# Evaluation of a Serious Game on Hand Hygiene for Health Care Professionals

## A randomized crossover exploratory study

Doctoral thesis

to obtain a doctorate (Dr. med.)

from the Faculty of Medicine

of the University of Bonn

**Britta Kießler**

from Soest, Germany

2026

Written with authorization of

the Faculty of Medicine of the University of Bonn

First reviewer: Prof. Dr. Stephan Jonas

Second reviewer: Prof. Dr. Matthias Weigl

Day of oral examination: 3 March 2026

From the Institute of Digital Medicine

# Table of contents

## List of abbreviations

| | |
|---|---|
| CDC | Centers for Disease Control and Prevention |
| GUI | graphical user interface |
| HCAI | healthcare associated infection |
| HCW | healthcare worker |
| RKI | Robert Koch-Institut |
| WHO | World Health Organization |

## List of figures

## List of tables

## Abstract


Background

Although healthcare-workers' hands are one of the major sources of healthcare associated infections (HCAIs), compliance with hand hygiene remains low. This leads to millions of preventable infections each year worldwide. Major reasons for non-compliance are a lack of knowledge regarding hand hygiene guidelines among staff as well as missing motivation.

Objectives

The objective of our study was to evaluate a mobile application which aims to improve its users' hand rubbing technique of hand hygiene based on World Health Organization's (WHO) recommendations. We also evaluated the application's influence on the users' motivation to perform hand hygiene.

Methods

A mobile application based randomized, controlled, cross-over study was carried out to measure the effect of a 2-weeks training of the WHO hand rubbing technique. We used a pre- (at start t0) and post-questionnaire (at cross-over t1 and end t2) to evaluate and compare the study participants' knowledge about and attitude towards hand hygiene.

In the test group, participants were asked to train the hand rubbing technique with the use of gesture control armbands as well as tutorial videos during the first two weeks. In the control group, participants were asked to train by tutorial videos only during that time. During the following two weeks, the instructions were vice versa.

Results

Knowledge concerning correct hand disinfection according to the WHO standard improved through training with gesture control armbands but also through watching tutorial videos. After the test group stopped using the gesture control armbands and were asked to train by watching tutorial videos only, knowledge started to decrease. Whereas in the control group, improvement could be achieved during the first two weeks when only watching tutorial videos, but the group showed further improvement during the last two weeks when being able to use gesture control armbands. Regarding the participants' attitude towards hand hygiene, the use of the application did not cause any changes.

Conclusions

Our results indicate that a mobile application could be an appropriate tool to provide easy and time efficient training of hand hygiene technique knowledge. The use of immediate feedback through wearables could not achieve better results than the use of video-training only.

# 1. Background

## 1.1 The burden: Healthcare associated infections

In the 19th century Ignaz Semmelweis first identified healthcare workers' hands as the major source of puerperal fever transmission. He observed that the risk of post-delivery mortality was significantly higher in a clinic where women were treated by physicians and medical students than in a midwife clinic. He assumed a connection between cadaveric contamination of hands due to postmortem examination of corpses. Each day in the clinic in which women were treated by physicians and medical students started with the examination of corpses of women who had died of purpureal fever. Afterwards, the professionals performed vaginal examination on the women as part of their training. In the midwife clinic however neither postmortem examinations were performed nor any routine vaginal examinations.
After Semmelweis introduced washing of hands and medical instruments with a chlorine solution, maternal mortality in the clinic where women were treated by physicians and medical students was reduced from 12.3 % to 2 - 3 % within a few months (Semmelweis, 1861; Loudon, 2013).

Consistent with Semmelweis' findings, good hand hygiene is still considered to be the most important factor of preventing healthcare associated infections and furthermore the spread of multi-resistant pathogens according to the current scientific level of knowledge. Nevertheless, transmission through contaminated HCWs' hands with pathogens remains the most common reason for HCAIs. The WHO estimates that 50 % of infections could be prevented by better hand hygiene (Pittet et al., 2006; World Health Organization, 2009a). However, hand hygiene remains unsatisfyingly low even almost two decades after Semmelweis' observations (Pittet et al., 2000; Randle et al., 2006).

Still in the 21st century, HCAIs affect hundreds of millions of patients each year. These infections lead to more serious illnesses, prolonged hospital stays and preventable deaths. In addition, these infections often induce long-term disabilities. Furthermore, HCAIs cause high costs to the patients and their families and contribute to the financial

burden on the health-care systems all around the world (Robert Koch-Institut, 2020a; Centers for Disease Control and Prevention, 2021a).
One could think that HCAIs only affect low-income countries, but even in high-income countries, as much as 7 % of hospitalized patients acquire at least one HCAI (World Health Organization, 2009a).

The last health crisis evolving around the new SARS-CoV-2 virus stressed the importance of hygiene measures (Sun et al., 2020). Main routes of virus transmission are respiratory droplets, but also hand contact with contaminated body parts e and surfaces plays a role in transmission (European Centre for Disease Prevention and Control, 2020; World Health Organization, 2020).

Taking a look at current hygiene recommendations, the WHO stresses the importance of frequent and correct hand hygiene as one of the most important measures preventing COVID infections and referres therefore to their own guidelines already published in 2009 (World Health Organization, 2020). Also other governmental authorities such as the German RKI or the US-American CDC stress the major importance of hand hyiene fighting the global pandemic of COVID-19 both in professional health-care and in private settings (Robert Koch-Institut, 2020b; Centers for Disease Control and Prevention, 2022).

In relation to the outbreak of Mpox (formerly known as monkeypox), which began affecting Germany in 2022, institutions such as the Robert Koch Institute (RKI) emphasize the importance of consistent hand hygiene (Robert Koch-Institut, 2024).

## 1.2 Guidelines on Hand Hygiene

These ‘WHO Guidelines on Hand Hygiene in Health Care’ mentioned above are an international reference and provide specific recommendations on when (compliance with indications) and how (compliance with technique) HCWs are supposed to perform hand hygiene. These guidelines were developed by international experts of infection control with specific expertise in hand hygiene and published in the year 2009. They are part of the program ‘Clean Care is Safer Care’ which aims at reducing the occurrence of HCAIs

(World Health Organization, 2009a). As being referenced at the time of COVID-19, the guidelines are still considered up-to-date (Centers for Disease Control and Prevention, 2021b).
Regarding the compliance with indications the WHO bases its recommendations on the ‘Five Moments for Hand Hygiene’ firstly defined by Sax et al. (Sax, H. et al., 2007). These are key moments in which HCWs should perform hand hygiene by rubbing their hands with an alcohol-based hand sanitizer.

1. Before touching a patient
2. Before clean/aseptic procedure
3. After body fluid exposure risk
4. After touching a patient
5. After touching patient surroundings

Hand washing with soap and water is recommended when hands are visibly dirty or visibly soiled with blood or other body fluids or after using the toilet. Furthermore, hand washing is recommended after exposure to potential spore-forming pathogens (Sax, H. et al., 2007; World Health Organization, 2009a).

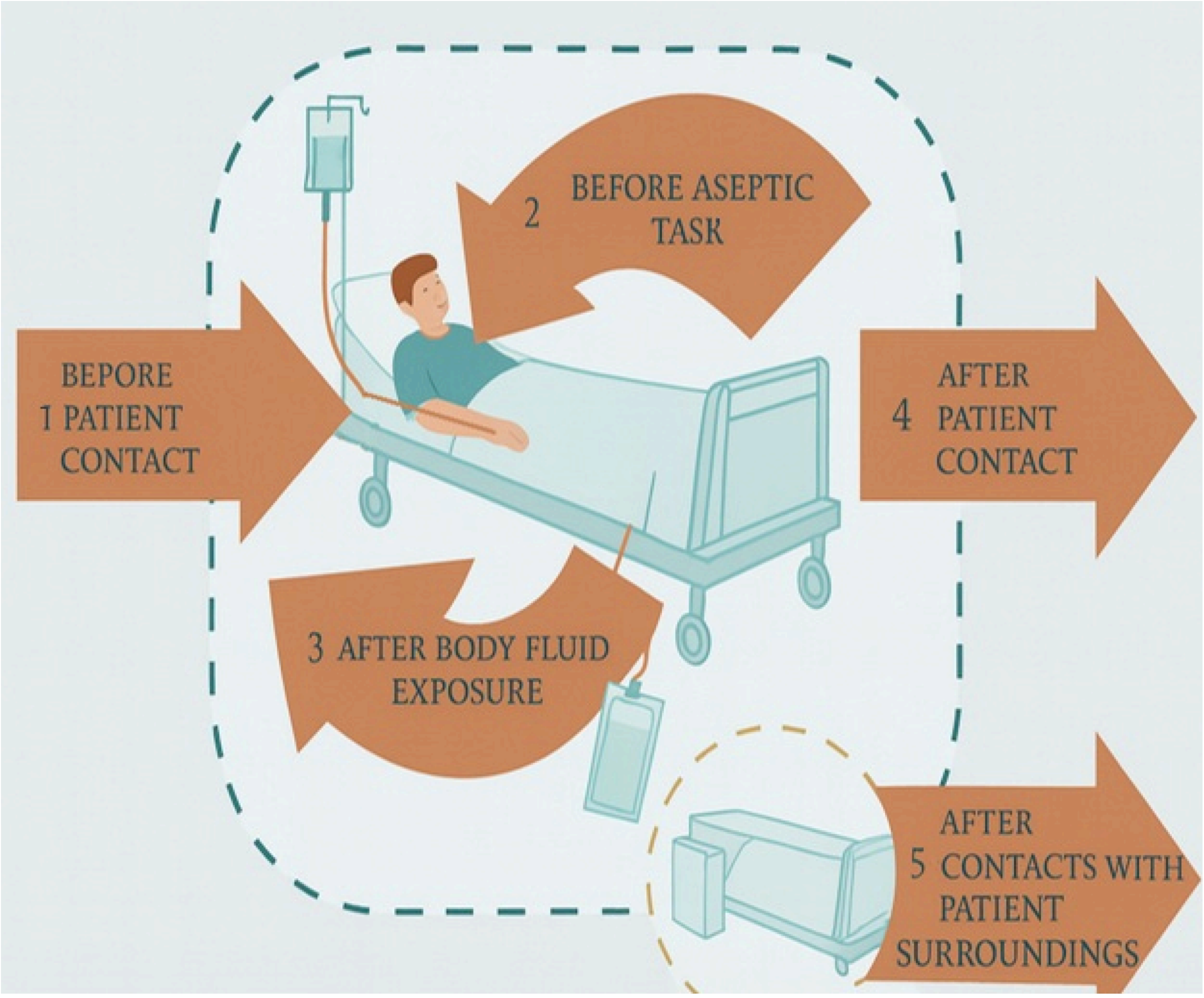



**Fig. 1:** Representation of the 'Five Moments for Hand Hygiene' modified from Sax et al. (2007) with the assistance of an AI-based graphic tool.

The recommended hand hygiene techniques with alcohol-based hand sanitizers as well as the hand washing technique with soap and water include specific gestures in a defined order (World Health Organization, 2009a):

1. Application of a palmful of product in a cupped hand
2. Rubbing hands palm to palm
3. Rubbing right palm on the back of the left hand with interlaced fingers. Repetition with left palm on the back of the right hand
4. Rubbing hands palm to palm with interlaced fingers
5. Rubbing backs of fingers to opposing palm with fingers interlocked
6. Disinfection of the thumbs through rotational rubbing of the left thumb clasped in right palm and vice versa

7. In the end rotational rubbing of the fingertips on the palm of the contralateral hand

The impact of both compliance and technique are intermingled; both play an important role in preventing HCAIs.


