

User Acceptance of Augmented Reality Glasses in Comparison to Other Interaction Methods for Controlling a Hand Exoskeleton

A Study among Technology-Oriented Young Persons

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ABSTRACT

Every year, several hundred thousand people suffer a stroke often leading to long-term motor disabilities that impair their quality of life. In this context, hemiplegia including paralysis of hand and fingers plays a key role, leaving stroke survivors unable to perform tasks requiring both hands. In case of lesions at the level of the brain stem or the spinal cord, paralysis can also affect both sides resulting in very severe constraints for performing most activities of daily living.

A neural-guided hand exoskeleton can restore motor hand function after a stroke or spinal cord injury. However, controlling such hand exoskeleton raises several challenges related to human-machine interaction. While it should be operated without the user's hands and require as little physical and cognitive strain on them as possible, it should be also as inconspicuous as possible to avoid stigmatization of the users. To tackle these challenges, we conducted a survey among 62 healthy test persons to shed more light on the aspects of user acceptance regarding 12 input and 14 output methods, as well as 3 different application contexts.

We found that there are differences in user acceptance for the various input and output methods between public contexts on

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the one hand and home and rehabilitation contexts on the other. In general, inconspicuous, handy and widely used devices are preferred in public. Also, we found that spectacle wearers are slightly more open to using AR glasses than non-spectacle wearers.

CCS CONCEPTS

• Social and professional topics~Assistive technologies

KEYWORDS

Augmented reality, assistive technology, input and output methods, hand exoskeleton, user acceptance

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1 Introduction

In Germany, an estimated 260,000 people suffer a stroke every year [1]. For one third of those affected, long-term restrictions - such as hand paralysis - remain [2]. In addition to strokes, however, paraplegia or other craniocerebral injury can also lead to hand paralysis. In the case of high paraplegia - also called tetraplegia - both hands are often affected by the paralysis. In 2015, there were about 320,000 people in Germany with

musculoskeletal disorders resulting from craniocerebral injuries (including strokes) and paraplegia [3].

Even the loss of motor skills in just one hand can lead to considerable limitation of autonomy and quality of life. If the hands are paralyzed on both sides, the restrictions become more severe. Often the affected persons can no longer eat and drink independently [4, 5].

A non-invasive neural-guided hand exoskeleton has been developed at the University Hospital of Tübingen. With its support, it is possible to restore a part of the original motor abilities of the paralyzed hand to such an extent that, for example, independent eating and drinking is possible again [6]. In combination with a brain-computer interface (BCI) based control, where the user controls the hand exoskeleton via his brain waves or thoughts, regular use can even lead to a rehabilitation effect [7, 8]. Control via the non-invasive BCI, however, has the disadvantage of a 30% false-positive classification [9]. In addition, the information bandwidth of a BCI for controlling the functionality of the hand exoskeleton is too small. At least within a rehabilitation context, the goal must therefore be to develop a user-friendly combination of the BCI and other input and output methods for controlling the hand exoskeleton. The control of a neural-controlled hand exoskeleton poses further challenges to human-machine interaction in addition to the integration of a non-invasive BCI. On the one hand, it should be operated without the user's hands and place only a minimal physical and cognitive strain on them so that the hand exoskeleton would be intuitively integrated into everyday activities. On the other hand, it should be as inconspicuous as possible in order to prevent stigmatization of the user.

2 Methodology

We conducted a survey, to get an initial assessment of which input and output methods are suitable in general for controlling the hand exoskeleton. In a questionnaire, the respondents were asked to evaluate 12 input and 14 output methods on a Likert scale of 1 to 3 (1 = no, 3 = yes, meaning "I would not use it" and "I would use it", respectively) with regard to their suitability and user acceptance for the following 3 application contexts: (C1) home, (C2) public and (C3) rehabilitation. In order to realize a systematic evaluation of the different forms of human-computer interaction by the questionnaire, it included all input and output methods, which, according to discussions with the medical and human computer interaction experts, are basically suitable for controlling the hand exoskeleton. We hereby distinguished between variations of input and output methods as caused by the use of different input and output devices because this will impact the user experience. For example, the touch input on the smartphone is evaluated separately from the touch input on the smartwatch. Combinations of input and output methods, such as those currently required by the BCI due to the high error rate, were not included in the survey because otherwise the survey would have become too extensive.

