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Research Article

Analyzing Typical Mobile Gestures in mHealth Applications for Users with Down Syndrome

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Mobile technology has provided many advantages for all members of the Information Society. Communication, Organization, Transportation, Health, and Entertainment are just a few areas of mobile technology application. Nevertheless, there are still some people who find difficulties using it. Although there are a lot of applications of mHealth available for almost any kind of mobile device, there is still a lack of understanding and attending users' needs, especially those of users with disabilities. People with Down syndrome have the potential to function as active members of our society, taking care of themselves and their own, having jobs, voting, and so on, but their physical limitations prevent them from handling correctly technological tools that could enhance their performance, including mobile technology. In this paper, we had analyzed how suitable the mHealth applications are for users with Down syndrome. We tested 24 users and analyzed their physical performance in fine-motor movements while developing a set of tasks over a mHealth application. Results showed that the design of a mHealth application for users with Down syndrome must center its interaction with simple gestures as *tap* and *swipe* avoiding more complex ones as *spread* and *rotate*. This research is a starting point to understand the fundamentals of people with Down syndrome interacting with mobile technology.

1. Introduction

The benefits of mobile technology can be found anywhere: communication, education, scientific research, healthcare, and entertainment, to name a few, but despite its multidisciplinary application, mobile technology and all its advantages are far away from being accessible to people with disabilities [1], people with Down syndrome among them [2]. Researchers in Human-Computer Interaction (HCI) have recognized and analyzed several barriers that people with Down syndrome face when interacting with mobile technology [3–9].

Talking specifically about mobile Health (mHealth) software, it has various limitations, such as small screens, tiny graphical elements, tiny movements of the hand and fingers, and a very reduced interactive area [10, 11]. Due to their common problems in fine-motor skills, the potential of people with Down syndrome as mobile users might be perceived as limited. Nevertheless, the question is not if they are capable to manipulate the mHealth application, but if it is enough suitable for them.

People with Down syndrome can be benefited by many mHealth applications such as communication enhancers, treatment support tools, nutrition control tools, and so on. These tools in general will provide a more independent living. This is the main reason of why mHealth software designers and developers must know how these users learn, use, and enjoy their products.

The reminder of the paper is organized as follows: the main characteristics of people with Down syndrome and some relevant studies involving mobile technology are shown in Section 1. Section 2 presents the research methodology. The experimental work is presented in Section 3. Results are presented in Section 4. And, finally in Section 5, we present all concluding remarks.

1.1. Down Syndrome. Down syndrome is a genetic anomaly that affects chromosome 21, making a full or partial extra copy of it; it brings limitations in the physical and cognitive profile of people who are born with it [12, 13]. Worldwide, the estimated incidence of Down syndrome is between 1 in 1,000 to 1 in 1,100 live births [14]. About 6,000 babies are born in the United States with Down syndrome each year [15]. The prevalence of this condition is in about 8 people with Down syndrome per each 10,000 people in the United States [15], 7 per 10,000 in England and Wales [16], and 8 per 10,000 in Spain [17], to quote some data. According to the National New York State Department of Health, the life expectancy for people with Down syndrome is around 60 years of plenty life, in which they attend school, work, participate in decisions that affect them, have meaningful relationships, vote, and contribute to society in many other ways [18].

According to the Diagnostic and Statistical Manual of Mental Disorders, almost 80 percent of the people with Down syndrome have moderate intellectual disability, which means that they can reach basic capabilities in reading, writing, mathematics, sports, computing, and other academic activities applicable further in jobs; people can be responsible of their personal needs such as feeding, dressing, and daily living. All these skills can be achieved after a long process of learning and training [19].