**Fig. 2:** 'How to handrub' (World Health Organization, 2009). This figure is licensed under CC BY-NC-SA 3.0 IGO and may be reproduced and published for non-commercial purposes with attribution.

## 2. Assessment of hand hygiene quality and training

### 2.1 Compliance with indications for hand hygiene

Hand hygiene compliance can be assessed directly, for example through direct observation, or indirectly, by measuring hygiene product usage such as paper towels, alcohol-based hand sanitizers or soap (World Health Organization, 2009a). At the current state, direct observation by a qualified individual is considered the gold standard of hand hygiene monitoring (Boyce et al., 2002). In the last decades, research has also included electronic assessment of compliance with indications for hand hygiene (Boscart et al., 2009; Rosenfeldt Knudsen et al., 2023).

In another study starting in 2000, an ambient electronic monitoring system with motion detectors was used to track entry and exit into patient rooms. Compliance was rated as 'positive' if health-care workers washed their hands with soap and water or used antiseptic foam in a defined time period before or after exiting a patient room. However, the system failed to calculate exact compliance rates when being compared to direct observation (Swoboda et al., 2004).

Similarly, Boscart et al. used wearable hand hygiene monitors when a HCW entered or exited defined areas where hand hygiene was required. These wearables communicated with dispensers for alcohol-based hand rub and recorded the use of wearable alcohol-based hand sanitizers, as well as wall-mounted alcohol-based hand sanitizers and soap dispensers (Boscart et al., 2008, 2009). The wearables also provided the user with a reminding sound signal at hand hygiene opportunities. This trial showed a high acceptance of the wearable devices used by the HCWs.

Hagel at al. compared direct monitoring and electronic monitoring and indicated at good agreement between both methods (Hagel et al., 2015). Nevertheless, when HCW were not directly monitored, compliance rates were much lower. This indicates that direct observation can be a strong confounder in studies where compliance with indications of hand hygiene is monitored. The authors explained these results through the Hawthorne effect.

The Hawthorne effect describes that individuals change their natural behavior due to their awareness that they participating in a study and are being observed (Colbjørnsen, 2003). Still, all these electronic monitoring systems cannot evaluate the actual quality of the execution of the recommended hand hygiene gestures and thereby the compliance with hand hygiene technique.

## 2.2 Compliance with hand hygiene technique

Compliance with hand hygiene technique is also commonly assessed through direct observation.

Compliance with all 6 gestures of the WHO guidelines is reported to be extremely low. Tschudin-Sutter et al. reported an adherence as low as 8.5 % even though the compliance rate with hand hygiene indications was above 90 % (Tschudin-Sutter et al., 2015).

There is scientific evidence that the adherence to all steps of the WHO guidelines results into increased elimination of pathogens such as bacteria. It ensures that all areas of the hands are covered with the disinfection solution. Therefore the sequence commended by the WHO is highly effective compared to other techniques (Widmer and Dangel, 2004; Tschudin-Sutter et al., 2015; Reilly et al., 2016).

Compliance with hand hygiene indications is also affected by the familiarity of HCWs with the hand-rub protocol: In multiple studies a lack of knowledge and institutional guidelines was reported a factor of low adherence and compliance (Larson and Killien, 1982; Larson and Kretzer, 1995; Sax, H. et al., 2007; World Health Organization, 2009a).

## 2.3 Training of indications for hand hygiene and hand hygiene technique

To ensure compliance with the indications for hand hygiene and - as a secondary target – compliance with hygiene technique, the RKI recommends that training of all staff should be organized at least once a year (Robert Koch-Institut, 2016). A common form of teaching and promoting the WHO guidelines are in-service lectures and posters (World Health Organization, 2009a). However, visual demonstration of the effectiveness of hand hygiene was named an important aspect of training by HCWs themselves (Nicol et al., 2009).

In general, the effect of feedback on learning achievement has been shown by Hattie and Timperley (Hattie and Timperley, 2007). Mobile applications can provide this direct positive feedback and medical professionals and also students are open-minded to adopt new technologies for learning (Ponce et al., 2014). The potential of these mobile applications in medical education has been recognized by most German faculties already, as by the current time, most German universities pay for their students to be able to use a web and mobile application called AMBOSS® which provides the user with a medical encyclopedia but also can be used to test the user's knowledge (AMBOSS GmbH, 2025).

Focusing on hand hygiene, the serious game SureWash® uses a mobile computer that guides the user through the steps of hand hygiene and allows the user to practice. The system monitors the user's hand movements with a camera and evaluates the performance through gesture recognition in comparison to the WHO's guidelines.
Firstly, SureWash® offered the product ELITE and GO. To use these products, SureWash® hardware is required (amongst a computer/tablet and a camera).
SureWash® latest release is a mobile application called SureWash® APP. This application enables the user to practice hand hygiene on his or her private smartphone. SureWash® APP is only programmed to recognize the gestures but not to evaluate their actual quality (Surewash, 2025). However, in a test of the application on a private smartphone, randomly performed gestures were evaluated correctly, which indicates that the application at that time still needed further improvement.

In prior work, Kutafina et al. were able to recognize the gestures of the WHO hand disinfection guidelines using Myo® gesture control armbands placed on both forearms to collect motion data. The armbands collect movement data and muscle activity (see Fig. 3) through an inertial measurement unit and surface electromyography.
This study therefore uses a different approach to identify gestures correctly. The gestures are classified with a neural network and hidden Markov model with an accuracy of 98 % (Kutafina et al., 2016).

Based on this work, the mobile application IdealPure was developed to make this technique useable outside of a standardized setting.

In this work, we aimed to test this application with health care professionals to evaluate if knowledge about and attitude towards hand hygiene changed due to the use of the mobile application IdealPure.

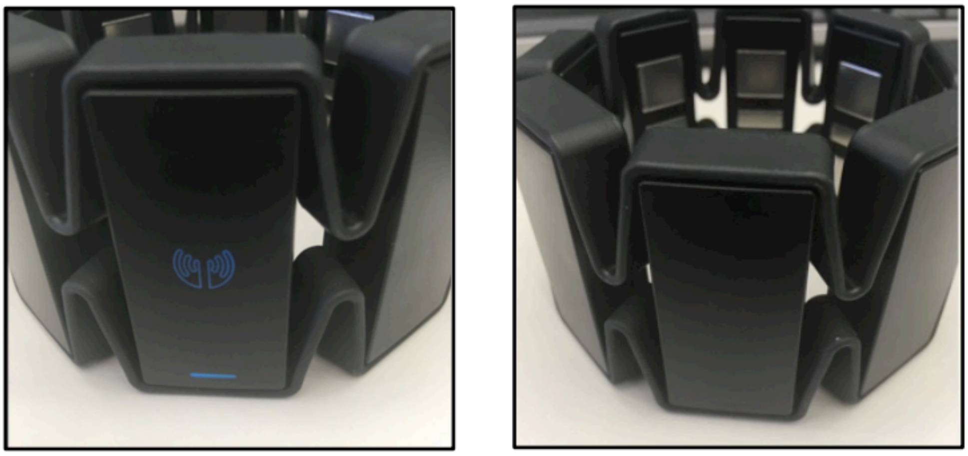


**Fig. 3:** Myo® gesture control armband shown from two perspectives. The device records arm and hand movements using surface electromyography (sEMG) and a nine-axis inertial measurement unit (IMU), enabling gesture recognition and motion tracking (Sathiyanarayanan and Rajan, 2016). Photograph taken by the author.

2.4 Devices

The Myo® armband itself was developed and manufactured by Thalmic Labs (Kitchener, Canada), a company specializing in wearable gesture-control technology. Thalmic Labs later discontinued the Myo® armband in 2018, rebranded as North, and shifted its focus to developing smart glasses; the company was eventually acquired by Google in 2020, which marked the end of Myo® armband production and support (TechCrunch, 2020).
At the time of the present study, the Myo® armbands were already in the possession of the Institute of Medical Informatics at RWTH Aachen University, as they had previously been used in other studies such as the one by Kutafina et al. (Kutafina et al., 2016). Initially, the devices had been obtained directly from the manufacturer, Thalmic Labs.
The mobile application IdealPure was developed by the Institute of Medical Informatics at RWTH Aachen University and is not commercially available. The author was a member of the development team.

## 3. Methods

### 3.1 Scientific background of IdealPure

IdealPure gives the user the opportunity to practice the hand disinfection gestures based on the WHO standard. The application connects to two Myo® gesture control armbands and collects data during hand rub training to give immediate performance evaluation as a total score and individual scores per WHO hand rub gesture. The application also provides learning material in form of videos of correct hand rub execution.
Since the objective was to take gesture recognition on a higher level, we aimed not only at the recognition of the performed gestures but also at the evaluation of the actual quality. Therefore approximately 100 data sets were collected from a various of people, including health care professionals but also people who had no prior training. People were being supervised by the author while being asked to perform the gestures correctly. These data sets were used to develop a machine learning model for evaluation of the hand hygiene technique and implemented into the app to rate the user's performance.

Prior to the initiation of the study, the responsible ethics committee was consulted. The committee confirmed that there were no ethical or professional concerns. The study was therefore approved by the ethics committee of the RWTH Aachen University Hospital (EK 323/17). A copy of the statement is included in the addendum (Fig. 2).

### 3.2 Machine-learning based classification and evaluation of hand hygiene data

The collected data sets of hand hygiene signals were processed to report evaluation results of each individually performed hand hygiene gesture.

The data was split into segments containing only data from only one single hand hygiene. Then each datapoint in the segments was classified to correct or wrong execution and individual and overall scores were calculated based on the ratio of correct and wrong executed datapoints.

### 3.2.1 Splitting of data

The exact timing of the transition between two hand hygiene gestures is known from the recording protocol. Therefore, the data can be split exactly at the timepoints of transition between two gestures. However, at these timepoints the users switch between two hand hygiene gestures and therefore the data might not be classified as belonging to one of the gestures. To reduce error based on incorrectly classified datapoints at the beginning or ending of a gesture, and thereby making a perfect score impossible to reach, the first and last second of the segments were cut.

### 3.2.2 Classification of data

Based on training data recorded prior to the trail, a neural network model was built and used for classification of the data.

The model consists of 9 sub models. Gestures which have to be performed twice to either clean the left or the right hand's part are counted twice.

1. Rubbing hands palm to palm
2. Rubbing right palm on the back of the left hand with interlaced fingers
3. Repetition with left palm on the back of the right hand
4. Rubbing hands palm to palm with fingers interlaced
5. Rubbing backs of fingers to opposing palm with fingers interlocked
6. Disinfection of the thumbs through rotational rubbing of the left thumb clasped in right palm
7. Disinfection of the thumbs through rotational rubbing of the right thumb clasped in left palm
8. Rotational rubbing, backwards and forwards with clasped fingers of right hand in left palm
9. Rotational rubbing, backwards and forwards with clasped fingers of left hand in right palm

Each model uses a sliding window of 30 data points to classify if a sample within its context is part of a gesture. The output is a number between 0 (incorrect execution) and 1 (correct execution = 100 %). For simplicity’s sake, a threshold is applied at 0.5, which classifies each datapoint as correct or incorrect.

### 3.2.3 Scoring of data

A total score and individual scores for each hand hygiene gesture are calculated. The individual score is the ratio of datapoints classified as correctly executed to the total number of datapoint in the segment. Thereby, a maximum of 100 % and a minimum of 0 % correct execution could be achieved. The total score is calculated as the average of the individual scores.