The following input methods were part of the questionnaire:

- (I1) hardware button,
- (I2) touch display / smartwatch,
- (I3) touch display / smartphone,
- (I4) touch display / tablet,
- (I5) touch display / laptop,
- (I6) touch field / temple arm of glasses,
- (I7) voice control,
- (I8) head movements,
- (I9) eye tracking,
- (I10) electrooculography (EOG),
- (I11) brain computer interface (BCI),
- (I12) electromyography (EMG).

Also, the following output methods were part of the questionnaire:

- (O1) visual / smartwatch,
- (O2) visual / smartphone,
- (O3) visual / tablet,
- (O4) visual / laptop,
- (O5) visual / Augmented Reality glasses (AR glasses),
- (O6) vibro-tactile / bracelet,
- (O7) vibro-tactile / temple arm of glasses,
- (O8) vibro-tactile / any other body part,
- (O9) sound output / loudspeaker,
- (O10) sound output / headphones,
- (O11) sound output / bone conduction headphones,
- (O12) speech output / loudspeaker,
- (O13) speech output / headphones,
- (O14) speech output / bone conduction headphones.

In addition to the comparative survey on preferred output methods, we asked the respondents in more detail about their user acceptance of AR glasses. To this end, we collected their experiences with AR glasses, their basic willingness to use AR glasses, the Likert scale (1 = definitely not, 5 = definitely yes), their user acceptance for controlling a hand exoskeleton using AR glasses on a finer resolution Likert scale (1 = definitely not, 5 = definitely yes) and their associated anxieties / worries. In addition, we recorded data on the subjects' demography, their technical affinity and their general acceptance of a hand exoskeleton. Also, the subjects were able to make their own suggestions on human-machine interaction with the hand exoskeleton on the questionnaire.

The survey took place as part of an internal class at Stuttgart Media University. The participants answered the question about their technological affinity on a Likert scale from 1 to 5 (1 = not applicable, 5 = applicable) with $M=4.44$ $SD=0.74$. The interviewees were students of media informatics and mobile media who can be assumed to have an above-average technological affinity compared to persons of their age in general. The students had 45 minutes to answer the questionnaire.

3 Results

A total of 62 students (age: M=21.65 SD=3.21) answered the questionnaire. Of these, 48 were male and 14 female.

3.1 Input methods

Figure 1 shows the requested input variants as well as their average user acceptance in relation with the application contexts C1-C3. Refer to Table 1 for exact results.

	C1		C2		C3	
	M	SD	M	SD	M	SD
I1	2.47	0.78	2.08	0.71	2.52	0.72
I2	2.50	0.78	2.53	0.72	2.52	0.70
I3	2.52	0.74	2.48	0.74	2.53	0.67
I4	2.32	0.81	1.95	0.82	2.26	0.77
I5	2.19	0.88	1.79	0.85	2.06	0.81
I6	2.32	0.74	2.18	0.82	2.35	0.75
I7	2.60	0.69	1.45	0.64	2.48	0.70
I8	2.48	0.72	1.90	0.82	2.42	0.74
I9	2.32	0.76	1.94	0.87	2.35	0.75
I10	2.24	0.82	1.92	0.80	2.32	0.83
I11	2.50	0.76	1.95	0.84	2.56	0.74
I12	2.61	0.69	2.50	0.76	2.61	0.66
O1	2.63	0.61	2.69	0.62	2.65	0.60
O2	2.48	0.76	2.35	0.79	2.45	0.76
O3	2.08	0.86	1.74	0.81	2.03	0.83
O4	1.98	0.88	1.61	0.80	1.92	0.87
O5	2.44	0.78	2.15	0.85	2.35	0.81
O6	2.65	0.66	2.56	0.67	2.66	0.60
O7	1.95	0.88	1.92	0.86	2.05	0.88
O8	2.34	0.85	2.31	0.80	2.35	0.81
O9	2.16	0.81	1.31	0.50	2.10	0.80
O10	2.05	0.80	1.92	0.80	2.19	0.83
O11	2.19	0.81	2.03	0.85	2.26	0.83
O12	2.02	0.84	1.32	0.62	2.02	0.84
O13	2.08	0.82	1.94	0.85	2.21	0.83
O14	2.15	0.87	2.00	0.83	2.29	0.84

Table 1: User acceptance of I1-I12 and O1-O14 depending on C1-C3 (1 = no, 3 = yes).

