An Empirical Study on Usability Operations for Autistic Children

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Abstract. Leo Kanner defined autism as a distinct personality disorder, a great difficulty to communicate with others. Some autistic persons show cognitive and motor difficulties. Due to the problem presented in users with autism, it is necessary to create interfaces and applications that fit the capabilities of this type of user. This paper identifies operations to perform tasks in mobile applications that an autistic child can execute with less complexity based on the metrics KLM-GOMS and TLM-GOMS. Mobile applications were tested to calculate such metrics in different use cases. The results presented in this paper show how autistics users from different autism levels perform different type of tasks; the results are compared with the model proposed by GOMS. The experimentation shows the total time in seconds that it is necessary to realize every use case and be able to complete the goal assigned for each application. Our results show that an autistic user need more time to interact with the technology; this address to adjust the classification of the operations for interacting with computer-based systems and develop applications that they adapt to the autistic user.

Keywords: Autism spectrum disorder · Abilities · TLM-GOMS · KLM-GOMS · Usability

1 Introduction

According to the Diagnostic and Statistical Manual of Mental Disorders (DSM-V) [1], Autism Spectrum Disorder (ASD) is defined as a disability that affects brain in two main areas: (1) deficits in social communication and social interaction; and (2) restricted, repetitive patterns of behavior, interests, or activities. DSM-V classifies autism kids according to the required support in three levels: (1) Requiring support, (2) Requiring substantial support, and (3) Requiring very substantial support. Some autistic persons show cognitive and motor difficulties, which reduce the capability to perform activities and to operate technology.

Technological interventions for children with autism have been popular in recent years [2]. Some of these studies show that the use of computers with autistic persons in an environment of education brought increase in the focused attention, attention skills,

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fine motor skills, and generalization skills [3, 4]. In spite of these big efforts, there is work to be done in software design for this type of users.

Software for users with autism must be carefully designed due to the special capabilities of these users. There exists a cognitive difference between typical children and autistic ones that it does that the usability diminishes considerably before the second group. Therefore, it is necessary to identify which are the operations that autistic children can realize with more facility to develop directives that guide the development of software for this type of users [5].

Previous investigations had addressed this problem. Reference [6] propose an Autistic User Model and some cases of study with apps which describe his functioning. In [7] authors present the initial experimentation of a study to try to determine a model of user and model of interaction for the adaptive interfaces for the persons with ASD. In [7] the usability of two applications was evaluated measuring the rate of mistake and the success of a task for each application. But in previous studies authors did not consider the operations or the time that users need to complete a use case. They only evaluated the usability of the interfaces and the different design patterns that are easy to use for users with autism.

This work aims to identify the operations that users with autism can execute with less complexity while using mobile applications. We do this through a set of time estimation metrics to perform operations on technology based on tactile interfaces. The results from this work can help software designers to create projects with greater levels usability, especially for autistic specific applications.

The rest of this paper is organized into the following sections: Sect. 2 explains the concepts of the models GOMS, KLM, TLM-GOMS, and Autistic Spectrum Disorder. Section 3 discusses the design of the experiment. Section 4 describes the results obtained. Section 5 shows the discussion of the present experimentation. Section 6 gives the conclusions and future work of the research.

2 Theoretical Fundament

In this section we describe the theoretical background used to support our proposal.

2.1 The GOMS Model

The main existing form of engineering model for interface designs is the GOMS model, first proposer by Card, Moran, and Newell (1983) [8]. GOMS model is a description of the knowledge a user must have to perform tasks on a device system. The acronym GOMS stands for Goals, Operators, Methods and Selection rules. Briefly, a GOMS model consists of descriptions of the Methods needed to achieve specified goals. The Methods are a series of steps consisting of Operators that the user performs. The Operators are elementary perceptual, motor or cognitive acts, whose execution is necessary to change any aspect of the user's mental state or to affect the task environment. Goals are symbolic structures that define a state of affairs to be achieved and determinate a set of possible methods by which it may be accomplished.