## 3.3 The questionnaires

The questionnaires were designed to capture information on the participants’ demography, such as gender or profession, on their experience in health care and also on knowledge of and attitude towards hand hygiene.
Developing the questionnaire, we looked into existing questionnaires being published. For our study, we used parts of the WHO’s questionnaire ‘Perception Survey for Health-Care Workers’ which focuses on HCWs’ attitude towards HCAIs and hand hygiene (World Health Organization, 2009b). Additionally we used the questionnaire by Courtemanche & Associates as a template (Courtemanche & Associates, 2017). Moreover, we used several questions we developed for the purpose of this study.
The study participants completed a questionnaire at the beginning at the study (t0) and a slightly different one after two and four weeks (t1, t2).

At the beginning of the study, we gathered information on the overall demography of the study participants. Questions therefore included gender, profession, and work experience. We decided not to use a free text field asking the study participants on the period of time they have been working in their profession (training excluded). The reason behind that decision was that we only planned on including a small amount of only around 20 study participants in this explorative study and we considered that more detailed information would be critical in terms of protection of privacy.

Moreover, study participants were supposed to state if they received formal training on hand hygiene within the last three years. This question was supposed to evaluate the actual education a study participant received on hand hygiene. The question derived from the WHO questionnaire (World Health Organization, 2009b). We also asked if study participants had ever received formal training of hand hygiene. Referring to the RKI's recommendations that all health care professionals should receive training once a year (Robert Koch-Institut, 2016), all participants should answer both questions by yes.
We also used the WHO question whether alcohol-based hand rub for hand hygiene was routinely used (World Health Organization, 2009b)

To assess the development of the participants' knowledge on the execution of correct hand disinfection according to the WHO standard, all study participants were asked to put pictures of hand hygiene gestures into the correct order at t0, t1, and t2. These pictures contained drafts of the six hand disinfection gestures for the 'Hand Hygiene Technique with Alcohol-Based Formulation' of the WHO Guidelines on Hand Hygiene in Healthcare (World Health Organization, 2009a).
Participants had to label each picture with step one to step six. Gestures which are supposed to be performed with both the left and the right hand were subsumed in one picture as it is in the drafts in the WHO guidelines (World Health Organization, 2009a).

We consciously decided to test the gained knowledge through the method of putting the gestures in the order the WHO recommends even though studies have shown that there can also be advantages of performing the hand hygiene gestures in a different order (Pires et al., 2016). Regarding the fact that compliance with all six steps of the hand hygiene was under 8.5 % in a study of HCWs, this indicated that HCWs need to learn a certain standard to remember all of the scientifically tested gestures (Tschudin-Sutter et al., 2015).


**Fig. 4:** Screenshot of the study application developed by the research team. The illustrations of hand hygiene gestures were adapted from the poster "How to handrub" (World Health Organization, 2009). As the study was conducted in Germany, the interface shown in the screenshot appears in German.

Furthermore, participants had to answer a series of questions on their compliance regarding hand hygiene, the effort needed to perform good hand hygiene, reasons why they did not perform hand hygiene, and ideas to improve hand hygiene.

Additionally, the questionnaire contained questions on the importance of hand hygiene for the participants themselves and for their head of department. Study participants could choose between never/not important (0 points) to always/very important (6 points) on a

Likert scale as it was also utilized in the WHO questionnaire (World Health Organization, 2009b)

Moreover, study participants were asked to estimate in what percentage of WHO indications they actually performed hand hygiene

To allow participants to give individual feedback on the application, the questionnaires included free text fields. At both t1 and t2, all participants were asked what they liked and what they disliked about the application and to provide further comments.

The questionnaires were translated into German as the study was executed in Germany.

## 3.4 The graphical user interface of IdealPure

The application IdealPure was developed as an Android® smartphone application. Two different modes of the application have been developed to make it suitable for the study design which is explained in detail later in the thesis.

### 3.4.1 The test mode

The application in the test mode has 4 different click-on icons. This mode can be considered to be the 'normal' mode.

The one on top 'Training' (as seen in Fig. 5 (a)) leads the user to the training mode. The user then has to connect two Myo® armbands via Bluetooth with the smartphone. The user therefore needs to place a Myo® armband on both the right and the left proximal part of the forearm right underneath the elbow. The user then has to click 'vibrate' and has to select from a dropdown menu whether it was the right or the left Myo® armband. To confirm the entry, a checkbox had to be clicked for each Myo® armband. Afterwards 'Starten' (Start) had to be pressed (Fig. 5 (c)).

In this practical traning each gesture is presented individually for 5 seconds. An example of a gesture is presented in Fig. 2 (d). We additionally separated gestures which need to be performed with each hand individually resulting in 9 sub gestures as explained in 'Classification of the data'. The user meanwhile is supposed to perform the gesture displayed.

At the end of a practice sequence the user would get a score between 0 and 100 (value in percentage) for each gesture itself and for the whole sequence.

Under ‘Mein Profil’ (My profile) the user can see his or her scores for the last seven complete sequences and therefore get a visualization of the effect the trainings on the scores reached.

The section ‘Lernen’ (Learning) includes teaching videos. We based our teaching videos exactly on the WHO recommendations (World Health Organization, 2009a). Teaching videos were available on each gesture separately. Gestures which had to be executed with both left and right hand were included into one video. Furthermore, the user was able to watch a whole sequence on correct hand hygiene. Filming these sequences, we intentionally filmed the hand movements from the executer’s point of view as seeing videos from the demonstrator’s point of view has shown to have a positive influence on learning (Fung, 2015; Nederveen et al., 2019).

Under the icon ‘Einstellungen’ (Settings) was a password-secured area where the questionnaires for the study were implemented and the application’s GUI could be changed into the control mode.

### 3.4.2 The control mode

In the control mode, the user was only able to use the teaching videos (see Fig. 2 (b)). This mode therefore excluded the parts of the app where the user was animated to actively perform the hand hygiene gestures.


Nur Notrufe
IDEAL PURE
TRAINING
MEIN PROFIL
LERNEN
EINSTELLUNGEN

(a)


Nur Notrufe
IDEAL PURE
LERNEN
EINSTELLUNGEN

(b)


11:22
Myos auswählen
DF:EE:98:5B:05:25
Vibriere
← Links
EE:13:19:77:B2:78
Vibriere
Rechts →
Starten
VERBINDEN

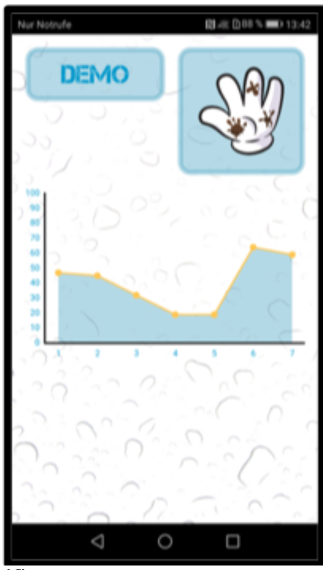
(c)


11:23
HANDINNENFLÄ-
CHEN
3

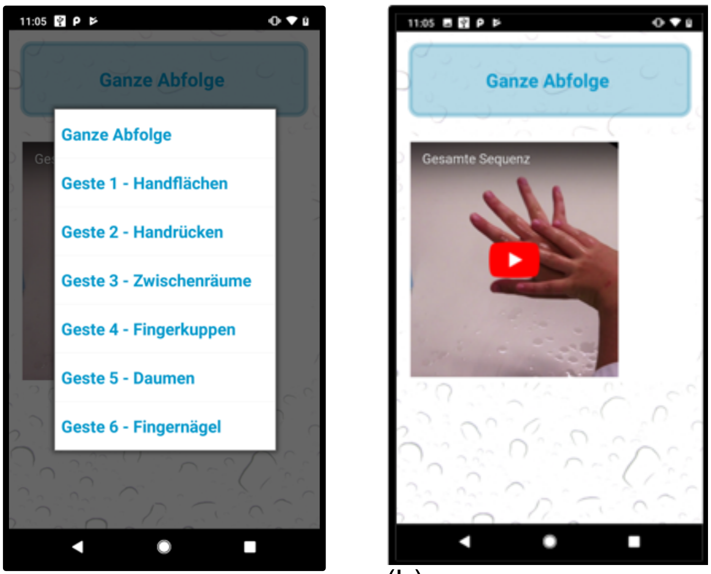
(d)


11:24
71
84
75
SCORE: 81
HAUPTMENÜ

(e)


Nur Notrufe
DEMO

(f)




(g) (h)

**Fig. 5:** Graphical user interfaces (GUIs) of the application IdealPure

- with the GUI of the test phase (a) and
- the GUI of the control phase (b),
- when connecting the Myo® armbands for training (c),
- an example of a gesture which is supposed to be performed while the picture is shown (d),
- training result shown after one completed sequence (e),
- the last seven total results (f),
- learning videos from which a user can choose (g) and
- an example of a learning video (h).

The illustration of the hand hygiene gesture shown in (d) is adapted from the poster “How to handrub” (World Health Organization, 2009).

As the study was conducted in Germany, the interface shown in the screenshot appears in German.

# 4. This work

In this work, we evaluate the mobile application IdealPure with a group of healthcare professionals in a randomized crossover study. The aim of the study is to evaluate if a mobile application can support learning of hand hygiene technique, which in turn might improve compliance.

## 4.1 The hypotheses

We aim to test three hypotheses:

**Hypothesis 1 (H1):** Knowledge on hand rub technique will improve when using the app Idealpure with and without immediate direct feedback through the wearable devices. We assume a greater learning effect when using direct feedback through the wearable device in comparison to learning through videos only.

**Hypothesis 2 (H2):** Attitude and behavior regarding hand hygiene will not change, as it is not part of the training process. Specifically, the self-perceived compliance should not change.

**Hypothesis 3 (H3):** After using IdealPure, study participants should consider mobile applications as an effective learning tool to improve hand hygiene.

## 4.2 Inclusion and exclusion criteria

Inclusion criteria were:

- Medical professional (i.e. registered nurse, physician, last-year medical student in his/her practical year or physiotherapist)
- General smartphone proficiency which means the ability to use a mobile application and the wearable sensors

Exclusion criteria were:

- Dependence on the study staff or the managing department, including employment
- Not sui juris
- Not being able to follow the instructions of the study staff

## 4.3 Recruitment

We recruited a group of 21 study participants that did meet the inclusion criteria and did not violate the exclusion criteria. After providing informed consent, participants were assigned through block randomization with block size 4 to either the test or the control phase first.
One participant had to be excluded retrospectively as the inclusion criteria were falsely claimed. In addition, one data set was not collected due to technical failure. Thus, data collection was completed for a total of 19 participants (10 test, 9 control).

All participants received a compensation of €50 for participating in the study.

## 4.4 Study design

The mobile application IdealPure was evaluated in a randomized crossover study. Participants were convenience-sampled from health-care professionals in Aachen, Germany.

Participants were randomly assigned to either the test- or control-phase for two weeks, followed by two weeks in the other phase (Fig. 6).

