleton.

1. Introduction

The burden that must be borne by stroke sufferers is long-term physical disability due to neurological disorders. Of people with disabilities, as many as 75% of them are stroke sufferers. From the patient's family side who do not necessarily know what treatment or therapy the sufferer must undergo so that they do not prepare themselves to treat the sufferer. It can affect the patient's quality of life. The uncertainty of healing stroke certainly creates other burdens, one of which is from the financial side. Even though there are health insurance services, the definite timeframe can lead to swelling of the health budget for the state. From 2016 to 2018, BPJS Kesehatan noted that the cost of health services for stroke continued to increase. In 2016, the financing figure reached 1.43 trillion rupiah, increasing in the following year to 2.18 trillion rupiah to reach 2.56 trillion rupiah in 2018. This made stroke ranked third in financing the National Health Insurance (JKN) (Kemenkes RI 2007, 2013).

Rehabilitation can be seen as a way to improve the quality of life for stroke sufferers. Basically, rehabilitation is an effort to return a person to their original condition or a condition that is better than their current condition (Sofwan 2013). In the medical and health field, the main objective of rehabilitation is to restore part or all of the patient's physical, sensory or mental capabilities that have been reduced or lost due to an illness or injury. Through rehabilitation efforts, it is expected that the motor, cognitive, visual and coordination abilities of stroke sufferers can be recovered so that their level of independence will gradually increase. Thus, along with their increased ability and level of independence, the quality of life for stroke survivors will also improve. In addition to efforts through drugs,

regular physical exercise is a rehabilitation therapy effort that is generally recommended for post-stroke. Physical therapy is generally done in the form of exercises to sit alone, stand up from a seat and walk. Other physical therapy includes practicing activities for daily living (ADL) such as bathing, eating, defecating, dressing and dressing, as well as training for hobbies such as cooking and gardening. Several studies have shown beneficial results obtained by stroke sufferers who perform routine physical therapy exercises such as increased lower limb ability, functional mobility (balance and walking) and quality of life (Dalgas et al. 2008, Motl and Gosney 2008).

The key to achieve a successful neurological rehabilitation is the duration and intensity of physical therapy exercise (Kwakkel et al. 1999). Physical therapy is generally carried out as part of a stroke rehabilitation program requiring continuous therapist assistance. The continuity (duration and intensity) of physical therapy exercise is limited to the therapist's availability. To reduce dependence on therapists in doing physical exercise, it is necessary to have an alternative form of rehabilitation that allows stroke sufferers to undergo physical therapy exercises without continuous assistance by a therapist. Advances in technology and the era of globalization are increasingly making the circulation of information faster. Ease of conducting research to fix problems is increasingly being done. This can be proven by the increasing number of inventions of tools to help human life both in certain conditions and in daily activities. One of them that has recently been discovered is a tool for stroke therapy in the limbs. The way this stroke therapy aid works is as a substitute for a therapist to help move hands in stroke sufferers.

The Wearable Elbow Exoskeleton (Fig 1) is one of the tools for stroke therapy in the limbs of the hand that was recently developed by Diponegoro University. Currently, this tool is still in the form of a prototype, so there are still a lot of experiments before it is used by stroke patients. One of the studies that can be done is whether the stroke therapy aid has met the existing ergonomic principles by considering existing anthropometric data. In addition to considering anthropometric data, ergonomic principles can also be done by testing these therapeutic aids on healthy people. From this research, we will analyze whether the tool is comfortable to use as a therapeutic tool. The results of trials on healthy people will also be used to repair the tool before being tested on patients.