2.2 Keystroke Level Model (KLM-GOMS)

The Keystroke Level Model is a simplified version of the original CMN- GOMS. Its purpose is simple: to model the time it takes a user to perform a task with a given method in an interactive computer system [9]. To predict the time a task will require, is decomposed into three broad categories of operators: *Physical-motor*, a user *Mental act (M)* and *system response (R)*. The Physical-motor operators are further differentiated as: keystrokes (K), pointing (P), homing (H), and drawing (D). The methods for accomplishing a task are coded as a sequence of these operators, and the reference times for each are then summed to return a time prediction for the method [9]. Table 1 shows a proposal of time to spend for executing the basic operators [10].

Table 1. Keystroke Level Model (KLM-GOMS)

Operator		Time (seg.)
G	Gestures	0.80
H	Homing	0.95
K	Keystroke	0.16–0.39
M	Mental	1.35
R	System	2.22–2.58
X	Distraction	6%/21%

2.3 Touch Level Model (TLM)

In addition of GOMS, there is a new proposal called Touch-Level Model for quantifying user interaction on model devices. The authors of [11] retain specific operators from the original KLM-GOMS model that stay applicable, and they introduce new operators to take into account the novel interactions afforded by touchscreen interfaces. There are a number of operators defined in the original KLM that are still appropriate for touchscreen devices, with slight modification. They are: Keystroke/Button Press (K), Homing (H), Mental Act (M), Response Time (R(t)). And the new operators are: Distraction (X), Gesture (G), Pinch (P), Zoom (Z), Initial Act (I), Tap (T), Swipe (S), Tilt (L (d)). Table 2 shows the new Operators proposed by [11].

Table 2. Touch-Level Model (TLM) Operators

K	**Keystroke/Button Press.** A button press on a purely virtual keyboard
M	**Mental Act.** The mental preparation needed to perform another action
X	**Distraction.** A multiplicative operator that adds time to other operators. It models the distractions that naturally take place in real world usage of a mobile device
G	**Gesture.** The time needed to physically form specialized gestures with one or multiple fingers

This model will be used to in our testing due to mobile devices are well accepted by autistic child.

2.4 Autistic Spectrum Disorder

Children with autism can be classified (considering the degree of functioning that they present for everyday life) into three levels, as is defined in D. E. L. DSM [1]. We organize them in levels: Level 1, Level 2 and Level 3.

(1) **Level 1:** Requiring support, without supports in place, deficits in social communication cause noticeable impairments. Has difficulty initiating social interactions and demonstrates clear examples of atypical or unsuccessful responses to social overtures of others.
(2) **Level 2:** Requiring substantial support, marked deficits in verbal and nonverbal social communication skills; social impairments apparent even with supports in place; limited initiation of social interactions and reduced or abnormal response to social overtures from others.
(3) **Level 3:** Requiring very substantial support, severe deficits in verbal and nonverbal social communication skills cause severe impairments in functioning; very limited initiation of social interactions and minimal response to social overtures from others.

In [4] the authors describe some of the most important skills a typical user needs to interact with a computer like: (1) Three of the senses (auditory, visual and touch), (2) Visual, (3) Attention, (4) Fine motor skills, (5) Memory skills and (6) Generalization skills. According [12, 13] the visual and visuospatial ability is the most developed in the users with ASD compared to the other skills needed to interact with technology and the most used to the actions they can do. People with ASD have auditory sense however, are very susceptible to sudden changes in the same [1].

On the other hand, fine motor skills [14], voice and memory skills, strongly depend on the autism level of the person [1]. In other words, people with autism have these skills but in a limited way; the level of the ability is determined by the level of autism the kid has [1]. Finally, the attention is a weakly developed ability in autistic people. That is why, the design of the environments for people with ASD is based in increasing their attention [1]. According to these authors most of these skills are necessary for a child with autism to interact with the computer.

3 Experimental Design

This experiment was designed to identify the difference in the interaction between kids with different level of autism. We tested children with autism between the ages of 5 and 12. We had a group of 12 children with autism of level 1 and another group constituted by 9 children with autism of level 2 classified as defined by the DSM-V [1], having a total of 21 children.

The objective of this experiment is to identify whether there is a variation of the results within and between the two groups in order to determine which GOMS operations the child can perform better and the time they need to perform it.

3.1 Experiment Sample

The experiment considered a group of 21 users with different cognitive abilities and different levels of autism.