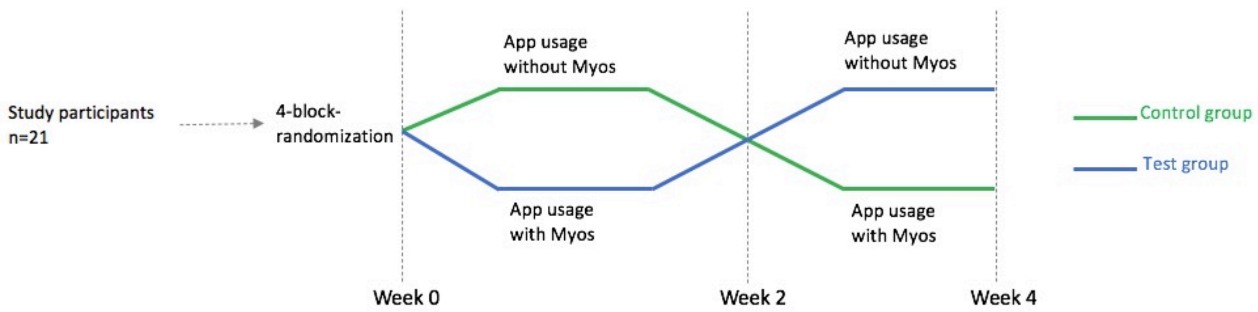



**Fig. 6:** The process of randomization showing the change in phases of the study in both groups before and after cross-over

All participants were supplied with an Android® smartphone with a pre-installed version of the mobile application IdealPure and a pair of two Myo® gesture control armbands. We abstained from using private mobile phones to ensure compatibility between smartphones and the application.

Additionally, the participants were supplied with three charging cables for the phone and the two gesture control armbands, a charger with multiple USB ports and an external battery.

The participants were asked to use the application at least twice a week in each phase. For this purpose, they received a short manual on the app with its functions and also possible bugs and how to solve them. This manual can be found in the addendum.

Each participant filled out a questionnaire before starting the first phase (t0), when switching between the two phases (t1), and after completing the second phase (t2).
Using the data that we acquired through these questionnaires, we compared the impact of a two weeks usage of the application on knowledge, motivation and attitude regarding hand hygiene between the participants of the two phases to test the hypothesis (H1-3) listed above.

During the test-phase, participants were asked to train the hand rubbing technique with the use of gesture control armbands and tutorial videos. The gesture control armbands provided the data necessary for the evaluation of the performance quality. Therefore, participants were able to use the full functionality of the app (Fig. 5a, c-h):

1. Learning videos: Participants could watch videos on how to perform each sub-gesture of the hand-rub technique individually, or the full procedure.
2. Training: Participants could start a training during which their arm movement and muscle activity was recorded by the two smart armbands and evaluated immediately afterwards. A score of performance for each individual gesture and in total was calculated in percent correct and presented at the end of the whole sequence.
3. Profile: Participants could see their progress in a profile page showing the score for the last seven training sessions.

During the control-phase, participants were asked to train by tutorial videos only and the application was restricted accordingly (Fig. 5b, h).

The participants were informed that all data was gathered anonymously and no personal data was stored along with questionnaire data at any point in time. Personal data was only used for management of the study in analogue form.

## 5. Study data

### 5.1 The questionnaire

The questionnaire gathered information on demography, knowledge of and attitude towards hand hygiene as well as compliance and motivation. All questions were implemented into the application IdealPure.
At t0, all study participants answered questions to collect information on the demography regarding gender, profession, years of practical experience, use of alcohol-based hand sanitizer and their past training of hand hygiene.

For analysis of the free text answers, the author created a bottom-up coding tree of positive and negative feedback individually. Duplicates between t1 and t2 answers from the same participant were only counted once. Number of answers matching to a code (and categories thereof) are reported in total (across test and control and both timepoints) and individually for test and control groups at t1. Timepoint t2 is not investigated individually, as a carry-over effect in the replies from t1 was observed in multiple instances.

### 5.2 Performance scores

Thus, the data collected in advance and the machine learning developed upon these data (s. above), we had to acknowledge that the data collected by IdealPure was not a reflection of the quality of executed gestures and could not provide additional data for analysis. While performance-scores of each participant were recorded, variation within and between individuals was high. At t0, t1 and t2 the usage of Myo® armbands was supervised which showed that the scores a user achieved did not reflect the actual performance quality.

We therefore refrain from reporting this data.

## 5.3 Statistical Analysis

Due to the experimental nature of the study and the low number of participants, only descriptive statistics such as mean and variance are reported.

In addition to reporting results for each group separately, we also provide overall (‘Total’) values, which are averages across all participants at each time point. These totals are presented only to give context — to show the general level of the outcomes and possible trends in the full sample. All conclusions, however, are strictly based on the group-specific analyses.

# 6. Results

Since the automated data analysis could not achieve any usable results in the everyday use, we cannot make any statements about the participants' knowledge based on the values recorded by the Myo® armbands, as already mentioned above.
Furthermore, other technical problems such as unstable internet connectivity and connectivity issues of the Myo® armbands limited our data usable for meaningful analysis.

## 6.1 Demography

21 study participants were included into the study (Tab. 1). A total of 19 datasets were evaluated in this study due to the exclusion of one participant and the loss of one data set. A total of 14 (74 %) female and 5 (26 %) male health professionals participated in the study. All participants confirmed the use of alcohol-based hand sanitizer during their work routine. 16 (84 %) of all participants indicated that they had professional training in hand hygiene at some point. However, only 7 (37 %) study participants confirmed a professional training in hand hygiene during the last three years.

**Tab. 1:** Baseline general study participants features

| | **Test Group** | **Control Group** | **Total** |
|---|---|---|---|
| **Study participants (n)** | **10** | **9** | **19** |
| Male | 4 (40 %) | 1 (11 %) | 5 (26 %) |
| Female | 6 (60 %) | 8 (89 %) | 14 (74 %) |
| **Profession** | | | |
| Registered nurse | 1 (10 %) | 2 (22 %) | 3 (16 %) |
| Physician | 3 (30 %) | 1 (11 %) | 4 (21 %) |
| Last year medical student (intern) | 2 (20 %) | 3 (33 %) | 5 (26 %) |
| Physiotherapist | 4 (40 %) | 3 (33 %) | 7 (37 %) |
| **Experience** | | | |
| < 10 years | 7 (70 %) | 4 (44 %) | 11 (58 %) |
| 11 - 20 years | 1 (10 %) | 0 (0 %) | 1 (5 %) |
| 21 - 30 years | 1 (10 %) | 5 (56 %) | 6 (32 %) |
| 31 - 40 years | 1 (10 %) | 0 (0 %) | 1 (5 %) |
| > 40 years | 0 (0 %) | 0 (0 %) | 0 (0 %) |
| **Hand Hygiene** | | | |
| Used alcohol-based hand sanitizer for hand dis-infection | 10 (100 %) | 9 (100 %) | 19 (100 %) |
| Had professional training ever | 9 (90 %) | 7 (78 %) | 16 (84 %) |
| Had professional training in the last three years | 5 (50 %) | 2 (22 %) | 7 (37 %) |

6.2 Knowledge of hand hygiene standard (H1)

Before training with the application, the mean of WHO gestures assigned in correct order was 1.79 ± 1.13, 1.44 ± 1.24 and 2.10 ± 0,99 out of six in the total study population and in the control and test group respectively. Both the control group and the test group showed a tendency towards improvement after using the application for two weeks.
At t1, the participants labeled 4.78 ± 1.99 and 5.00 ± 1.33 gestures correctly in the control and test group respectively. After ending the training with the gesture control armbands, the test group's knowledge appeared to decline slightly to 4.70 ± 1.77. In contrast to the

test group, the control group showed indications of a further increase in knowledge to 5.56 ± 0.88 when practicing with the gesture control armbands (Fig. 7).

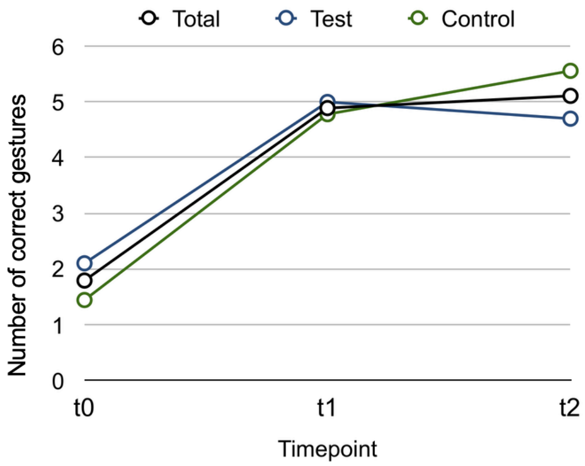



**Fig. 7:** Development of knowledge: number of WHO gestures placed in the correct order at t0 (week 0), t1 (after two weeks) and t2 (after four weeks) in all study participants and control and test group separately.

6.3 Self-report on adherence and attitude towards hand hygiene (H2)

An overview of the reported adherence and attitude towards hand hygiene can be found in Tab. 2.

**Tab. 2:** Self-report on adherence and attitude towards hand hygiene.

| | | Test | | Control | | Total | |
|---|---|---|---|---|---|---|---|
| | **Time-point** | **Mean** | **Standard deviation** | **Mean** | **Standard deviation** | **Mean** | **Standard deviation** |
| **Compliance** | **t0** | 4.20 | 0.92 | 4.22 | 1.62 | 4.21 | 1.32 |
| | **t1** | 4.60 | 0.84 | 4.00 | 0.94 | 4.32 | 0.95 |
| | **t2** | 4.80 | 1.03 | 4.22 | 1.13 | 4.53 | 1.12 |
| **Effort** | **t0** | 2.30 | 1.64 | 2.67 | 1.05 | 2.47 | 1.39 |
| | **t1** | 3.10 | 1.91 | 2.89 | 1.59 | 3.00 | 1.76 |
| | **t2** | 2.50 | 1.78 | 2.89 | 1.66 | 2.68 | 1.73 |
| **Importance for head of department** | **t0** | 5.10 | 1.20 | 3.67 | 2.21 | 4.42 | 1.92 |
| | **t1** | 4.80 | 1.55 | 3.56 | 2.06 | 4.21 | 1.93 |
| | **t2** | 4.80 | 1.03 | 3.67 | 1.63 | 4.26 | 1.48 |
| **Importance personal** | **t0** | 5.40 | 0.70 | 5.22 | 1.23 | 5.32 | 1.00 |
| | **t1** | 5.50 | 0.85 | 5.11 | 0.99 | 5.32 | 0.95 |
| | **t2** | 5.30 | 1.06 | 5.11 | 0.87 | 5.21 | 0.98 |
| **Relevance in job** | **t0** | 5.60 | 0.70 | 5.56 | 0.50 | 5.58 | 0.61 |
| | **t1** | 5.70 | 0.48 | 5.22 | 0.79 | 5.47 | 0.70 |
| | **t2** | 5.40 | 0.84 | 5.33 | 0.67 | 5.37 | 0.76 |

6.3.1 Compliance with hand hygiene technique

When asked how often participants performed hand disinfection as recommended by WHO, the mean showed a slight increase when analyzing both groups together (t0 = 4.21 ± 1.32, t1 = 4.32 ± 0.95, t2 = 4.53 ± 1.12) or test group (t0 = 4.20 ± 0.92, t1 = 4.60 ± 0.84, t2 = 4.80 ± 1.03) individually, but no increase in the control (t0 = 4.22 ± 1.62, t1 = 4.00 ± 0.94, t2 = 4.22 ± 1.13) (Fig. 8).