In addition to the intellectual disability, users with Down syndrome have physical disability that affects mainly their fine-motor skills (in the hand and fingers), visual and hearing perception, eye-hand coordination, and other psychomotor capabilities [12]; the most common limitations of Down syndrome people are as follows [20–22]:

(i) Short hands and broad fingers
(i) Difficulties in fine-motor skills
(ii) Low muscle tone
(iii) Poor eye-hand coordination
(iv) Vision problems
(v) Audition problems
(vi) Intelligence quotient average of 50
(vii) Low comprehension of abstract concepts
(viii) Delay in expressive language
(ix) Problems with short-term memory (verbal)
(x) Anxiety and stress propensity
(xi) Depression
(xii) Uncontrolled effusive behavior
(xiii) Lack of concentration in difficult problems.

1.2. Mobile Technology and Down Syndrome. Most individuals with Down syndrome are able to live independently, but they commonly require assistance in financial, medical, and legal matters [12], which is a gap that mobile technology can close. This is the reason why some researchers have analyzed the particular and specific needs of these people as users of mobile technology.

In [7], the authors applied a usability test of mobile devices, to analyze the work-place related skills of adult expert users with Down syndrome. Among all the tasks made by users, some of them were very challenging. Testing sessions were quite long, lasting between 2 and 3 hours. The authors also denote the difficulty of users to work with tiny elements of the touch screen device. Finally, they also provide a set of suggestions to those who apply usability tests over users with Down syndrome: (1) applying pilot sessions to reveal potential challenges, using real examples; (2) to be flexible in tasks; (3) to present satisfaction scales visually; and (4) to reinforce instructions with visual clues.

An empirical study of three input techniques used by Down syndrome children and young adults was presented in [23]. The authors analyzed the use of the keyboard, word prediction, and speech recognition to a group of 10 users with Down syndrome between 10 and 24 years old. Besides the surprising results of performance in the keyboard and preference of speech recognition (see original paper for more details), the evaluation of the users implied the collection of demographic data. The authors also reported that some users were easily distracted during evaluation and have fatigue and lack of patience. The authors suggested that the computer experience (number of years using computers) can be a good predictor of users' performance. Also, they suggested that low performance shown by users in some activities was due to lack of motivation, training, and exposure to technology, rather than limitations in ability.

In [3], the authors presented a process for usability testing for users with Down syndrome, which consists in 9 phases: recruiting participants, establishing tasks, writing instructions, defining test plan, pilot testing, refining test plan, testing, analyzing collected data, and presenting the results. It was made from a previous literature review. Nevertheless, the literature review seems to be limited, the process considered only 5 papers from 2009 to 2013, and the process is not applied or validated. Still, the authors presented the need of a process when working with users with Down syndrome.

A mobile assistant for workers with Down syndrome was presented in [24]. The authors developed a full-functional mobile tool that guides workers step by step throughout a task sequence read from a QR tag, presenting information through different channels: video, audio, text, and static images. The steps sequence is delivered to users depending on the activity, in some cases the next step is shown automatically, and in other cases, the users are asked to continue. The interface design of the assistant was enhanced by the comments of experts in Down syndrome, resulting in a simpler and usable one. By using the assistant, errors in tasks decreased, supervisor activity was less required, and time expended in training activities was reduced. The authors described how difficult it was to deal with the great variability in user's capabilities, denoting that they could not generalize the evaluation method to all of them.

Feng and Lazar in [4] presented a summary of the difficulties experienced by users with Down syndrome using technology:

(i) Typing

(ii) Frustration in navigation

(iii) Frustration in trouble shooting

(iv) Lack of patience

(v) Low error tolerance

(vi) Frustration when excessive information was found

(vii) Frustration in inconsistencies in the interface design

(viii) Frustration when there are too many windows opened.

There is an active and growing engagement of people with Down syndrome and mobile technology, but there are some characteristics of them that limit and delay progress and achievement of all new technology advances and benefits. Now, there is a gap in the analysis of why people with Down syndrome have troubles using mobile technology; one question arises: is it because of their intellectual capabilities or because of their physical ones? By studying the performance of individuals with Down syndrome interacting with mobile gestures, we are looking for the most basic interaction issues in the simplest form of communication with these touchable devices.