The experiment took place at the Eduke school (in Tijuana, Baja California, México), where a total of 12 users were chosen between 5 and 11 years of age. Also we visited the special education school ACI (in Tijuana, Baja California, México), where a total of 9 users between 5 and 13 years old were chosen. Users were organized in two groups: with a diagnosis of light classic autism (Level 1), and moderate classic autism (Level 2). The users with autism who were selected for the experiment were already diagnosed by personnel from each institution as well as by specialists in the area. Some of the tests they applied were: CARS (Childhood Autism Rating Scale) [15], M-CHAT (Instrument for early detection of ASD) [16]. Level 1 (N1) and Level 2 (N2) were chosen, to make the comparison between both groups and to obtain the results.

3.2 Instruments

(1) YoDigo
YoDigo is an AAC ("Augmentative and Alternative Communication") software application, developed in Android, to help with the communication of a speech impaired autistic user using the Picture Exchange Communication System (PECS) YoDigo was developed by our students as a part of a project in an undergraduate course [6]. The user can select icons that represent desires, food, specific items, and so on. After selecting a set of icons, a sentence (statement) in formed and pronounced (grammatically correct) by the application.
(2) Enmo
Enmo is an application to support the child in the identification of emotions. Also our undergraduate students developed this application. ENMO has a menu of the basic emotions. The user selects an option from the menu different types of emotions like happy, sad, etc. In this way the user can learn about the emotions [6].

3.3 Use Cases for Experimentation

The experimentation session consisted of a use case for each application in which the user was instructed on how to perform the use case. The first use case was to form a statement using the application YoDigo, the operation and the time proposed by GOMS, which were described in Sect. 2, as shown in Table 3. This table shows the time in seconds for each operation.

Execution begins when the user had to locate the options and press each option as indicated by the use case; this prompted the user to formulate a statement for which you must first locate the choice of pronouns, select it and wait system response. This is repeated for each of the actions defined in Table 3, until the user correctly formulates the statement and press the "listen statement" button.

Table 3. Use Case YoDigo (App1)

Use Case: *Elaborate a statement*		
Goal: *The goal is to form a statement*		
Actions	Operation	Time (seg.)
Locate Pronouns option	M	1.35
Press "Pronouns" option	K	0.16–0.39
Locate Wish option	M	1.35
Move your fingers across the screen	G	0.80
Press Wish Option	K	0.16–0.39
Locate Food and beverage option	M	1.35
Move your fingers across the screen	G	0.80
Wait for system response	R	2.22–2.58
Choose favorite food or drink	M	1.35
Move your fingers across the screen	G	0.80
Wait for system response	R	2.22–2.58
Choose next option	M	1.35
Wait for system response	R	2.22–2.58
Move your fingers across the screen	G	0.80
Press Play button	K	0.16–0.39
Wait for system response	R	2.22–2.58
Listen to chosen statement	M	1.35
Operator to Model Real-World Distractions	X	6%/21%

Table 4. Use Case Enmo (App2).

Use case: Choose emotion and identify an emotion		
Goal: The objective to choose an emotion and identify an emotion		
Actions	Operation	Time (seg.)
Locate character	M	1.35
Press selected character	K	0.16–0.39
Wait for system response	R	2.22–2.58
Locate option of activities	M	1.35
Press activity option	K	0.16–0.39
Wait for system response	R	2.22–2.58
Locate the emotion option	M	1.35
Wait for system response	R	2.22–2.58
Press the emotion option	K	0.16–0.39
Wait for system response	R	2.22–2.58
Operator to Model Real-World Distractions	X	6%/21%

The second use case was for ENMO application, which was described in a previous section, the aim was to locate the character and choose an activity that should make the character that make facial expressions and gestures showing emotions. The set of steps is shown in Table 4. This table shows the time in seconds for each operation proposed by GOMS.

In this use case the execution starts when the user is asked to choose the character that the user wants to play with, then the user has to choose an option from the list of activities that are displayed in the menu and perform the emotion what the image tells to the user to do

3.4 Procedure

For the experiment, a group of 21 children with ASD level 1 and 2 was used; the process of measuring time of performing operations was done individually with each of the participants of the group inside the installations of their aforementioned institute or school. Personnel of the institutions where instructed previously on the functionalities of each of the applications, guiding each child in each of the use cases.

For the App1 the use case consist of forming a sentence by selecting images, when finished the app can read the formed sentence. App2 consist of selecting an activity that the child must accomplish and follow the steps on screen, trying to identify an emotion or to act an emotion. The interactions with the apps were video recorded in order to record the time spent on each use case and to determine an average of time spent in each one until finished.