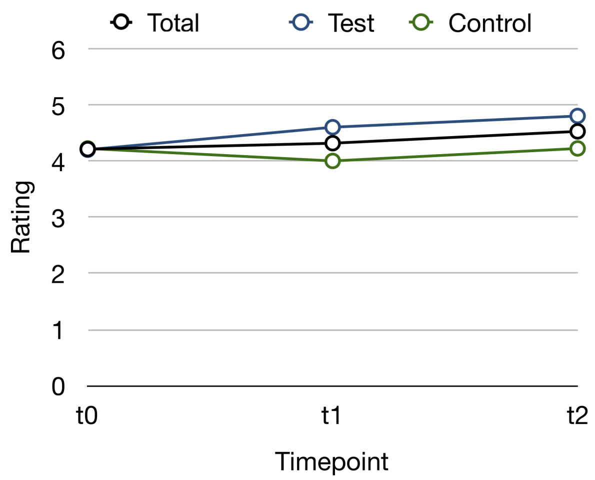



**Fig. 8:** Self-reported compliance with hand hygiene recommendations

6.3.2 Compliance with the five moments of hand hygiene

The estimated percentage of hand hygiene performance when indicated showed a pattern as demonstrated in Fig. 9 in total (t0 = 85 % ± 12.47, t1 = 85 % ± 12.47, t2 = 87 % ± 9.46), control (t0 = 80 % ± 13.39, t1 = 77 % ± 12.25, t2 = 84 % ± 9.06) and test group (t0 = 89 % ± 9.66, t1 = 92 % ± 6.55, t2 = 90 % ± 8.96).

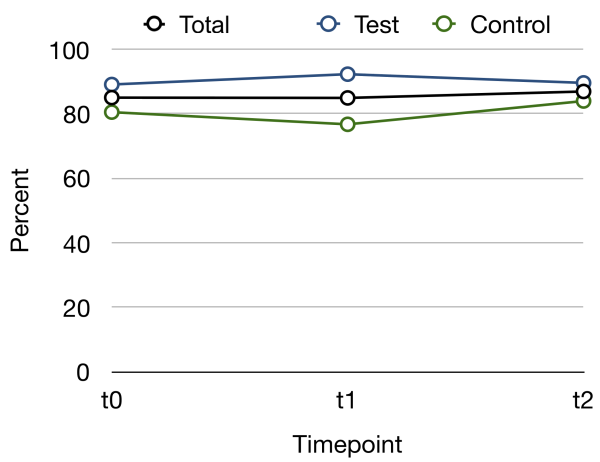



**Fig. 9:** Self-reported compliance with the five moments of hand hygiene

### 6.3.3 Effort to perform good hand hygiene

Regarding the effort to perform good hand hygiene, the effort was evaluated higher at t1 in the total (t0 = 2.47 ± 1.39, t1 = 3.00 ± 1.76, t2 = 2.68 ± 1.73), control (t0 = 2.67 ± 1.05, t1 = 2.89 ± 1.59, t2 = 2.89 ± 1.66) and test (t0 = 2.30 ± 1.67, t1 = 3.10 ± 1.91, t2 = 2.50 ± 1.78). In total and test group however, the effort at t2 was rated lower than at t1 (Fig. 10).

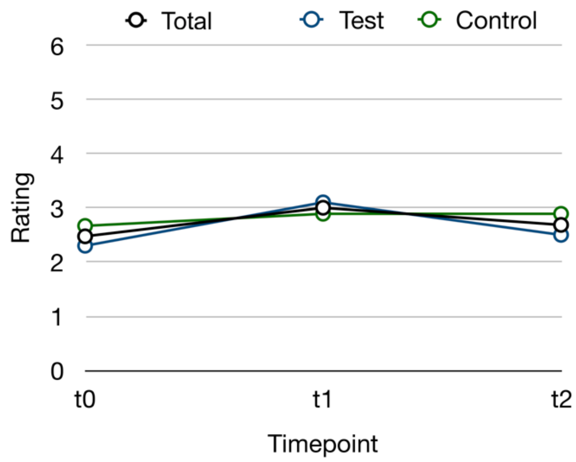



**Fig. 10:** Rated effort to perform good hand hygiene

### 6.3.4 Importance of hand hygiene

The importance of optimal hand hygiene for oneself stayed at a high level throughout the study and only showed minimal deviations for total (t0 = 5.32 ± 1.00, t1 = 5.32 ± 0.95, t2 = 5.21 ± 0.98), control (t0 = 5.22 ± 1.23, t1 = 5.11 ± 0.99, t2 = 5.11 ± 0.87) and test (t0 = 5.40 ± 0.70, t1 = 5.50 ± 0.85, t2 = 5.30 ± 1.06) group.

The importance for the supervisor of the department of total (t0 = 4.42 ± 1.92, t1 = 4.21 ± 1.93, t2 = 4.26 ± 1.48), control (t0 = 3.67 ± 2.21, t1 = 3.56 ± 2.06, t2 = 3.67 ± 1.63) and test (t0 = 5.10 ± 1.20, t1 = 4.80 ± 1.55, t2 = 4.80 ± 1.03) group showed a difference between test and control group, but no difference within the groups over time.

In contrast, the personal comfort when reminding colleagues of the hand hygiene routines for total (t0 = 2.47 ± 1.50, t1 = 2.53 ± 1.58, t2 = 2.68 ± 1.38) did not change, while the control group reported more comfort (t0 = 1.78 ± 1.40, t1 = 2.22 ± 1.40, t2 = 2.78 ± 1.55) and the test group reported less comfort (t0 = 3.10 ± 1.29, t1 = 2.80 ± 1.69, t2 = 2.60 ± 1.17) over time.

### 6.3.5 Reasons for non-compliance

All study participants were asked to tick reasons for not performing hand hygiene (Tab. 3). The main reason for non-compliance was the participants' reported forgetfulness, followed by products not in convenient location or out of products.
There was a slight decrease in the test group for the reason forgetfulness in the test group from t0 (6) to t1 and t2 (4). In the control group the total for this answer stays at a level of 6 at all times.
Notably, the number of replies for 'out of product' was 0 at t0 for all groups and increased to a total of 7 at t2 during the study. The replies for 'product not at convenient location' showed the inverse trend, starting with a total of 8 votes at t0 and ending with 2 votes at t2.

## 6.4 Expected effectiveness of different tools for improving hand hygiene (H3)

Expected effectiveness of any of the queried means of improving hand hygiene did not change. Specifically, the expected efficiency of mobile applications as a training tool in hand hygiene showed a slight increase at t1 for all groups, but also slightly decreased at t2 resulting in a value close to the starting point.

**Tab. 3:** Declared reasons for non-compliance of hand hygiene.

| **I sometimes do not perform hand disinfection because: (Ich führe ab und zu keine Händedesinfektion durch, weil/ aufgrund von):** | **Time-point** | **Test Group** | **Control Group** | **Total** |
|---|---|---|---|---|
| too busy (zu ausgelastet) | t0 | 1 (10 %) | 2 (22 %) | 3 (16 %) |
| | t1 | 1 (10 %) | 4 (44 %) | 5 (26 %) |
| | t2 | 1 (10 %) | 3 (33 %) | 4 (21 %) |
| forgot or did not think about it (vergessen oder nicht daran gedacht) | t0 | 6 (60 %) | 6 (67 %) | 12 (63 %) |
| | t1 | 4 (40 %) | 6 (67 %) | 10 (53 %) |
| | t2 | 4 (40 %) | 6 (67 %) | 10 (53 %) |
| out of product(s) (kein Händedesinfektionsmittel vorhanden) | t0 | 0 (0 %) | 0 (0 %) | 0 (0 %) |
| | t1 | 4 (40 %) | 2 (22 %) | 6 (32 %) |
| | t2 | 4 (40 %) | 3 (33 %) | 7 (37 %) |
| product(s) not in convenient location (kein Händedesinfektionsmittel an geeigneter Stelle vorhanden) | t0 | 5 (50 %) | 3 (33 %) | 8 (42 %) |
| | t1 | 5 (50 %) | 1 (11 %) | 6 (32 %) |
| | t2 | 2 (20 %) | 0 (0 %) | 2 (11 %) |
| product(s) or practice damages my skin (das Händedesinfektionsmittel oder die Prozedur schädigen meine Haut) | t0 | 1 (10 %) | 1 (11 %) | 2 (11 %) |
| | t1 | 0 (0 %) | 1 (11 %) | 1 (5 %) |
| | t2 | 0 (0 %) | 2 (22 %) | 2 (11 %) |
| do not like product(s) available; please state why (ich mag die verfügbaren Händedesinfektionsmittel nicht, weil) | t0 | 0 (0 %) | 1 (11 %) | 1 (5 %) |
| | t1 | 0 (0 %) | 0 (0 %) | 0 (0 %) |
| | t2 | 0 (0 %) | 0 (0 %) | 0 (0 %) |
| other (andere) | t0 | 1 (10 %) | 0 (0 %) | 1 (5 %) |
| | t1 | 1 (10 %) | 2 (22 %) | 3 (16 %) |
| | t2 | 1 (10 %) | 1 (11 %) | 2 (11 %) |

**Tab. 4:** Effectiveness of any of the queried means of improving hand hygiene for test, control and total at t0, t1 and t2.

| | | Test | | Control | | Total | |
|---|---|---|---|---|---|---|---|
| | **Time-point** | **Mean** | **Stan-dard devia-tion** | **Mean** | **Stan-dard devia-tion** | **Mean** | **Standard deviation** |
| | **t0** | 4.60 | 1.84 | 4.89 | 0.87 | 4.74 | 1.45 |
| **A** | **t1** | 4.60 | 0.97 | 5.11 | 0.99 | 4.84 | 1.01 |
| | **t2** | 4.60 | 1.17 | 4.56 | 0.68 | 4.58 | 0.96 |
| | **t0** | 5.70 | 0.67 | 5.11 | 1.10 | 5.42 | 0.96 |
| **B** | **t1** | 5.80 | 0.42 | 5.56 | 0.68 | 5.68 | 0.58 |
| | **t2** | 5.60 | 0.97 | 5.44 | 0.83 | 5.53 | 0.90 |
| | **t0** | 4.30 | 1.25 | 4.11 | 1.79 | 4.21 | 1.55 |
| **C** | **t1** | 4.40 | 1.26 | 4.44 | 1.26 | 4.42 | 1.26 |
| | **t2** | 5.00 | 0.94 | 4.11 | 1.59 | 4.58 | 1.39 |
| | **t0** | 4.70 | 1.34 | 4.78 | 1.55 | 4.74 | 1.45 |
| **D** | **t1** | 4.80 | 1.40 | 4.89 | 1.52 | 4.84 | 1.46 |
| | **t2** | 4.80 | 1.23 | 4.78 | 1.40 | 4.79 | 1.32 |
| | **t0** | 3.80 | 1.75 | 3.78 | 1.40 | 3.79 | 1.58 |
| **E** | **t1** | 4.20 | 1.75 | 4.11 | 1.45 | 4.16 | 1.61 |
| | **t2** | 4.00 | 1.56 | 3.78 | 1.23 | 3.89 | 1.41 |
| | **t0** | 4.90 | 0.99 | 4.33 | 1.56 | 4.63 | 1.34 |
| **F** | **t1** | 5.20 | 0.92 | 4.67 | 1.05 | 4.95 | 1.03 |
| | **t2** | 4.90 | 0.88 | 4.78 | 1.55 | 4.84 | 1.26 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **t0** | 4.50 | 1.65 | 4.44 | 1.42 | 4.47 | 1.54 |
| **G** | **t1** | 4.40 | 1.84 | 4.56 | 0.83 | 4.47 | 1.43 |
| | **t2** | 5.00 | 1.15 | 4.44 | 1.34 | 4.74 | 1.28 |
| | **t0** | 4.50 | 1.18 | 3.89 | 1.73 | 4.21 | 1.51 |
| **H** | **t1** | 4.50 | 1.18 | 4.22 | 0.79 | 4.37 | 1.01 |
| | **t2** | 4.70 | 1.06 | 4.11 | 1.10 | 4.42 | 1.12 |
| | **t0** | 4.00 | 1.94 | 2.78 | 1.40 | 3.42 | 1.80 |
| **I** | **t1** | 3.40 | 2.01 | 3.67 | 1.56 | 3.53 | 1.81 |
| | **t2** | 3.50 | 2.17 | 3.00 | 1.49 | 3.26 | 1.88 |

A) Leaders and senior managers at your institution support and openly promote hand hygiene.
B) The health-care facility makes alcohol-based hand rub available at each point of care.
C) Hand hygiene posters are displayed at point of care as reminders.
D) Each health-care worker receives education on hand hygiene.
E) Every health-care worker gets the opportunity of autonomous training hand hygiene with the help of a mobile application. Clear and simple hand hygiene instructions are made visible for every health-care worker.
F) Clear and simple hand hygiene instructions are made visible for every health-care worker.
G) Health-care workers regularly receive feedback on their hand hygiene performance.
H) You always perform hand hygiene as recommended (being a good example for your colleagues).
I) Patients are invited to remind health-care workers to perform hand hygiene.