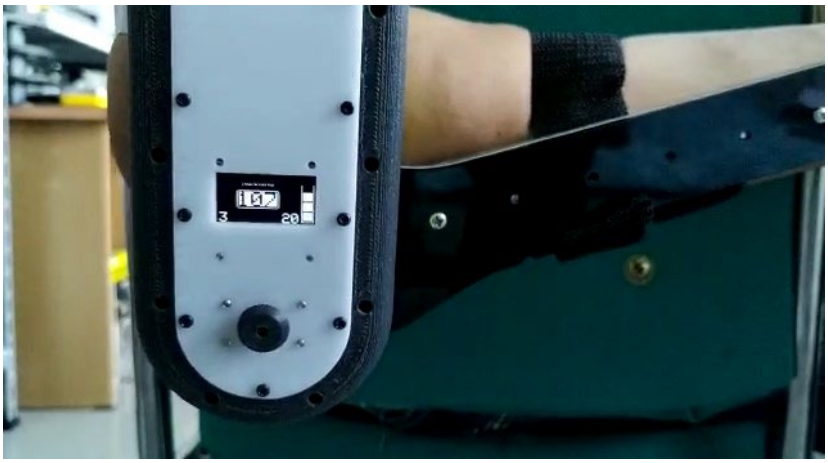

Figure 1. Elbow Exoskeleton Prototype

The further study is to examine how to use this therapeutic aid. Is this aids can make stroke therapy sufferers able to perform therapy independently or still use the assistance of a therapist? Usability of this therapeutic aid can be tested using various approach such as the Nielsen Attributtes of Usability (NAU) questionnaire (Nielse, 1993) or many else (Chisnel 2008, Jokela 2004, Lund 2001) . By taking respondents from several stroke patients as well as from therapists, qualitative data was obtained about testing the quality of stroke therapy aids. It is hoped that with this research, later stroke therapy aids can be developed until they are commercialized to help stroke sufferers and therapists. This stroke therapy aid has a long-term plan so that patients can do therapy themselves at home. Meanwhile, the therapist reduces the workload and the therapist can focus more on stroke patients who have more severe levels of paralysis. Several studies related to this study have been conducted by Aprilian (2014), Barri et al. (2017), Bevan et al (2015), Brown et al (2008), Chuang (2010), Crea et al (2016), Dharma et al (2018), Dinh (2017), Ghani et al (2016), Harris et al (2018a, b), Hoy et al (2013), Hussain et al (2016), Koesdijati (2017), Kusuima et al (2009), Looned et al (2014), Misbach and Ali (2001), Mustakim (2016), Nursiswati et al (2017), Pandian et al (2007), Pandian et al (2011), Senjaya (2017),

Päivinen and Heinima (2009), Paramitha (2017), Park et al (2015), Purba et al (2015), Susanto et al. (2017), Susanto et. al (2019), Susanto et al (2020), Syafei (2017), Trivedi et al (2008), Vitiello et al (2013), Wen and Chou (2016), and Wu and Asada (2016).

Based on the background, it is known that the current technological advances have produced several tools to help stroke sufferers undergo recovery therapy. Through the results of a preliminary study conducted at the Diponegoro National Hospital, it shows that therapy is currently still running manually, so there is no research that shows a comparison of therapy using assistive devices with manuals. In addition, based on the above background, it can be concluded that it is necessary to see how the patient responds to stroke therapy aids both in terms of comfort of use to expectations for speed of recovery. Based on these problems, a study was conducted to find out how easy it was for patients and therapists to undergo therapy using stroke therapy aids and whether the stroke therapy aids had fulfilled the ergonomic aspects based on anthropometry.

2. Methods

The initial stages of research were carried out through preliminary research and literature studies related to research problems. Literature study is carried out by looking for information related to research. In this study, a research study was conducted on stroke, anthropometry in humans, usability and the Nielsen questionnaire. In addition to conducting literature studies, the author also conducted consultations with supervisors, neurologists and the research team for the Elbow Exoskeleton tool in order to strengthen understanding of the research topic. The results of this literature study can later be a tool for writers when conducting research.

2.1 Ergonomic Testing

At the ergonomic testing stage, an analysis of the Elbow Exoskeleton is carried out. Currently, the Elbow Exoskeleton tool is still in the form of a prototype and can still be repaired several times. From several trials conducted, the Elbow Exoskeleton is expected to be in accordance with ergonomic principles and to have a tool size that is in accordance with human anthropometry in general.

In studies before the device is used by patients, initial testing by a stroke therapist is required. This is performed because the assistive device is still in the form of an early prototype and has not paid attention to the steps of stroke therapy in general. It is expected that with the therapist's tool testing, the therapist will be able to evaluate what needs to be repaired or added from the Elbow Exoskeleton before it is tested on patients. After testing by a stroke therapist, the next step is to check the readiness of the device with an ergonomic checklst. This checklist will be compiled based on several factors, namely seen from Visibility, Safety, Convenience and Portable. Later this checklist will be one of the determining factors whether the device is ready to be tested on patients.