2. Methodology

We divided our study in five stages. This methodology was proposed by our research team, and it has been enhanced through the years:

(1) Selection of target users to be evaluated

(2) Definition of test sessions and materials

(3) Definition of testing metrics

(4) Definition of users' tasks

(5) Definition of roles and functions.

3. Experimental Work

A task development test was applied in a group of 24 users with Down syndrome (further detailed) to assess physical challenge that implied the use of an mHealth application. In this section, we detail the stages of our experimental work.

3.1. Target Users. The study involved 24 subjects with Down syndrome, 14 men and 10 women between 12 and 20 years old ($\overline{X} = 16.1$, $S = 3.9$); all of them were enrolled in an institute of special education. This institute evaluated all students in six points: communication skills, physical development, self-direction, social behavior, literacy, and mathematics.

In these schools, students are categorized in three levels of psychoemotional development, by implementing a battery of tests, based on WISC-IV [25] and Valpar [26] tests. The objective of this categorization was to offer academic services according to student's needs. The next scale is used:

(1) Communication skills: grade for expressing ideas and emotions to others.

  (a) High: the student has no problems in communication.
  (b) Appropriated: the student need some help to put together and to express some ideas.
  (c) Low: the student needs a lot of help to communicate.

(2) Physical skills: grade to develop gross movements such as walking, running, and crawling, among others.

  (a) High: there are no difficulties in movement.
  (b) Appropriated: the student has some troubles in coordination and precision.
  (c) Low: the student has difficulties developing any movement.

(3) Self-direction: grade to be independent in daily living and self-care, to follow schedules, and to solve common problems.

  (a) High: the student is independent in daily living tasks and has no trouble in learning new ones.
  (b) Appropriated: the student needs help in some tasks, especially in the new ones.
  (c) Low: the student cannot do any daily tasks by him/herself.

(4) Social behavior: capability to get integrated in social groups and to respect its rules.

  (a) High: the individual can socialize easily and has no trouble with social behavior rules.
  (b) Appropriated: the individual has some problems socializing and understanding the accepted social behavior.
  (c) Low: it is very difficult for the student to get integrated in a social group.

(5) Literacy: ability to read and write.

Table 1: Participants skills.

Characteristic	Target users (%)
Communication skills	High: 37.5 Appropriated: 58.3 Low: 4.2
Physical skills	High: 41.7 Appropriated: 54.2 Low: 4.2
Self-direction	High: 37.5 Appropriated: 45.8 Low: 16.7
Social behavior	High: 12.5 Appropriated: 87.5 Low: 0
Literacy	High: 16.7 Appropriated: 70.8 Low: 12.5
Math	High: 0 Appropriated: 58.3 Low: 41.7

Table 2: Technology usage of participants.

Preferred device	PC: 25% Tablet: 29.2% Smartphone: 33.3% None: 12.5%
Frequency of use (hours/week)	0 (zero): 20.8% Less than 10: 25% Between 10 and 30: 33.3% More than 30: 20.8%
Purpose	Academic: 37.5% Leisure: 50% None: 12.5%
Computer classes	Yes: 45.8% No: 54.2%
Owns a device	Yes: 33.3% No: 66.7%
Device availability	None: 20.8% Borrowed: 20.8% Home/school: 37.5% Anywhere: 20.8%

(a) High: the student can read and write without troubles.
(b) Appropriated: the student can read and write simple sentences.
(c) Low: the student cannot read and write.

(6) Math: ability to solve problems involving numbers.

(a) High: the student can solve additions, subtractions, and multiplications.
(b) Appropriated: the student can read and write numbers, identifying tens and hundreds, but has some trouble in solving additions and subtractions.
(c) Low: the student at much can read and write numbers.

Table 1 presents the level of each skill for the test participants.

Table 3: Division of the participants.

Group	Number of participants
Isolated	5
Occasional	6
Regular	8
Unlimited	5

We asked parents and teachers about the use of technology by the kids: type of devices they use, software used, common activities, frequency of use, and so on. The results of how participants interact with technology are presented in Table 2.

This specific information of technological background shown clears the differences in their experience using technology (computers, video game, mobile, etc.).