I12 (EMG) has the highest user acceptance in C1 (home) and in C3 (rehabilitation), closely followed in C1 by I7 (voice control), which also has the lowest user acceptance in C2 (public). In C1 and C3, I5 (touch / laptop) has the lowest acceptance among respondents. In C2, I2 (touch / smartwatch) has the highest user acceptance. While I12 has the highest average user acceptance for controlling the hand exoskeleton in C1 and C3, other input methods – like I2 (touch / smartwatch), I3 (touch / smartphone) and I12 (EMG) – were also rated almost equally high for C1-C3.

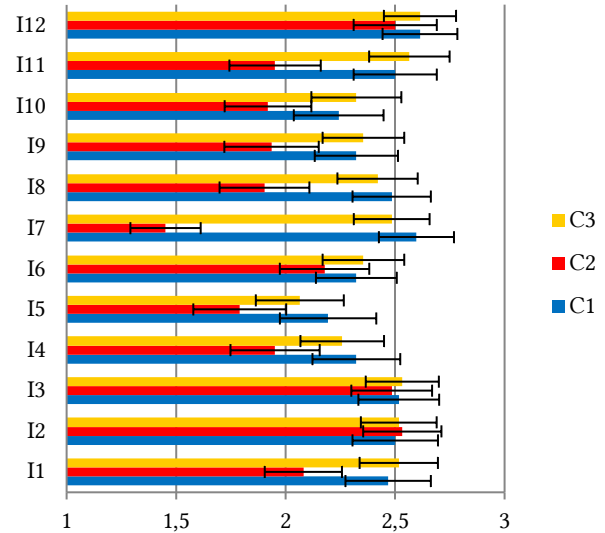


Figure 1: User acceptance of I1-I12 depending on C1-C3 (1 = no, 3 = yes). Error bars: 95% confidence interval.

3.2 Output methods

The Figure 2 shows the user acceptance of the output methods O1-O14 as a function of C1-C3. For exact results refer to Table 1, too.

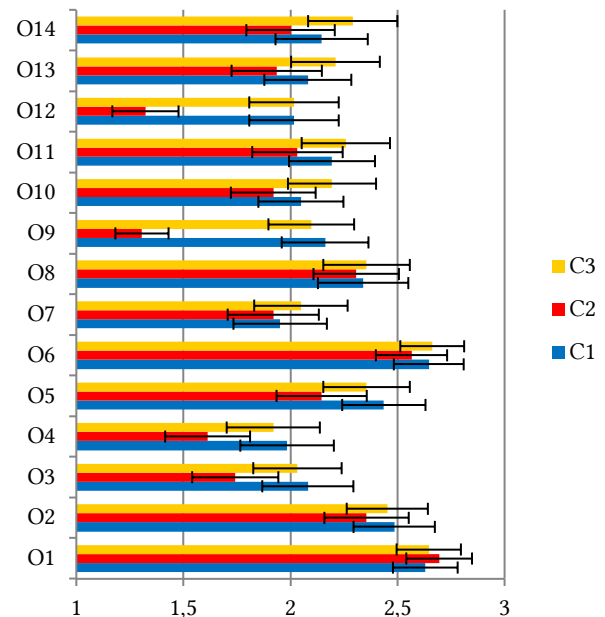


Figure 2: User acceptance of O1-O14 depending on C1-C3 (1 = no, 3 = yes). Error bars: 95% confidence interval.

In C1, O6 (vibro-tactile / bracelet) has the highest user acceptance and O4 (visual / laptop) the lowest. In C2, the study

participants clearly favored O1 (visual / smartwatch), whereas O9 (sound / loudspeaker) and O12 (speech / loudspeaker) are the most unpopular. For C3, O6 also has the highest acceptance and O4 (visual / laptop) the lowest. In summary, looking at all contexts (C1-C3), O1 and O6 have the highest user acceptance. In C1 and C3, the two visual output variants O2 (visual / smartphone) and O5 (visual / AR glasses) also yielded a high user acceptance.

3.3 Differences between spectacle wearers and non-spectacle wearers

Of the 62 people surveyed, 26 stated that they wear glasses. In addition, 3 other people stated that they had glasses for reading. Therefore, we differentiate between (P1) non-spectacle wearers and (P2) spectacle wearers (including the 3 people who need reading glasses) when evaluating user acceptance. This is particularly interesting for I6 (touch / temple arm of glasses) and I9 (eye tracking) as well as for O5 (visual / AR glasses) and O7 (vibro-tactile / temple arm). The exact results therefore are shown in Table 2. In comparison, spectacle wearers (P2) have a higher acceptance for I6 and I9 in C1-C3 than non-spectacle wearers (P1). For O5 and O7, the results are ambiguous. O5 has a higher user acceptance for C1-C3 among P2 than among P1. However, for O7 there are almost no differences between P1 and P2.