2.2 Usability Testing

At this stage, the activities including determination of the scope of the research, the criteria for appropriate respondents and the number of respondents required. The first is the scope of research where this research is located at the Diponegoro National Hospital (RSND). The criteria for respondents that are needed must meet several requirements, namely the stroke phase before 6 months, the type of stroke experienced is ischemic stroke, does not experience depression, there is no cognitive impairment and muscle tone is 3-4.

The subjects of this study were ischemic stroke patients with hemiparesis in RSND who met the inclusion and exclusion criteria of the study subjects. Inclusion criteria included Ischemic Stroke, muscle strength 3 based on Manual Muscle Testing, aged 40-80 years. The exclusion criteria included experiencing depression based on the Patient Health Questionnaire (PHQ-9) with a score of> 10, experiencing cognitive impairment based on the Mini Mental State Exam (MMSE) with a score of> 23, not running an independent home exercise program according to the predetermined frequency of exercise. The drop-out criteria included patients who did not attend training for three consecutive sessions or two consecutive sessions, did not show up at the start and end of the study and the patient refused to continue training.

After compiling the questionnaire (Table 1) according to the indicators on the Nielsen Questionaire, the next step is to consult a neurologist. Furthermore, this questionnaire will be examined whether the questionnaire is easily understood by stroke patients and whether it is in accordance with medical terms.

At the data collection stage, two stages of data collection were carried out, namely ergonomic testing, which was obtained from the development of the Elbow Exoskeleton from the prototype form until it was applied to the patient as well as evaluation during the using of the Elbow Exoskeleton. Collecting data from usability questionnaires given to seven stroke patients during the use of the Elbow Exoskeleton. In processing the questionnaire data, a descriptive statistical analysis is performed to obtain the average value and the tendency of the answers chosen by the respondents to determine conclusions about the usability of the Elbow Exoskeleton tool. The data collection procedures from the beginning of the patient's arrival to completion are as follows:

- Patients re-register at RSND.
- The patient waits for their turn to do therapy.
- Patients are called to do therapy.
- Initial ROM measurements by medical students.
- Patients undergo therapy using therapeutic aids.
- Patients are finished using therapeutic aids.
- Final ROM measurement by medical students.
- Interview patients according to the Nielsen questionnaire.
- The patient is finished undergoing a series of therapy

Table 1. Usability Testing

Questions	Score				
	1	2	3	4	5
A. Learnability					
1. I take therapy with ease					
2. I understand therapy is easy					
3. I can understand the flow of therapy easily					
4. I can understand the therapist's instructions easily					
5. I can do therapy without continuous instructions from the therapist					
B. Memorability					
6. I remember therapy steps easily					
7. I remember the therapist's directions / therapy aids easily					
8. I can remember therapeutic steps easily for a long period of time					
C. Efficiency					
9. I can feel a little change after therapy					
10. I can move my hands after therapy					
11. I feel my grip strength increase after therapy					
D. Errors					
12. I find it difficult to undergo therapy					
13. I feel the aids / therapists are not making a difference					
14. I feel that this therapy has no effect					
E. Satisfaction					
15. I feel good after doing therapy					
16. I feel comfortable using therapeutic aids / therapist assistance					
17. I feel the flow of therapy that is given is right					
18. I feel that the therapy is fairly easy					

The steps taken after data collection were analyzing. The analysis carried out is an ergonomic testing and fitness analysis. Measurement of ergonomic testing is done by looking at the development of the Elbow Exoskeleton tool starting from the prototype stage to being tested on the patient and getting suggestions and recommendations for improvement from the patient. Usability level (Table 2) is done by averaging the percentage of the learnability, memorability, efficiency, errors, satisfaction attributes.

Table 2. Status of usability level (Nielsen 1993).

Point	0-20%	21-40%	41-60%	61-80%	81-100%
Usability level	Bad	Poor	Moderate	Good	Excelent

3. Results and Discussion

3.1 Prototype Observation in Ergonomics Testing

The results of observations of the tools in the first, second and third stages can be seen in Table 3. The results of this first observation are still many aspects that have not been fulfilled so that the product needs to be repaired. Apart from that, from a medical perspective, according to therapists, the repetition rate is still too slow than what therapists usually do during manual therapy. In addition, there is no loading feature which is one of the stages of stroke therapy so that Prototype 1 still has a lot to do.