Considering this, we opted to divide the population into four groups:

(1) Isolated: They have very little experience using technology and do not commonly interact with technology in their daily living. They had their first encounter with mobile technology in the first session of this study.
(2) Occasional: They can use basic features of computers (always with help), with which they interact 2 or 3 times per week at home or at the school. They use other devices such as video games consoles, music players, and mobile technology at home but twice a month as much.
(3) Regular: They can use basic features on computers, video games, and mobile technology without help. They interact frequently with them but for short periods of time every day.
(4) Unlimited: They can use several features of computers, video games, and mobile technology with independence. They use technology as video games, media players, computers, and mobile devices every day for more than 4 hours per day.

The number of participants by group is shown in Table 3.

Summarizing, around 50% of the test participants use mainly mobile devices (tablet, computers, and smartphones) over PC and other technological devices; nearly 60% of participants use them frequently at the basic level; 20% of participants are experts, and the last 20% has not used them at all.

3.2. Sessions and Materials. The study was extended throughout 6 months, having a total of 24 sessions per user. Each session lasted 20 minutes. Three different schools were involved, and each one provided a classroom to work in. There was not any characteristic of the classroom different from others: rectangular area, windows, a blackboard, several desks, and so on. We mounted three high-definition video cameras: one in front of the user (Figure 1), one in the right side (Figure 2), and one in the left side of the user (Figure 3).

All users worked with a 7.1″ screen Samsung® tablet computer and with a 5″ screen LG® smartphone, both with Android 4.4.

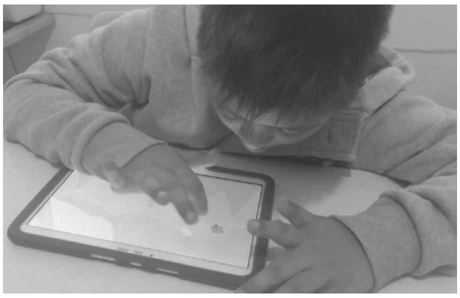

Figure 1: In front camera.

Figure 2: Right-side camera.

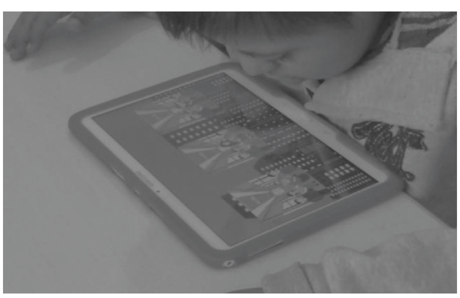

Figure 3: Left-side camera.

Searching in literature, users can apply between 12 and 15 different gestures to manipulate mobile applications of any device; but, in accordance with [27–29], there are 9 more commonly used gestures: tap, double tap, swipe, drag, hold, hold and drag, spread, pinch, and rotate. Among the less common gestures are those used only for some vendors like the 5 and 3 fingers pinch for iOS® and all their 3D taps [30]; for this reason, they were not taken into consideration for this study.

To assess these mobile gestures, we developed nine different applications, in order to clearly observe, analyze, and assess each one. As an example, Figure 4 shows a user interacting with the application of *rotate* gesture in the 7.1″ screen device, and Figure 5 shows in the 5″ screen device.

3.3. Definition of Test Metrics. Based on [31], the next performance metrics were used:

(i) Success in tasks: percentage of tasks completed successfully, arranged by gesture

(ii) Number of errors: number of trials that users took to complete a task

Figure 4: Rotate gesture app 7.1″ screen.

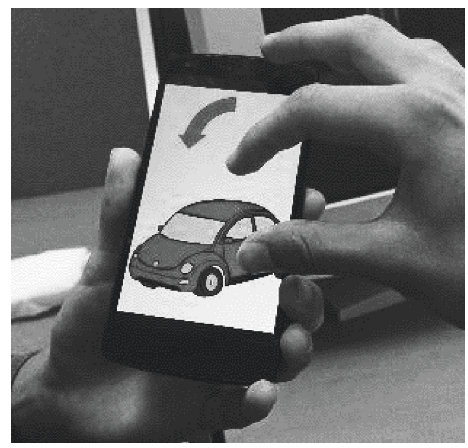

Figure 5: Rotate gesture app 5″ screen.