## 6.5 Coding of free text items

Codings for positive and negative answers are reported individually. As the study was carried out in Germany, examples given in this section have been translated from German into English.

Codings of positive comments included, for example, ‘ease of use’, ‘fast learning’ and ‘fun’. Codings were further summarized into categories (Usability, Learning, Motivation, Media quality, directed feedback, basic information on HCAIs and general appreciation).

For instance ‘ease of use’ and ‘clear arrangement’ were included under the key heading ‘usability‘.
Negative comments were coded in an analogous manner.

The positive comments amounted to 26 codings for total across both study phases, and 9 and 6 for test and control at t1 respectively. The most commonly stated positive aspects of the application were ‘learning’ (9 total, 4 test at t1, 1 control at t2), ‘usability’ (7 total, 2 test at t1, 3 control at t1) and ‘quality of media’ (3 total, 2 test at t1, 1 control at t1) in both total and test at t1. The only notable positive aspect in the control group was usability (3 control at t1).
The only two major negative aspects of the application were ‘technical difficulties’ (8 total, 3 test at t1, 0 control at t1) and ‘invalid scores’ (5 total, 3 test at t1, 0 control at t1).

Overall, participants liked the application for its way of promoting hand hygiene and for the positive effect it had on hand hygiene. The most positive stated comment was that people were learning through the application, which is evidenced by the results of the questionnaires as reported above.

Positive comments included:

- ‘Constant training promotes the correct execution of hand disinfection’ and
- ‘Training under supervision’ and
- ‘Systematic training, i.e. the experience/participation’

In general, participants liked the usability even though facing technical difficulties and even though our application was unable to produce fully valid scores for the training with gesture control armbands.

Negative comments included:

- ‘I considered the accuracy of the Myo® gesture control armbands difficult to estimate as I had the feeling that it did not match the evolution’ and
- ‘Achieved percentage not robust’ and
- ‘Crashes at times’ and

- ‘Connection difficulties with Myo® armbands at times’

The complete list of the coding can be found in the Addendum, Tab. 1.

## 7. Discussion

### 7.1 General findings

The main finding of our study is that knowledge of the international standard defined by the WHO is extremely low, as it is reported in other publications (Zakeri et al., 2017). In contrast, both test and control group stated at the very beginning of the study (t0) that they mostly performed hand hygiene as recommended by the WHO. This finding is in line with other studies that showed that self-report is of low validity to measure hand hygiene (Haas and Larson, 2007).
However, both test and control groups achieved high improvement from t0 to t1, indicating that the training of hand hygiene even through simple means such as learning videos is highly effective.

Anecdotal evidence: During the study, a lot of participants told other people about the study. We got the impression that the participation in our study was proudfully reported, presumable due to the moral aspect of hand hygiene. One participant approached the study personal several months after the study ended. She shared that her co-workers had inquired why her hand hygiene execution was that accurate. This indicates that hand hygiene is an important issue to medical staff.

### 7.2 Knowledge on hand hygiene standard (H1)

Knowledge on hand hygiene increased in both test and control group between t0 and t1. In the test group, however, the knowledge decreased in the second phase, when training by videos only. In contrast, when the test group entered the second phase and started practicing with the gesture control armbands, their knowledge showed further improvement.
We assume that both groups improved due to the novelty of the application and the regular revision of content. The test group, however, had no further novelty effect in the second phase, when training with videos only. In the control group, the practice via gesture control armbands is still novel in the second phase and therefore this group had a novelty effect

in both study phases. The novelty effect is reported in learnings situations where new technologies are being introduced. Therefore new learning technologies with novelty features lead to a higher interest among users which lead to higher scorings when first introducing a software (Pisapia et al., 1993; Tsay et al., 2020).

For many years, learning videos have found their way into modern education to promote knowledge and specific skills. Even the tool as easy as watching short videos on one's smartphone can lead to improvement in knowledge as we could demonstrate in our study. This aligns with findings from Stewardson et al. (2014), whose controlled study showed that the SureWash video-measurement system significantly increased the number of correctly performed hand-hygiene poses per action, with sustained effects over time (Stewardson et. al., 2014).

We think that even though our hypothesis is not fully supported, these results show how a simple and inexpensive mobile application could lead to major improvement in hand hygiene knowledge if motivated correctly.

We therefore conclude that H1 is at least partially supported: Knowledge of hand hygiene techniques did increase when using the mobile application. However, no direct difference during phase 1 could be observed between the two groups, although the control group could further improve when using the gesture recognition armbands.

Still, to test this hypothesis, more studies with a higher number of study subjects seem essential.

### 7.3 Self-report on adherence and attitude towards hand hygiene (H2)

We expected no change in self-reported adherence and attitude towards hand hygiene. These parameters only changed slightly during the study phase. Most noticeable results were the importance of hand hygiene to the participant, within the work environment and the change in non-compliance as reported below.

### 7.3.1 Importance of hand hygiene

The importance of hand hygiene for the HCWs who participated in the study was high in both test and control group at all times of our study. This result allows only little conclusions about the overall importance of hand hygiene in general for HCWs. A selection bias is likely to have occurred in this study as only HCWs with a high interest in hygiene might have participated in our study.

Importance for the head of department was different in the two groups. A possible reason for this divergence could originate in the inhomogeneity of both groups. One of the major differences between both groups were their clinical experience. The test group consisted of people with less experience. Maybe at an early stage of HCWs careers they have a higher opinion of their head of department's interest in hygiene. Moreover, the topic of hand hygiene has become more and more important during the last years. This could have had an influence on the younger people's estimation.

The different change in the comfort of reminding colleagues with the comfort decreasing in the test group and increasing in the control group might be explained by the same phenomenon but does not support H2.

### 7.3.2 Reasons for non-compliance

The reasons for non-compliance show only little development. The self-reported forgetfulness increased during the study period. Likely the study participants were more critical as they are more aware of hand hygiene and realized how often they used to forget the hand hygiene.

The most obvious developments were the inverse trend for 'out of product' and 'product not at convenient location'. The increase of the reason 'out of product' could also be an increased awareness of hand hygiene. That might have caused participants to be more mindful when it comes to hand hygiene so that they have noticed that they were out of product. The decrease of 'product not at convenient location' might be caused by a higher willingness to perform hand hygiene.

As we did not aim to influence the participants' attitude and behavior regarding hand hygiene, H2 is supported. Nevertheless, the awareness of their own behavior might have increased.

## 7.4 Motivation towards using a mobile application (H3)

In both groups, motivation towards a mobile application as a tool to improve hand hygiene via autonomous training of staff shows a slight increase from t0 to t1 and a slight decrease from t1 to t2. Still these changes are only very marginal. Possibly, the novelty of the application leads to a higher motivation for that kind of training. But participants also faced a lot of technical difficulties while using the application for a longer time, especially with the gesture control armbands.

As especially these technical difficulties must have affected motivation towards using a mobile application as a learning tool for hand hygiene negatively, we think that a technically more mature application might potentially increase motivation in contrast to a research prototype. We therefore think that our hypothesis is not disproved yet. But to convince people of the application, it needs further improvement.

## 8. Limitations

Our study was mainly explorative investigating the possibility of using a mobile application with learning videos and gesture control armbands to improve knowledge on hand hygiene. Therefore, only a small number of study participants were included in this study. For that reason, our findings can only give indications that this form of training might be a promising tool to practice hand hygiene.

Furthermore, a high number of technical difficulties did arise during the study, like connectivity difficulties with the gesture control armbands or the internet. Especially the evaluation of disinfection gestures via gesture control armbands was not perceived as reliable by the study participants. While Kutafina et al. reported a high recognition rate, these tests were done in a controlled laboratory setting (Kutafina et al., 2016). Performance of the participants and usage of the devices varied which led to lower reliability of the scoring algorithm. This was also observed by the study personnel during the face-to-face sessions at t0, t1 and t2. Therefore, we could only measure knowledge via questionnaire.

Due to randomization, slightly imbalanced groups were compared in this study (gender-wise, experience-wise).

An important limitation of this study is the short period of time in which we measured our results. Overcoming the novelty effect of a mobile application is a challenge many developers are facing (Tsay et al., 2020). Other studies however also suggest that the familiarity not the novelty enhance the memorized facts (Poppenk et al., 2010). Therefore, long term data on the usage data and the gained knowledge we aimed to teach not only from weeks or months of usage, but of years are needed.

Furthermore, to evaluate the effect of this form of training on the burden of HCAIs, measurements of the impact on the long-term incidence of HCAIs is needed.

However, the proposed intervention only aims at training hand hygiene technique, and we were able to achieve a high gain in knowledge through our application IdealPure.

## 9. Comparison to state of the art

Only very limited literature is available on the training of hand hygiene technique using wearable devices.

The company SureWash® provides solutions for training hand hygiene based on the WHO standard. They all use a video camera to measure hand motions and provides the user with real time feed-back (Higgins and Hannan, 2013).

Two of the SureWash® systems use a stationary camera (Surewash, 2021). In several studies an improvement of hand hygiene quality and quantity could be achieved (Higgins and Hannan, 2013; Lacey et al., 2016). Still these systems are cumbersome, limited in mobility and might raise privacy concerns due to the camera use.

At the end of 2019, when our study was already closed, a mobile application called SureWash® APP was released. This mobile application uses the smartphone's camera to detect hand movement. The mobile phone is placed on top of a surface and the user has to perform hand hygiene. When the user performs the correct movement for a defined time, the next movement can be performed. By January 2025, no scientific literature has been published to evaluate the effect on hand hygiene quality of this intervention, or on its performance (SureWash, 2025). Furthermore, when testing the SureWash® app for this work, in multiple sessions random gestures were recognized as being correct. This indicates that this current commercially available system is prone to errors as well.

Also, in contrast, our application aims to evaluate the execution of each hand hygiene gesture individually. The user receives feedback on the quality of the performed gesture. Moreover, educational videos are implemented in IdealPure.

## 10. Conclusion

Behavioral research shows that learning through individual experience is of higher impact than formal education itself when it comes to hand hygiene behavior (Nicol et al., 2009).
We were not able to fully prove our hypotheses, especially due to technical difficulties. Nonetheless, our results give reason to assume that a mobile application can be a time-efficient and easy to use tool for improving HCWs' knowledge on correct hand disinfection. Training hand disinfection through a mobile application even without gesture control arm-bands achieves an improvement in knowledge about the execution of correct hand hygiene. However, our machine learning technology needs further improvement to give the user reliable feedback of the quality of the gestures performed.
At this time, our mobile application does not replace in-service lectures or the display of educational posters at medical institutions. Still we think that after major technical improvement, it could be used as a supplementary form of teaching in the future.
Even by 2025, there is no other technology available that could fully replace practical training supervised by a trained professional.