The result of this second observation show that the product is classified as having good improvement. However, there are still some aspects that have not been improved so that the product needs to be repaired again before being tested on patients. Apart from that, from a medical point of view, the repetition speed is still too slow so that it still needs to be repaired. Besides, new problems are arise due to slippery gears during the experiments. The sound of the gear is rough so that the tool is still not declared worthy to be tested on patients.

The results of this third observation of the product showed good improvement. In addition, the product also fulfills all the existing checklists so that the product is declared good so that it can be tested directly on the patient. In terms of medical and therapeutic stages, the product is good because it can withstand the load and the repetition speed is good. The delay between reps is also not long so the product is declared feasible to be tested.

Table 3. Ergonomics Testing of the Prototypes

		Prototype 1			Prototype 2			Prototype 3		
Nr	Observation item	OK	NO	Information	OK	NO	Information	OK	NO	Information
	A. Visibility									
1	The product is comfortable to use in the hand (hands are upright and body is straight)		√	Hands are still hanging, there is no rest	√		There is already a support on the hand	√		
2	The product has a hand width according to anthropometric data standards aged 50 years (9.43cm)		√			√		√		The product already has a width of 10 cm
3	The product has a hand grip length according to anthropometric data standards aged 50 years (64.51cm)		√	The product still uses hand samples aged 20	√		The length of the grip can be adjusted	√		
4	The product is able to show the angle of the user's hand	√		In some cases. the angle still doesn't match	√		Still not accurate	√		The angle is appropriate
5	The product can indicate the number of repetitions performed	√			√			√		
6	The product is able to show the load assigned to the user		√	The product does not have an loading program	√			√		
7	The product is able to withstand the user's load when loading mode is carried out		√	The product does not have an loading program		√	The product is still lifted when it is loaded	√		
8	The product grip is easy to grip and does not slip easily	√			√			√		
	B. Safety									
9	The elbow does not hit hard parts while the product is running		√	The elbows are still free and nothing is closed		√	The elbow hits the part of the armrest	√		The elbows are protected by foam
10	The hand does not strike sharp areas of the product while the product is running	√			√		No hitting but required protection to avoid hitting	√		
11	The limbs do not touch the electrical area of the product		√	There are still some dangling cables	√		The cables are neatly arranged	√		
12	The sharp part does not hit the hand	√			√		Prevention is necessary	√		
13	The electrical area is neatly closed		√	There are still some dangling cables	√			√		
	C. Convenience									
14	Users do not feel sore when using the product	√			√			√		
15	Users feel comfortable during the product in the therapeutic process		√	Hands still hanging no backing	√			√		
16	The user's hand does not show any bruises after using the product	√			√			√		
	D. Portable									
17	Products are easy to assemble and disassembly	√			√			√		
18	The product is easy to store when not in use	√			√			√		A special container to pack the product
19	The process of preparing a product from initial assembly to being ready for use has a short duration	√		Small size og Protype I, so it can be assembled in a short time	√		Because the design is different from the first so it takes longer to prepare, but it is still relatively fast	√		

3.2 Usability Testing

After evaluating the feasibility of the tool based on the ergonomic checklist, the next step is the evaluation of the prototype by the patient directly based on the Nielsen method. This assessment is carried out directly to the patient after the patient undergoes therapy with the Wearable Elbow Exoskeleton, so that the patient can still remember clearly using the tool. Table 3 shows the percentage of answers given by the respondents regarding the usability testing.