(iii) Time: time to complete successfully a task.

Based on [32] in the Durivage Test for physical performance [33], we defined the next metrics and divided into three groups: movement, metrics, and pressure:

(i) Movement:

 (a) Fluent: the gesture was made without hesitation, and its action is triggered.
 (b) Stepwise: user hesitated to develop the gesture, and its action was triggered.
 (c) Disrupted: user did not complete the gesture.

(ii) Position:

 (a) Looseness: the fingers and hands are relaxed.
 (b) Rigidity: the fingers and hands are tense.
 (c) Trembling: the hand or fingers are shaking while making the gesture.

(iii) Pressure:

 (a) High: the gesture was not detected because the user pressed too hard.
 (b) Low: the gesture was not detected because the user pressed weak.
 (c) Detectable: the pressure made in the screen allows the gesture to be detected.

Table 4: Users' tasks involving tap gesture.

Skill level	User task	Success state
Very easy	Single tap (7.1′ screen)	User touches only one time the indicated object, and the next slide is displayed.
Easy	Multiple tap in "X" (7.1″ screen)	User touches the four figures one time, making an X figure in the indicated order. When user touches the last figure, the next slide is shown.
Moderate	Single tap (5″ screen)	User touches only one time the indicated object (while holding the device), and the next slide is displayed.
Hard	Multiple tap in "X" (5″ screen)	User touches the four figures one time (while holding the device) making an X figure in the indicated order. When user touches the last figure, the next slide is shown.

3.4. Definition of User's Tasks. To analyze the physical challenge, the assessment was focused on the mobile gestures; considering this, we defined 36 user tasks, and each one implied the following:

(i) The use of only one gesture

(ii) A recognizable result

(iii) A skill level going from very easy to hard

(iv) A state of success.

To facilitate the application of all the sessions, we arranged users' tasks with the mobile gesture that implies. As an example, Table 4 presents a full description of the four tasks related to the tap gesture (a complete description of all activities can be requested by an e-mail to the main author of this paper). Instructions were given verbally to users, at the beginning of the task, and each time the user got confused, as a reminder, no other kind of help was provided to participants.

3.5. Definition of Roles and Functions. The next roles were involved during the evaluation:

(i) Test Applicator: an expert in user testing, researcher in HCI.

(ii) Applicator assistant: a college student specialized in computer science.

(iii) Physical therapist: a practitioner in physical therapy, with more than 10 years working in special education programs.

(iv) Observers: one psychology practitioner, specialized in intellectual disability and Gestalt therapy, working for more than 20 years in special education programs, one researcher in HCI, one teacher of special education, and two participants' parents.

Although the test applicator and the assistant are present in the testing room, only the applicator interacts with the users. Both, the physical therapist and the observers analyze the users through a video recording, to not interfere with the real user interaction. The applicator and the assistant socialized previously with users following the activities of the *user-background* phase.

4. Results

The resulting data of the study includes two axes: physical performance and tasks performance. To homogenize data analysis, results should be coded as *improvement rates*. The calculation can be made using the percentage increase formula:

$$\text{percentage change} = \frac{\text{amount of increase}}{\text{starting point}} \times 100. \quad (1)$$

Thus, the improvement rate is calculated as follows:

$$\text{improvement rate} = \frac{\text{final value} - \text{initial value}}{\text{initial value}} \times 100. \quad (2)$$

where the initial value is the data obtained in test 1 and the final value is the data obtained in the last test. At the end, the data analysis can be formed by a set of improvement rates that can be grouped as an average improvement in physical performance, tasks performance, or global performance (the global performance is the average of the other two rates).