## 11. Conflict of interest

The author declares that there are no conflicts of interest related to the Myo® armband or the mobile application IdealPure. No financial or non-financial support was received from the manufacturers, and no commercial interests are involved. The research was conducted independently at the Institute of Medical Informatics, RWTH Aachen University.

## 12. References

AMBOSS GmbH (2025), AMBOSS GmbH, https://next.amboss.com/de/, accessed on 15.01.2025

Boscart VM, Gorski S, Holliday PJ, Hufton G, Levchenko AI, Marquez-Chin C, McGilton K, Momen K, Tsang M, Fernie GR. Advanced technologies to curb healthcare-associated infections. Healthc Pap. 2009; 9: 51-55 discussion 60-62

Boscart VM, McGilton KS, Levchenko A, Hufton G, Holliday P, Fernie GR. Acceptability of a wearable hand hygiene device with monitoring capabilities. J Hosp Infect. 2008; 70: 216-222

Boyce JM, Pittet D; Healthcare Infection Control Practices Advisory Committee; HICPAC/SHEA/APIC/IDSA Hand Hygiene Task Force. Guideline for Hand Hygiene in Health-Care Settings. Recommendations of the Healthcare Infection Control Practices Advisory Committee and the HICPAC/SHEA/APIC/IDSA Hand Hygiene Task Force. Society for Healthcare Epidemiology of America/Association for Professionals in Infection Control/Infectious Diseases Society of America. MMWR Recomm Rep. 2002 Oct 25; 51:1-45, quiz CE1-4.

Centers for Disease Control and Prevention (2025), Handwashing in Communities: Clean Hands Save Lives | CDC, https://www.cdc.gov/handwashing/index.html, accessed on 17.05.2022

Centers for Disease Control and Prevention (2021a), Current HAI Progress Report, https://www.cdc.gov/hai/data/portal/progress-report.html, accessed on 24.05.2021

Centers for Disease Control and Prevention (2021b), COVID-19 and Your Health, https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/prevention.html, accessed on 24.5.2021

Colbjørnsen, T. Der Hawthorne-Effekt oder die Human-Relations-Theorie: Über die experimentelle Situation und ihren Einfluss. In: Larsen, SU and Zimmermann E, Publisher. Theorien und Methoden in den Sozialwissenschaften, Wiesbaden: VS Verlag für Sozialwissenschaften, 2003: 131–143

Courtemanche & Associates, 2017: Hand Hygiene Questionnaire. http://www.courtemancheassocs.com/Free%20Library/Hand%20Hygiene%20Staff%20Questionaire.doc, accessed on 27.8.2020

European Centre for Disease Prevention and Control, 2020: Transmission of COVID-19, https://www.ecdc.europa.eu/en/covid-19/latest-evidence/transmission, accessed on 11.2.2021

Fung, FM. Using First-Person Perspective Filming Techniques for a Chemistry Laboratory Demonstration To Facilitate a Flipped Pre-Lab, J. Chem. Educ. 2015; 92: 1518–1521

Haas JP, Larson EL. Measurement of compliance with hand hygiene. J Hosp Infect. 2007; 66: 6-14

Hagel S, Reischke J, Kesselmeier M, Winning J, Gastmeier P, Brunkhorst FM, Scherag A, Pletz MW. Quantifying the Hawthorne Effect in Hand Hygiene Compliance Through Comparing Direct Observation With Automated Hand Hygiene Monitoring. Infect Control Hosp Epidemiol. 2015; 36: 957-62

Hattie J, Timperley H. The Power of Feedback, Review of Educational Research. 2007; 77: 81-112

Higgins A, Hannan MM. Improved hand hygiene technique and compliance in healthcare workers using gaming technology. J Hosp Infect. 2013; 84: 32-37

Kutafina E, Laukamp D, Bettermann R, Schroeder U, Jonas SM. Wearable Sensors for eLearning of Manual Tasks: Using Forearm EMG in Hand Hygiene Training. Sensors (Basel). 2016; 16: 1221

Lacey G, Corr M, Morrow H, McQueen A, Cameron F, Connolly C. The Impact of Structured Incentives on the Adoption of a Serious Game for Hand Hygiene Training in a Hospital Setting. Stud Health Technol Inform. 2016; 220: 179-184

Larson E, Killien M. Factors influencing handwashing behavior of patient care personnel. Am J Infect Control. 1982; 10: 93-99

Larson E, Kretzer EK. Compliance with handwashing and barrier precautions. J Hosp Infect. 1995; 30: 88-106

Loudon I. Ignaz Phillip Semmelweis' studies of death in childbirth. J R Soc Med. 2013; 106: 461-463

McCarney R, Warner J, Iliffe S, van Haselen R, Griffin M, Fisher P. The Hawthorne Effect: a randomised, controlled trial. BMC Med Res Methodol. 2007; 7: 30

Nederveen JP, Thomas ACQ, Parise G. Examining the first-person perspective as appropriate prelaboratory preparation. Adv Physiol Educ. 2019; 43: 317-323

Nicol PW, Watkins RE, Donovan RJ, Wynaden D, Cadwallader H. The power of vivid experience in hand hygiene compliance. J Hosp Infect. 2009; 72: 36-42

Pires D, Bellissimo-Rodrigues F, Soule H, Gayet-Ageron A, Pittet D. Revisiting the WHO "How to Handrub" Hand Hygiene Technique: Fingertips First? Infect Control Hosp Epidemiol. 2017; 38: 230-233

Pisapia J, Schlesinger J, Parks A. Learning Technologies in the Classroom: Review of the Literature. Virginia State Dept. of Education, Richmond. 1993; passim

Pittet D, Allegranzi B, Sax H, Dharan S, Pessoa-Silva CL, Donaldson L, Boyce JM; WHO Global Patient Safety Challenge, World Alliance for Patient Safety. Evidence-based model for hand transmission during patient care and the role of improved practices. Lancet Infect Dis. 2006; 6: 641-52

Pittet D, Hugonnet S, Harbarth S, Mourouga P, Sauvan V, Touveneau S, Perneger TV. Effectiveness of a hospital-wide programme to improve compliance with hand hygiene. Infection Control Programme. Lancet. 2000; 356: 1307-1312

Ponce LB, Méndez JAJ, García-Peñalvo FJ. Analysis of certificated mobile application for medical education purposes, Second International Conference on Technological Ecosystem for Enhancing Multiculturality, conference paper, New York, NY, USA, 2014: 13-17

Poppenk J, Köhler S, Moscovitch M. Revisiting the novelty effect: when familiarity, not novelty, enhances memory. J Exp Psychol Learn Mem Cogn. 2010; 36: 1321-1330.

Randle J, Clarke M, Storr J. Hand hygiene compliance in healthcare workers. J Hosp Infect. 2006; 64: 205-209.

Reilly JS, Price L, Lang S, Robertson C, Cheater F, Skinner K, Chow A. A Pragmatic Randomized Controlled Trial of 6-Step vs 3-Step Hand Hygiene Technique in Acute Hospital Care in the United Kingdom. Infect Control Hosp Epidemiol. 2016; 37: 661-666.

Robert Koch-Institut (2024), Empfehlungen des RKI zu Hygienemaßnahmen im Rahmen der Behandlung und Pflege von Patienten mit einer Infektion durch Monkeypox-Viren in Einrichtungen des Gesundheitswesens, https://www.rki.de/DE/Content/InfAZ/A/Affenpocken/Hygiene.html?nn=16732866#doc16733606bodyText2, accessed on 19.12.2024

Robert Koch-Institut (2020a), Epidemiologisches Bulletin - Aktuelle Daten und Informationen zu Infektionskrankheiten und Public Health.

Robert Koch-Institut (2020b), RKI - Coronavirus SARS-CoV-2 - Empfehlungen des RKI zu Hygienemaßnahmen im Rahmen der Behandlung und Pflege von Patienten mit einer Infektion durch SARS-CoV-2, https://www.rki.de/DE/Content/InfAZ/N/Neuartiges_Coronavirus/Hygiene.html, accessed on 11.2.2021.

Robert Koch-Institut, Händehygiene in Einrichtungen des Gesundheitswesens: Empfehlung der Kommission für Krankenhaushygiene und Infektionsprävention (KRINKO) beim Robert Koch-Institut (RKI), Bundesgesundheitsblatt - Gesundheitsforschung - Gesundheitsschutz. 2016; 59: 1189–1220.

Rosenfeldt Knudsen A, Bo Hansen M, Kjølseth Møller J. Individual hand hygiene improvements and effects on healthcare-associated infections: a long-term follow-up study using an electronic hand hygiene monitoring system. J Hosp Infect. 2023; 135: 179-185.

Sawers, P. (2020, June 30). Google acquires smart glasses company North, whose Focals 2.0 won’t ship. TechCrunch. https://techcrunch.com/2020/06/30/google-acquires-smart-glasses-company-north-whose-focals-2-0-wont-ship (accessed September 2, 2025).

Sax H, Allegranzi B, Uçkay I, Larson E, Boyce J, Pittet D. 'My five moments for hand hygiene': a user-centred design approach to understand, train, monitor and report hand hygiene. J Hosp Infect. 2007; 67: 9-21.

Sax H, Uçkay I, Richet H, Allegranzi B, Pittet D. Determinants of good adherence to hand hygiene among healthcare workers who have extensive exposure to hand hygiene campaigns. Infect Control Hosp Epidemiol. 2007; 28: 1267-1274.

Semmelweis IP. Die Aetiologie, der Begriff und die Prophylaxis des Kindbettfiebers, Hartleben: 1861: passim.

Stewardson, A. J., Iten, A., Camus, V., Gayet-Ageron, A., Caulfield, D., Lacey, G., & Pittet, D. (2014). Efficacy of a new educational tool to improve hand-rubbing technique amongst healthcare workers: A controlled, before–after study. PLOS ONE, 9, Article e105866.

Sun J, He WT, Wang L, Lai A, Ji X, Zhai X, Li G, Suchard MA, Tian J, Zhou J, Veit M, Su S. COVID-19: Epidemiology, Evolution, and Cross-Disciplinary Perspectives. Trends Mol Med. 2020; 26: 483-495

SureWash (2025), SureWash Research Papers, https://surewash.com/research-papers/, accessed on 15.01.2025

Surewash (2025), SureWash Hand Hygiene Training Technology - Surewash, https://surewash.com/, accessed on 15.01.2025

Swoboda SM, Earsing K, Strauss K, Lane S, Lipsett PA. Electronic monitoring and voice prompts improve hand hygiene and decrease nosocomial infections in an intermed-iate care unit. Crit Care Med. 2004; 32: 358-363

Tsay CHH, Kofinas AK, Trivedi SK, Yang X. Overcoming the novelty effect in online gamified learning systems: An empirical evaluation of student engagement and performance. JCAL. 2019; 36: 128–146

Tschudin-Sutter S, Sepulcri D, Dangel M, Schuhmacher H, Widmer AF. Compliance with the World Health Organization hand hygiene technique: a prospective observational study. Infect Control Hosp Epidemiol. 2015; 36: 482-483

Widmer AE, Dangel M. Alcohol-based handrub: evaluation of technique and microbiological efficacy with international infection control professionals. Infect Control Hosp Epidemiol. 2004; 25: 207-209

World Health Organization (2020), Coronavirus disease (COVID-19): How is it transmitted?, https://www.who.int/news-room/q-a-detail/coronavirus-disease-covid-19-how-is-it-transmitted, accessed on 11.2.2021

World Health Organization (Hrsg.) (2009a), WHO guidelines on hand hygiene in health care: first global patient safety challenge: clean care is safer care, World Health Organization, Patient Safety, Geneva, Switzerland.