	C1		C2		C3	
	M	SD	M	SD	M	SD
P1 I6	2.24	0.83	2.09	0.88	2.27	0.84
P2 I6	2.41	0.63	2.28	0.75	2.45	0.63
P1 I9	2.18	0.81	1.88	0.82	2.24	0.79
P2 I9	2.48	0.69	2.00	0.93	2.48	0.69
P1 O5	2.33	0.85	2.09	0.88	2.09	0.85
P2 O5	2.55	0.69	2.21	0.82	2.41	0.78
P1 O7	1.94	0.86	1.94	0.86	2.03	0.92
P2 O7	1.97	0.91	1.90	0.86	2.07	0.84

Table 2: User acceptance of I6, I9, O5 and O7 depending on non-spectacle wearers (P1), spectacle wearers (P2) and C1-C3 (1 = no, 3 = yes).

3.4 Special Augmented Reality questions

Of the 62 subjects, 55 said they knew AR glasses. Exactly half of the 62 respondents had used AR glasses before. The respondent groups P1 and P2 can thus be further divided into the following four respondent groups for the evaluation of user acceptance of AR glasses:

- (P1NoAR) non-spectacle wearers without AR experience,
- (P1AR) non-spectacle wearers with AR experience,
- (P2NoAR) spectacle wearers without AR experience,
- (P2AR) spectacle wearers with AR experience.

In numbers, the 62 test persons are distributed among the four groups as follows: P1NoAR: 14, P1AR: 19, P2NoAR: 17, P2AR: 12.

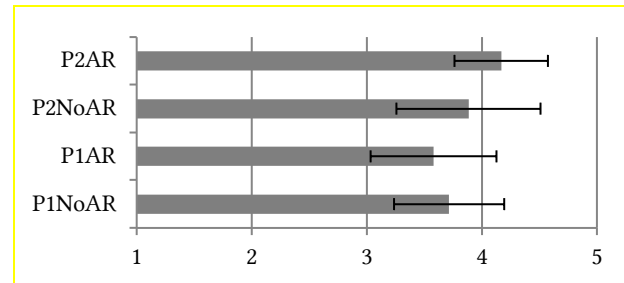


Figure 3: Basic willingness to use AR glasses (1 = definitely not, 5 = definitely yes). Error bars: 95% confidence interval.

	M	SD
P2AR	4.17	0.72
P2NoAR	3.88	1.32
P1AR	3.58	1.22
P1NoAR	3.71	0.91

Table 3: Basic willingness to use AR glasses (1 = definitely not, 5 = definitely yes).

Figure 3 shows the basic willingness of the four groups of test persons to use AR glasses independently of the use case, i.e. not specifically related to the control of the hand exoskeleton. For exact results refer to Table 3. P2 (spectacle wearers) (M=4.0, SD=0.4) has a slightly higher willingness to use AR glasses than P1 (non-spectacle wearers) (M=3.64, SD=0.37). If one additionally distinguishes whether the test persons have already used AR glasses, P2AR (M=4.20, SD=0.41) reaches the highest readiness to use AR glasses and P1AR (M=3.58, SD=0.55) the lowest readiness to use AR glasses. Even though there are differences between the test groups regarding the user acceptance of AR glasses, these are low and, regardless of this, all four test subject groups are basically prepared to use AR glasses, but with some reservations.

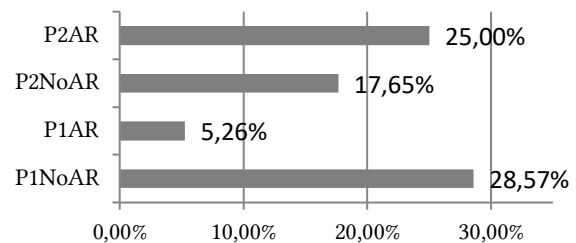


Figure 4: Subjects with worries or concerns about using AR glasses (O5) for controlling a hand exoskeleton. X-values represent percentages.

Figure 4 shows how many test persons indicated that they had anxieties / worries when controlling the hand exoskeleton with AR glasses. In P1 (non-spectacle wearers), 15.15% of respondents

said that they had worries or concerns about controlling the hand exoskeleton with AR glasses, compared to 20.69% in P2 (spectacle wearers). In addition, the results also allow a further differentiation of P1 and P2 on the basis of existing or non-existing experience with AR glasses. P1NoAR had the highest proportion of subjects with worries or concerns (28.57%), closely followed by P2AR (25.00%). P1AR has the lowest proportion of worries or concerns regarding the control of a hand exoskeleton with AR glasses (5.26%).