4 Results

The Tables 5 and 6 shows the results obtained for each user and operation such as M (Mental act), K (Keystroke), G (Gesture) and X (Distraction). Data represent the interaction time in seconds. The above was obtained for App1 and App2 for each level of autism (N1 and N2). For each user it the Mental Act (M) is shown in seconds, which is the mental work needed to start an action, also the Keystroke (K), which are the key presses; Gesture (G) which is the gestures needed for the task; and Distraction (X), which is the real world distractions happening around the user when attempting to do the task of the apps.

(a) Group of Autism Level 1. Children with level 1 (N1) performed the use case of App1 (made a sentence) in 31.9 s and 35.1 s for the use case of App2 (Identify an emotion), as shown in Table 5.

The results show that the maximum time of a N1 use case was 64.3 s and the minimum was 23.3 s. Two users did not complete the use case. Considering operations (M, K, G and X), on average operation M (Mental act) was complete in 7.5 s, 2.7 s for K (Keystroke), 4.9 s G (Gesture) and 26.5 s X (Distraction).

Table 5. Task GOMS for Level 1

User	App1					App2				
	TLM-GOMS Task				Total	TLM-GOMS Task				Total
	M	K	G	X		M	K	G	X	
1	4.5	2.0	4.0	25	35.5	2	2.8	6	33	43.8
2	4.2	1.3	9.8	16	31.3	3	4.3	8	8	23.3
3	x	x	x	x	x	4.5	3.3	12	14	33.8
4	15.8	2.0	7.5	39	64.3	7.5	3.5	9	16	36.0
5	7.8	4.0	3.5	18	33.3	4.0	2.0	4	11	21.0
6	4.2	4.0	3.8	49	60.9	3.0	1.5	9	6	19.5
7	5.5	2.3	3.5	12	23.3	3.5	5.0	11	9	28.5
8	6.3	3.3	4.0	11	24.7	5	3.3	22	14	44.3
9	x	x	x	x	x	6	3.3	13	8	30.3
10	8.5	2.0	3.0	44	57.5	5	3.5	9	23	40.5
11	10.5	3.7	4.8	32	50.9	3	x	5	31	39.3
12	x	x	x	x	x	13	4.5	15	29	61.5
Avrg	7.5	2.7	4.9	26.5	31.9	5.0	3.1	10.3	16.8	35.1

For the interaction of N1 users with the App2, the user who took the most time to complete the task did it in 61.5 s (maximum) and the fastest user in 19.5 s. In this case all users completed the task. On average for operation, in 5 s was completed operation M (Mental act), 3.1 s for K (Keystroke), 10.3 s G (Gesture) and 16.8 s X (Distraction).

(b) Group of Autism Level 2: Children with level 2 (N2), on average complete the use case (made a sentence) in 65.5 s and 62.4 s to complete the use case in App2 (Identify an emotion) as shown in Table 6.

Table 6. Task GOMS for Level 2

User	App1					App2				
	TLM-GOMS Task				Total	TLM-GOMS Task				Total
	M	K	G	X		M	K	G	X	
1	x	x	x	X	x	4	5	21	45	75.0
2	15.2	1.3	10.5	55	82	6.5	6.5	33	32	78.0
3	x	x	x	x	x	6.5	3.5	23	35	68.0
4	x	x	x	x	x	7.0	4.0	22	23	56.0
5	19.0	2.3	5.8	22	49.1	6	3.5	12	12	33.5
6	x	x	x	x	x	12	2.8	27	31	72.8
7	x	x	x	x	x	10	4.8	18	22	54.8
8	x	x	x	x	x	6.5	4.5	14	44	69.0
9	x	x	x	x	x	8.0	3.0	22	22	55.0
Avrg	17.1	1.8	8.1	38.5	65.5	7.4	4.2	21.3	29.6	62.4

For App1, the user who took most time to complete the use case did it in 20.5 s and the fastest user did it in 12.3 s. For App1, only two users complete the use case. On average, the operations were performed in: 17.1 s for M (Mental act), 1.8 s for K (Keystroke), 8.1 s G (Gesture) and 38.5 s X (Distraction). The same users (N2) complete App2 tasks in maximum 19.5 s and the minimum 8.4 s. On average, 7.4 s for M operation (Mental act), 4.2 s for K (Keystroke), 21.3 s for G (Gesture) and 29.6 s X (Distraction).