The physical performance of each gesture was calculated by considering the improvement rate in the percentage of users who made each activity (of the corresponding gesture) with fluent movement, loose position, and detectable pressure, as the study progressed. In Figure 6, it is shown, for example, that users developing activities of *double tap*, improved their physical performance to almost 80%, in the six months the study lasted. Using *spread*, on the contrary, users only improved performance around 25%.

Task performance involved success in tasks, number of errors, and time. Figure 7 presents the improvement of success in tasks to each gesture. The greater improvement was observed in *swipe* gesture, having more than 70%. *Hold and drag* had lower improvement, almost 40% of improvement.

The error making rate improvement is shown in Figure 8. Big differences may be observed between *pinch* gesture, which had around 65% of improvement, and *rotate* gesture, which had only 20%. This means that, even after six months and 24 tests, users still made many errors using *rotate* gesture.

Figure 9 presents data about how users improved their time, making the activities to each gesture. The greater improvement was observed in gestures *tap* and *drag*, with

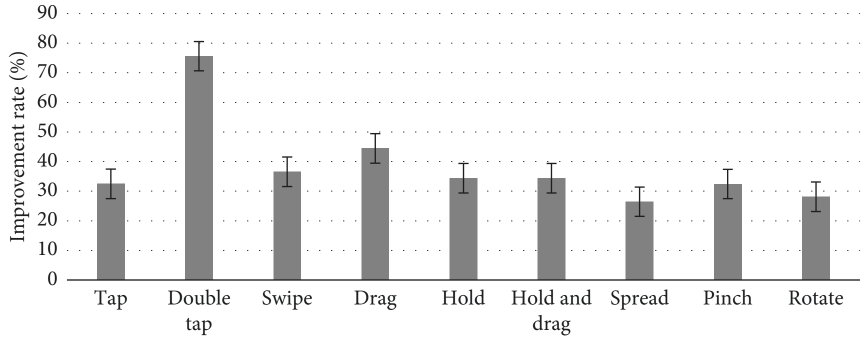

Figure 6: Physical success per gesture.

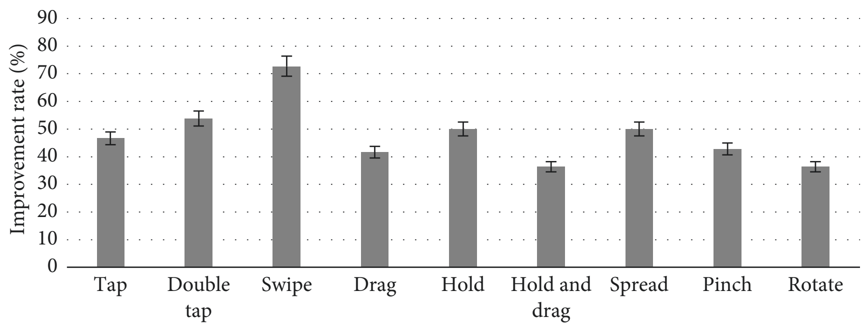

Figure 7: Success in tasks per gesture.

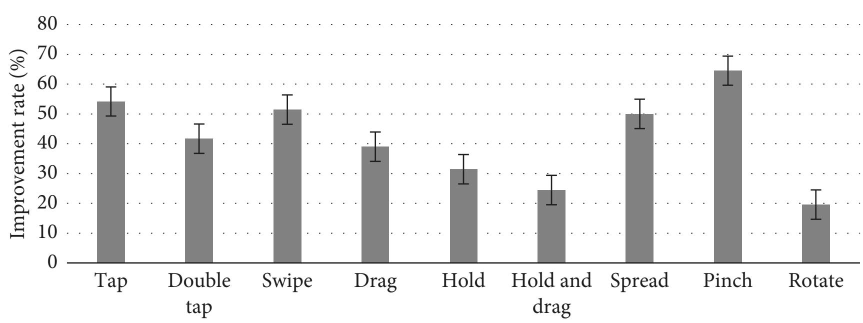

Figure 8: Error making results.