The groups P1 and P2 of the O5 output method (AR glasses) are divided into subjects with and without AR experience as follows (see Figure 5 and Table 4): P2AR has the highest user acceptance regarding controlling a hand exoskeleton with AR glasses, whereas P1NoAR has the lowest user acceptance. The test person groups P1AR and P2NoAR lie between the two groups in terms of user acceptance.

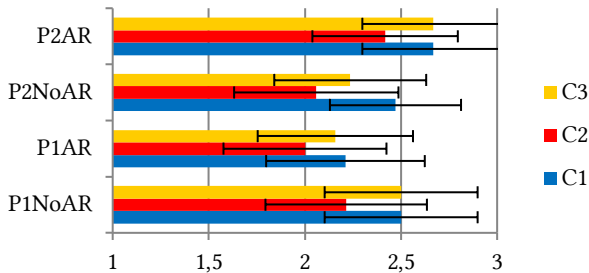


Figure 5: User acceptance of O5 depending on non-spectacle wearers, spectacle wearers, AR experience and C1-C3 (1 = no, 3 = yes). Error bars: 95% confidence interval.

	C1		C2		C3	
	M	SD	M	SD	M	SD
P2AR	2.67	0.65	2.42	0.67	2.67	0.65
P2NoAR	2.47	0.72	2.06	0.90	2.24	0.83
P1AR	2.21	0.92	2.00	0.94	2.16	0.90
P1NoAR	2.50	0.76	2.21	0.80	2.50	0.76

Table 4: User acceptance of O5 depending on non-spectacle wearers, spectacle wearers, AR experience and C1-C3 (1 = no, 3 = yes).

4 Discussion

The results of our study allow conclusions to be drawn about user acceptance of input and output methods for controlling a hand exoskeleton by young people and people with an affinity with technology. The results show that this user group prefers to control a hand exoskeleton in public with small, handy, inconspicuous input variants that are already widely used today (e.g. I2 or O1, I3 or O3 and I12). It can be assumed that the motivation behind this is not to stand out even more by controlling the hand exoskeleton and as a result to be exposed to stigmatization.

At home and for rehabilitation, the differences between the input and output methods in user acceptance are smaller than in public. Therefore, we conclude that at home and for rehabilitation, the respondents are more open to novel and not so widely used input methods than in public, especially if these promise a gain in comfort. This could explain why input variant I7 (voice control) performs better at home and for rehabilitation than in public, as do eye movements in the form of I9 (eye tracking) and I10 (EOG).

User acceptance of AR glasses (O5) as an output method for controlling a hand exoskeleton is obviously highest in spectacle wearers with AR experience (P2AR). In this group, O5 has the highest user acceptance in comparison with the other three groups of test persons, both in terms of the general willingness to use AR glasses and specifically in terms of controlling the hand exoskeleton in the three application contexts C1, C2 and C3. This could be due to the fact that the test persons already wear glasses in everyday life and have already used AR glasses in the past, which makes them more familiar with this new technology. Also, since they wear glasses in everyday life anyway, they may feel less stigmatised by AR glasses (O5). At the same time, P2AR has the second highest proportion of subjects who said they had anxieties when using AR glasses (O5) to control the hand exoskeleton (25%), just little lower than P1NoAR (28.57%). It is understandable that persons who have never worn spectacles nor AR glasses are more prone to fears / worries than persons with experience in both (spectacles and AR glasses).

Regarding spectacle wearers, persons with AR experience are slightly more worried about using AR glasses (P2AR: 25.00%) than those without AR experience (P2NoAR: 17.65%). This could be due to the difficulty of wearing spectacles and AR glasses at the same time in the past.