5 Discussion

In the results shown in Table 1, a time variation between N1 users while using App1 (YoDigo) can easily be spotted. This table also shows that in KLM-Goms K operation (keystroke) users needed the shortest time of all operations, mainly because the operation does no need too much cognitive effort, for the K operation users only needed to press a button or choose an option on the screen.

The same task as N1 user, was performed by N2 users (results shown in Table 6), and the results shows a marked contrast in the time need, as N2 users needed more time to perform the same task, furthermore, most of N2 users were unable to complete the task assigned for App1. Also, is important to note the N2 users got distracted more often, we adjudicate this to the fact the user interface presented, and the task assigned require a slightly greater cognitive and fine motor skills that N2 users possess.

For TLM-GOMS M (mental operation), G (gestures) and X (distraction) N1 users completed the task in less time that N2 users. Nevertheless, comparing the N1 and N2 users times with the proposed on GOMS model (shown in Table 1), all autistics users from both groups needed more time than the assigned in GOMS for each operation. For K operation GOMS proposed 0.27 s and N1 users needed an average of 2.74, having a 2.47 s difference for App1, as for the App2 we got a 2.80 s difference. For G operation, N1 users shows 3.51 s for App1, and N2 users shows an 8.90 for the App2 compared to the time assigned in GOMS. Comparing the assigned time in GOMS for M operation, the results shows a 6.68 s for N1 users with App1 and 4.20 s for App2; for the same operation N2 users shows a 16.2 s for App1 and 6.59 s for App2, this differences are depicted in Fig. 1.

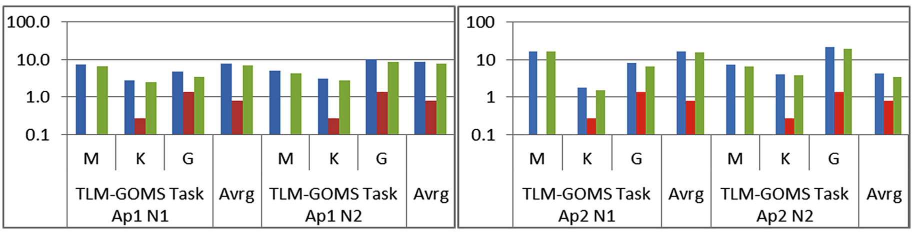

Fig. 1. Time results for Level1 (N1) and Level 2 (N2) users.

From the results, we can appreciate that users with level N1 autism can perform K operations in the time established in GOMS by [9], as the operation does not require cognitive processing, the operation consist of select and option from the screen once the users had decided which option wants to select. For M, G and X operations, N1 users needed more time than the assigned in [9], as this operations require greater cognitive processing to perform and the users in the spectrum mainly have memorization, retention, attention to small details, concentration for very long periods of time, visual learners and reading decoding abilities.

The results shows a high variation of time between groups, which exhibit the nature of the autism spectrum, this shows that if an application will be designed for autistic users, is important to consider the type of operation users can perform better with, in order to create more usable interfaces for autistic users.

6 Conclusions

In this paper we present an experiment design to evaluate the time required for a user with autism level 1 and level 2 to perform the operations to complete a task. Two applications that were designed to support the user with autism to develop communication and emotion recognition skills were used; these applications had already been evaluated for usability and in this experiment the time required by level of autism was evaluated to carry out the operations proposed by the TLM model which is a variant of the GOMS model.

It is concluded that level 1 users performed operations in less time, while level 2 users required more time and did not complete the use case tasks for the first application. With this we conclude that the more complex the task, the more cognitive ability and mental effort the autism user will need to be able to perform it. Compared with the times proposed by GOMS, a significant variance is found for each task. In this case, if you develop an application that considers only the operations that children with autism could perform, it could be supported in the teaching of skills for daily living.

This work is the basis of several future works, such as:

(1) Conduct the same experiments with typical children in order to compare the time spent by autistic users.
(2) State guidelines for the design and develop of mobile application more usable for autism children.
(3) Design an application based on components that are necessary for a user with autism to interact with mobile technology.

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