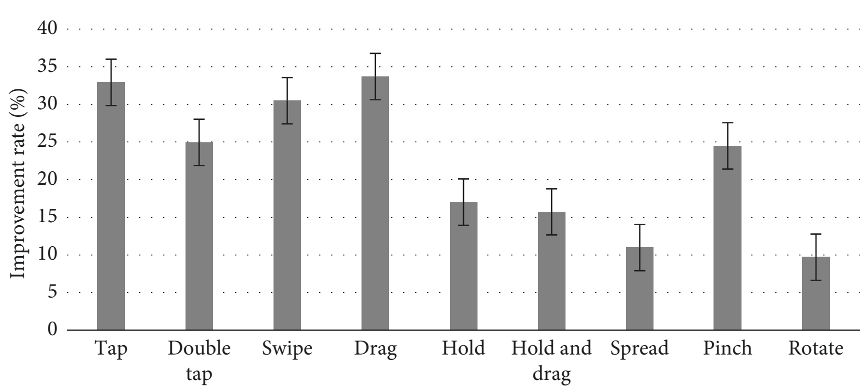

Figure 9: Time improvement results.

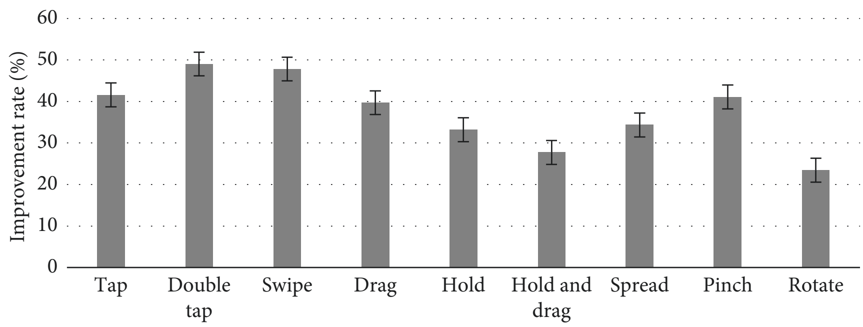

Figure 10: Global improvement level per gesture.

more than 30%; *spread* and *rotate*, had the smallest with just around 10% of improvement.

Finally, we present the global performance. It was calculated as the average improvement rate of users' performance, considering physical and tasks performance. Figure 10 shows, in general, how easy-to-learn the nine gestures were to participants. *Double tap* and *swipe* were the gestures in what users presented more improvement, having nearly 50%. Rotate, however, had only around 25% of improvement.

5. Concluding Remarks

mHealth applications require to attend the needs of users with Down syndrome in order to reach accessibility and provide to these group of users all health services. This paper presented an analysis of the physical challenge involved in the use of mHealth application, by the profile of people with Down syndrome. By analyzing the most basic form of communication with mobile devices, we found that the physical limitations of users with Down syndrome make quite hard to work in reduced areas, such as tablet computers and smartphones screens, developing the fine movements that mobile gestures require.

We had developed a study focused in the nine most common mobile gestures: tap, double tap, swipe, drag, hold, hold and drag, spread, pinch, and rotate. The analysis of 24 users with Down syndrome throughout the six months showed that gestures like *tap* and *swipe* are very easy to develop; double-tap and pinch gestures can be easily learned by users, even when they represent a challenge at the beginning. Spread and rotate gestures turn to be the hardest to learn, since when users deal with complex gestures they are more susceptible to making mistakes.

For mHeath software, it is very important to fit all users' needs and due to their own nature must fit the needs of users with disabilities. mHealth applications can provide the help, guidance, and knowledge that allow people with Down syndrome to be more independent, reach a better life, and realize as members of the information society. To do so, mHealth specialists must find the way to create more suitable products.

As future work, we have interest in applying a similar study to new gestures, such as the 3D tap of iOS, and to those gestures that do not involve the physical contact with devices. It is also important to extend this study, involving individuals with others disabilities (physical and intellectual) and without any, in order to compare experiences and results. To continue working with people with Down syndrome, we have started a project to evaluate the usability of brain-computer interfaces with children with Down syndrome, applying the same methodology of the current work.