World Health Organization (2009b), Perception Survey for Health-Care Workers (revised August 2009), https://cdn.who.int/media/docs/default-source/integrated-health-services-(ihs)/hand-hygiene/monitoring/surveyform/perception-survey-for-health-care-workers.doc, last accessed on 15.01.2025

Zakeri H, Ahmadi F, Rafeemanesh E, Saleh LA. The knowledge of hand hygiene among the healthcare workers of two teaching hospitals in Mashhad. Electron Physician. 2017; 9: 5159-5165

## 13. Statement of personal contribution

The doctoral project was initially supervised by Prof. Dr. Dr. Klaus Kabino, who originally served as the primary doctoral advisor. Shortly after the project had started, he transferred the supervision to Prof. Dr. Stephan Jonas, who at that time was working as a Postdoctoral Researcher at the Institute of Medical Informatics, RWTH Aachen University. Following Prof. Dr. Dr. Kabino's retirement, Prof. Dr. Jonas fully assumed the role of doctoral supervisor and continued to oversee the project.
Prof. Dr. Jonas provided the research framework, resources, and academic guidance. Technical support for software development and data management was provided by Dr. Ekaterina Kutafina and Marko Jovanović.

My independent contributions included designing the study protocol, recruiting participants, conducting the evaluation, analyzing and interpreting data, and writing the manuscript. I developed the methodological approach for the assessment of user feedback and the statistical evaluation of study results. I also took initiative in integrating the serious game concept into the research design and contributed substantially to the scientific outcomes of the project.

I hereby declare that I wrote this thesis independently. No sources or resources other than those explicitly mentioned in this dissertation have been used. The author declares—as already mentioned—that there are no conflicts of interest related to the Myo® armband or the mobile application IdealPure. No financial or non-financial support was received from the manufacturers, and no commercial interests are involved. The research was conducted independently at the Institute of Medical Informatics, RWTH Aachen University.

## 14. Addendum

**Tab. 1:** Coding categories for positive (a) and negative (b) comments

| **(a) Coding of positive comments** | **Conditions** | | |
|---|---|---|---|
| **Coding categories** | **Test at t1** | **Control at t1** | **Total** |
| Usability | 2 | 3 | 7 |
| Learning | 4 | 1 | 11 |
| Playful/ Fun/ Motivation | 1 | 0 | 2 |
| Quality of media | 2 | 1 | 3 |
| Direct feedback | 0 | 0 | 1 |
| Overall good | 0 | 0 | 2 |
| Information / importance | 0 | 1 | 2 |

| **(b) Coding of negative comments** | **Conditions** | | |
|---|---|---|---|
| **Coding categories** | **Test at t1** | **Control at t1** | **Total** |
| Technical difficulties | 3 | 0 | 8 |
| Invalid scores | 3 | 0 | 5 |
| Difficult learning materials | 0 | 1 | 1 |
| Color design | 0 | 1 | 1 |
| Enforcement of separate mobile phone | 1 | 0 | 1 |

# IdealPure - Anleitung

## Nutzung

**Stellen Sie stets sicher, dass Ihr Smartphone mit dem Internet verbunden ist!**

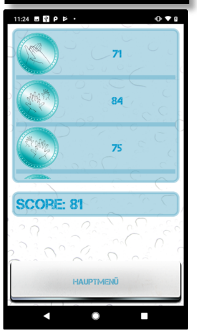


**Benutzeroberfläche**

- Links: Oberfläche der Interventionsgruppe (mit Myos)
- Rechts: Oberfläche der Kontrollgruppe (ohne Myos)
    - Hier stehen Ihnen die Funktionen Training und mein Profil nicht zur Verfügung



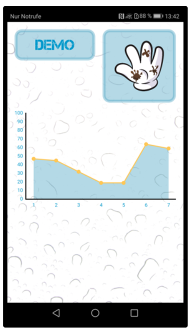





**Training**

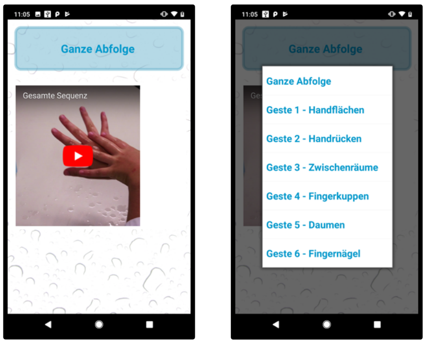
1. Legen Sie die zwei Myo-Gestenarmbänder an (achten Sie darauf, dass diese geladen sind und die USB-Anschlüsse in Richtung Ihrer Handflächen zeigen)


2. Tippen Sie auf „TRAINING"
3. Nach einigen Sekunden erscheinen beide Myos
4. Tippen Sie auf den oberen „Vibriere"-Button, nach kurzer Zeit vibriert eines der Myos
5. Wählen Sie nun aus, welches der Myos vibriert hat und setzten sie durch Tippen in die rechte quadratische Box dort einen Haken
6. Wiederholen Sie für das andere Myo die Schritte 4 & 5
7. Durch Tippen auf „Starten" beginnt nach 5 Sekunden das Training: Führen Sie die angezeigten Gesten für je 5 Sekunden aus




**Mein Profil**

- Hier haben Sie Einsicht in die Gesamtergebnisse Ihrer letzten 7 Trainingsdurchgänge mit den Myos und können somit Ihren Lernfortschritt einsehen




**Lernen**

- hier können Sie sich Lehrvideos anschauen
- Ihnen stehen Videos zur gesamten Abfolge und zu jeder Geste zur Verfügung
- Tippen Sie auf den blauen Button „Ganze Abfolge", um anderes Video auszuwählen
- Drücken Sie auf den roten Start Button im Video, um da YouTube-Video zu starten

Durch Tippen auf den eckigen Button im Video erreichen Sie den Vollbildmodus


**Einstellungen**

- Passwort-geschützter Bereich: hier sind Ihre ausgefüllte Fragebögen hinterlegt, die Sie mit dem Prüfer zu verschiedenen Zeitpunkten ausfüllen

**Fig. 1:** Manual of the application IdealPure as handed out to the study participants

**ETHIK-KOMMISSION AN DER MEDIZINISCHEN FAKULTÄT**
**DER RHEINISCH-WESTFÄLISCHEN TECHNISCHEN HOCHSCHULE AACHEN**
Pauwelsstr. 30, 52074 Aachen - Tel. 0241-80 89 963 – FAX 0241-80 82 012
E-Mail: ekaachen@ukaachen.de

Ethik-Kommission an der Medizinischen Fakultät
der RWTH Aachen – Pauwelsstr. 30 – D - 52074 Aachen
Herrn
Dr. rer. medic. Stephan Jonas
Abteilung mHealth
Institut für Medizinische Informatik
Im Hause
[redacted]

Aachen, den 05.12.2017

Schmal/km

**Betrifft:**

| | |
|---|---|
| EudraCT-Nr.: | - |
| Protokoll-Nr: | - |
| Titel: | Evaluation of Serious Games in Hospital Hygiene |
| Sponsor: | - |
| Eingereicht von: | Dr. rer. medic. Stephan Jonas, Abteilung mHealth, Institut für Medizinische Informatik, Uniklinik RWTH Aachen, Pauwelsstraße 30, 52074 Aachen |
| Antragsteller: | Dr. rer. medic. Stephan Jonas, s.o. |
| LKP: | - |
| Lokaler Hauptprüfer: | Dr. rer. medic. Stephan Jonas, s.o. |
| Internes Aktenzeichen: | EK 323/17 |

**Hier: Stellungnahme**

Sehr geehrter Herr Dr. Jonas,

vielen Dank für Ihr Schreiben vom 07.11.2017 - Eingang in der Geschäftsstelle der Ethik-Kommission am 16.11.2017, in dem Sie uns die o. g. Bitte um Stellungnahme eingereicht haben.

Die anonymisierte Datenerhebung und Befragung (Fragebögen) sowie die Qualitätssicherungsmaßnahmen zur Verbesserung der Händedesinfektion bei Mitarbeitern des UKA fallen nicht in den Zuständigkeitsbereich der Ethik-Kommission.

**Es bestehen keine ethischen und berufsrechtlichen Bedenken gegen das Forschungsvorhaben.**

Die eingereichten Unterlagen wurden nicht im Rahmen einer Sitzung, sondern im Auftrag der Ethik-Kommission satzungsgemäß im vereinfachten Verfahren durch den Vorsitzenden und den stellv. Vorsitzenden der Ethik-Kommission bewertet.

Viel Erfolg bei Ihrem Forschungsvorhaben.



Prof. Dr. G. Schmalzing, Vorsitzender; Geschäftsstelle: Tel. +49 241 80 89 963,
Fax +49 241 80 82 012; E-mail:ekaachen@ukaachen.de, Homepage: www.medizin.rwth-aachen.de/EK

Mit freundlichen Grüßen

[redacted]

Prof. Dr. med. G. Schmalzing
Vorsitzender

PD Dr. med. R. Hausmann
Stellv. Mitglied der Ethik-Kommission
in Vertretung von Prof. Büll

Die Ethik-Kommission ist nach Landesrecht konstituiert und bei den zuständigen Landesbehörden, beim Bundesamt für Arzneimittel (BfArM) sowie beim Bundesamt für Strahlenschutz (BfS) registriert. Sie berät unabhängig nach den Regeln des Weltärztebundes in der Deklaration von Helsinki über Forschung am Menschen in der Fassung von 1996 in Somerset West, nach nationalen Gesetzen, Vorschriften und der ICH-GCP-Leitlinie in der jeweils gültigen Fassung (siehe Homepage der Ethik-Kommission unter www.medizin.rwth-aachen.de/EK).



Prof. Dr. G. Schmalzing, Vorsitzender; Geschäftsstelle: Tel. +49 241 80 89 963,
Fax +49 241 80 82 012; E-mail:ekaachen@ukaachen.de, Homepage: www.medizin.rwth-aachen.de/EK

**Fig. 2:** Statement of the Ethics Committee

## 15. Acknowledgments

In particular I would like to thank my doctoral advisor Prof. Dr. Stephan Jonas for developing this extraordinarily interesting research topic together with me. Through our regular exchange – both professionally and personally – my project was continuously influenced in a positive way. I was particularly impressed by how he not only advances his team scientifically, but also creates an exceptionally pleasant and supportive working environment.

Moreover this dissertation was made possible in particular by Marko Jovanović, who continuously and with great effort improved IdealPure. I would also like to thank Dr. Ekaterina Kutafina and Prof. Dr. Cord Spreckelsen for their great support. I sincerely thank Michaela Huth for the archiving of collected data.

My thanks also go to my colleagues at the Institute of Medical Informatics for their remarkable helpfulness and kindness during my time there, through which lasting friendships have developed.

I thank my parents and my brother, Achim Kießler, for their constant encouragement throughout my entire studies and during the writing of this dissertation.

I am also thankful to my partner, Dr. Andreas Alexander Himmen, for his support, constant encouragement and understanding.

Lastly, I wish to thank all relatives, friends, and fellow students who supported me during this dissertation and throughout the entirety of my academic journey. Their support played a significant role in helping me achieve my goals.