Table 4. Usability Testing

Questions	Score				
	1	2	3	4	5
A. Learnability					
1. I take therapy with ease	0%	0%	25%	62,5%	12,5%
2. I understand therapy is easy	0%	0%	12,5%	62,5%	25%
3. I can understand the flow of therapy easily	0%	0%	25%	50%	25%
4. I can understand the therapist's instructions easily	0%	0%	12,5%	62,5%	25%
5. I can do therapy without continuous instructions from the therapist	0%	0%	25%	50%	25%
Average	0%	0%	20%	57,5%	22,5%
B. Memorability					
6. I remember therapy steps easily	0%	0%	62,5%%	37,5%	0%
7. I remember the therapist's directions / therapy aids easily	0%	0%	75%	25%	0%
8. I can remember therapeutic steps easily for a long period of time	0%	0%	75%	25%	0%
Average	0%	0%	70,83%	29,17%	0%
C. Efficiency					
9. I can feel a little change after therapy	0%	25%	75%	0%	0%
10. I can move my hands after therapy	0%	50%	50%	0%	0%
11. I feel my grip strength increase after therapy	0%	0%	87,5%	12,5%	0%
Average	0%	25%	80,83%	4,17%	0%
D. Errors					
12. I find it difficult to undergo therapy	75%	25%	0%	0%	0%
13. I feel the aids / therapists are not making a difference	75%	25%	0%	0%	0%
14. I feel that this therapy has no effect	62,5%	37,5%	0%	0%	0%
Average	70,83%	29,17%	0%	0%	0%
E. Satisfaction					
15. I feel good after doing therapy	0%	0%	0%	62,5%	37,5%
16. I feel comfortable using therapeutic aids / therapist assistance	0%	0%	12,5%	67,5%	25%
17. I feel the flow of therapy that is given is right	0%	0%	25%	50%	25%
18. I feel that the therapy is fairly easy	0%	0%	12,5%	67,5%	25%
Average	0%	0%	20%	60,5%	22,5%

In learnability category, it can be seen that 0% of the respondents chose options 1 and 2, while about 20% of the respondents chose to be neutral. Respondents who agree to strongly agree are 80%. Based on these results, the respondents agreed that the stroke therapy aids were easy to understand and acceptable. Table 3 shows the results of the assessment of the Memorability awareness variable, as well. It can be seen that 0% of the respondents chose options 1 and 2, while 70.83% of the respondents chose to be neutral. Respondents who chose option 4 were 29.17% and 0% for choice 5. Based on these results, the respondents chose neutral that stroke therapy aids could help them make it easier to undergo therapy. One of the determining factors is the age of the respondents who are elderly so that it is difficult to remember the therapeutic steps. In efficiency category, it can be seen that 0% of respondents chose option 1, while 25% of respondents chose option 2. And respondents who chose option 3 or neutral were 80.83% and 4.17% for choice 4. Based on these results, the respondents chose neutral that stroke therapy aids are able to provide a more efficient impact in undergoing therapy. One of the determining factors is that this therapy is carried out regularly so that the results can only be felt after the series of therapy has been completed. The errors category show that 0% of the respondents chose options 3,4 and 5, while 70,83% of the respondents chose option 1 and respondents who chose option 2 were 29.17%. Based on these results, the respondents chose that there was an error while undergoing therapy with stroke therapy aids and felt comfortable undergoing therapy with the help of stroke therapy aids. The percentage of answers given by respondents regarding the satisfaction category show that 0% of the respondents chose options 1 and 2, while about 20% of the respondents chose to be neutral. Respondents who agree

to strongly agree are 83%. Based on these results, the respondents felt happy undergoing therapy with stroke therapy aids and were able to adjust to the differences.

4. Conclusion

Assessment of the wearable elbow exoskeleton prototype based on ergonomics and usability testing shows the prototype is ready to be tested on patients after going through three iterations. The results of ergonomics testing in the third iteration of observation show that the product has met all the existing checklists and is ready to be tested directly on the patient. In terms of medical and therapeutic stages, the product can withstand the load, the repetition speed is good and the delay between reps is also not long. The respondents agreed that the stroke therapy aids were easy to understand and acceptable (80%). Respondents chose neutral level of memorability (70.83%). It means stroke therapy aids can help them make it easier for them to undergo therapy. Respondents chose neutral regarding the level of efficiency (80.83%) of the stroke therapy aid. There was an error while undergoing therapy with a stroke therapy aid but felt comfortable undergoing therapy with the help of a stroke therapy aid. Respondents feel happy, satisfy and comfortable (83%) undergoing therapy with stroke therapy aids and are able to adjust to the differences**.** When collecting data, there were several inputs that were obtained by the researchers, both from a medical and ergonomic perspective. Among them is the opportunity to add other features or other variations to the tool, the straightening resistance is still not smooth, and the size can be made more flexible. Patient response when using the Wearable Elbow Exoskeleton is very good and accept and even have a suggestion that therapy using the tool can recover faster so that there is a wide opportunity to develop this product.

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