The results obtained by the questionnaire only allow conclusions to be drawn as to which input and output methods the respondents would prefer to use to control the hand exoskeleton at home, in public and for rehabilitation. However, this does not imply that these are the most suitable in practice in general. For example, the use of a smartwatch (I2 or O1) might not be satisfactory in everyday life because it is too often obscured by the primary activities the user performs with their hands, which could limit visual feedback (O1) or hinder touch input (I2). Furthermore, every user of a hand exoskeleton is different. Stroke patients usually have hemiplegia, which allows them to make touch inputs (I2-I6) or use a button (I1) with the non-paralyzed hand. However, it is suboptimal if the intact hand is "occupied" with the control of the hand exoskeleton. Tetraplegics, who can also benefit from a hand exoskeleton, have bilateral paralysis, which means that they cannot even use the input methods I1-I3, which according to the questionnaire have a high user acceptance in at least one of the three application contexts. In addition, the disease or the injury that caused the hand paralysis can lead to further limitations. Among other things, paraplegia can also cause a loss of perception below the spinal cord injury. In the case of high paraplegia, the affected

person may only perceive haptic feedback in the form of O6-O8 on the head. Likewise, I12 would not be usable for them. In a study on disability-accessible control of smarthomes, Ableitner showed that I7 functions less well in tetraplegics than in intact volunteers. This is probably due to the fact that high paraplegia also affects the diaphragm, which in turn impairs the quality of speech [10]. Speech is also affected by 30-40% of strokes [11]. For this reason, I7, even at home where it achieved the highest user acceptance, is not suitable as the only input for controlling a hand exoskeleton.

It is interesting to note that even highly rated input methods perform less well in some application contexts. For example, users would often find I7 in public annoying or would be afraid that the input will be disturbed by ambient noise.

5 Conclusion

It is important to note that the survey was conducted among young people with an affinity with technology who had healthy hands and no experience with a hand exoskeleton. This limits their ability to make meaningful statements about the use of a hand exoskeleton in a situation that involves a paralyzed hand. It is likely that the result would have been different if the respondents had been in the real situation of living with a paralyzed hand and its consequences. However, it would be very difficult to recruit subjects who suffer from hand paralysis and at the same time are technology oriented – since the purpose of the study was to identify interaction technologies that will work for future patients. Nevertheless, it can be assumed that – in the real case of one or two paralyzed hands – the relative acceptance rates between the interaction methods would rather not change, albeit the absolute values may change.

In our study, those input and output methods that are inconspicuous, handy or are already widely used in everyday life achieved the highest user acceptance for the public application context. We conclude that it is important for the respondents to avoid stigmatization in public. This is why AR glasses (O5), especially in public (C2), probably do not yet have such a high user acceptance for controlling a hand exoskeleton. However, this could change as AR glasses become smaller and more widely available. This can be deduced from the fact that the group of test subjects (P2AR) who already wear spectacles in everyday life and are in public eye with them and have also already gained experience with AR glasses is more open to controlling the hand exoskeleton using AR glasses than the group of non-spectacle wearers without experience with AR glasses (P2NoAR).

Regarding the use at home (C1) versus for rehabilitation (C3), the subjects gave different ratings for user acceptance of the input and output methods. However, there is a tendency that – in these contexts – more novel and not yet so widely used input and output methods for controlling the hand exoskeleton are accepted. For this reason, we first of all see the application contexts C1 and C3 as offering the greatest opportunities for developing an interaction concept combined with AR glasses and sufficient user acceptance for controlling the hand exoskeleton.

Furthermore, it is important to consider flexible personalization for human-machine interaction when controlling the hand exoskeleton, that is, to implement several alternative variants. This is indicated by the fact that the subjects do not favor a common input and output method across all application contexts. Also, users of hand exoskeletons may have other restrictions in addition to hand paralysis, so they may only be able to use a subset of the input and output methods considered in our study.

Finally, we can only conclude from the results of our study which input and output methods are acceptable for our subjects for controlling a hand exoskeleton. We cannot conclude which methods would actually be suitable for controlling the hand exoskeleton. This would require a study involving a high number of subjects who have a long-term experience with the use of hand exoskeletons. But this is out of reach as of today – with hand exoskeletons just starting to move beyond the prototype stage of development.

6 Future work

In a next step, we plan to conduct the same interview with patients who have either unilateral or bilateral paralysis of the hands. We will compare the results with those from the healthy, technology-oriented young subjects. Thus we will identify a combination of input and output methods, including those suitable for AR glasses, for the control of a hand exoskeleton, which have a high degree of acceptance in various application contexts (home and rehabilitation vs. public), and for various user groups (stroke patients / paraplegic on one side, paraplegic on the other / paraplegic on both sides). Furthermore, we will especially consider those input and output methods (e.g. BCI) that have the potential to yield a rehabilitation effect.

We will thus develop our human-machine interaction concept for controlling a hand exoskeleton, implement it as a prototype and finally evaluate it with subjects from the target group (persons wearing a hand exoskeleton for a longer period) for its practical suitability for controlling a hand exoskeleton.

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