Data Availability

All test data can be requested by email to the first and second authors. An .xls file will be provided.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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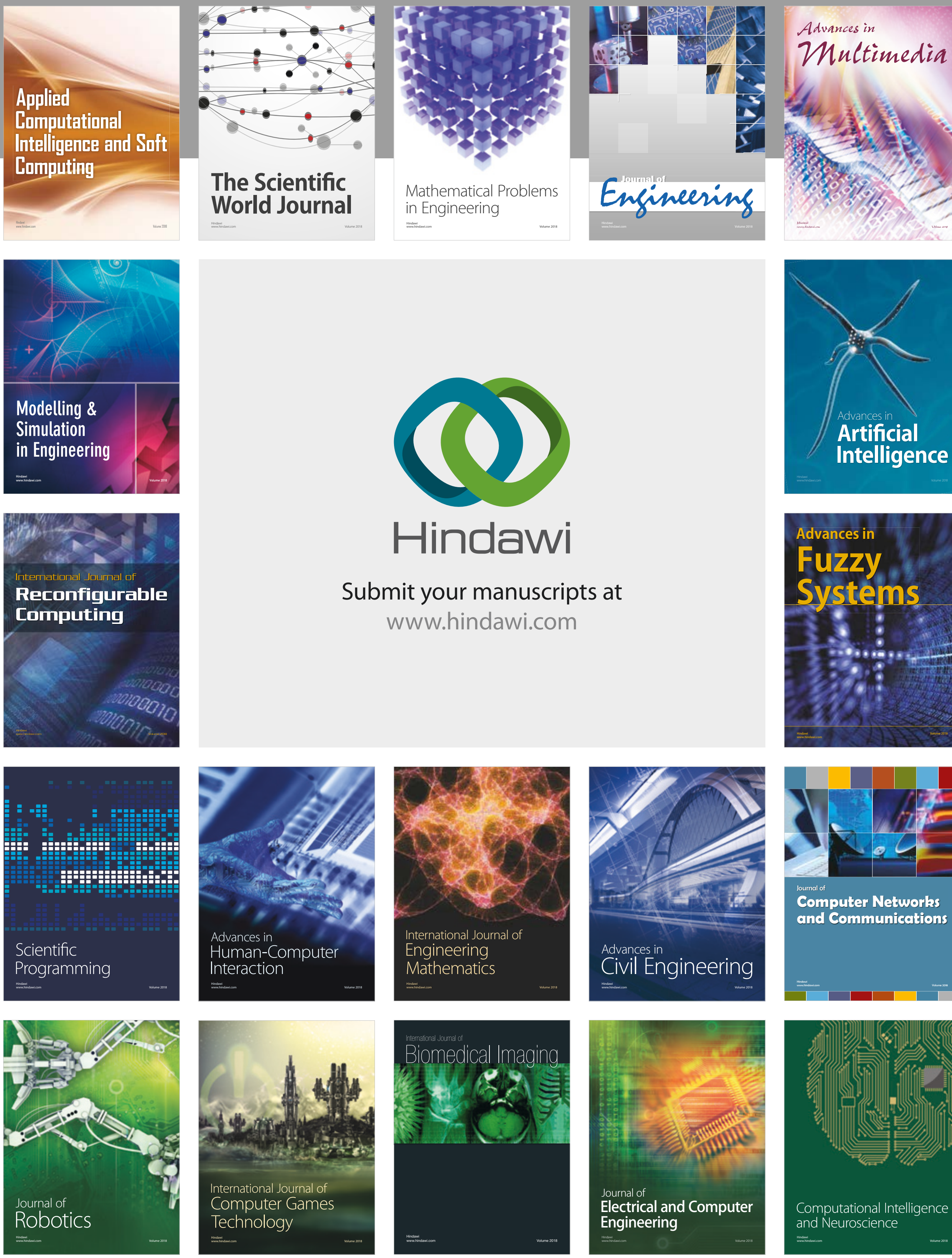
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