Evaluating Alternative Interfaces Based on Puff, Electromyography and Dwell Time for Mouse Clicking

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ABSTRACT

Computer systems are approaching human behavior in the sense of performing similar tasks, such as listening, understanding, thinking, and speaking. Although the forms of interaction with these systems have also followed the path of technology evolution, computer mice and keyboards do continue to play the leading role as a bridge between human and computer. The design of these devices forces the user to use their hands and this represents a major problem that has been already recognized in the literature with several proposed solutions. Nevertheless, in spite of the various methods found, it is difficult to find papers that make comparisons between them. Therefore, this work proposes an evaluation, using quantitative and qualitative analyses, of three alternative methods for mouse click: dwell time, mouth-puffing and electromyography. As result, both analyses showed that the interactions based on mouth-puffing and electromyography performed better than the dwell time method.

CCS CONCEPTS

• **Human-centered computing → Interaction devices**; *Interaction techniques*; *Empirical studies in HCI*.

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KEYWORDS

mouth-puffing, electromyography, dwell time, alternative click methods

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1 INTRODUCTION

Communication between people and computational systems has been intensified over the last decades. Technological developments have achieved a stage in which the human-computer interaction can incredibly resemble the communication established between two people. As a matter of fact, machines are getting closer to human behavior in the sense of performing similar tasks such as listening, understanding, thinking, speaking, and acting accordingly, all by themselves.

In spite of all the improvements obtained by the research community in pattern recognition and user interface design fields, the so-called conventional interactions [26] are still the most used ones to control electronic devices. For instance, computer mice and keyboard are dominant on the world of desktop computers, as touch screens are for smartphones and tablets. The design of these devices forces the user to use their hands and this does not result in any novelty in the interaction issue, in addition to restricting the public that can use these types of tools. In that case, non-conventional interactions must be explored in order to provide alternative methods that allow the control of devices without needing the tools available.

Non-conventional interactions, by definition, occur when the user is able to communicate with a computational system using a not-so-ordinary communication device such as a camera, a microphone, or any other kind of sensor for data input or output [19]. For example, one could use speech as a non-conventional interaction for typing. Note that, while the task of typing is kept unchanged, the input device (typically, a keyboard) needs to be replaced by a microphone.

With respect to the computer mouse in particular, both head- and eye-tracking methods are good examples of non-conventional interactions that are often used as alternative methods for mouse cursor control. The first approach usually tracks feature points defined on the person's face, which results in the tracking of the head [12]. The latter follows the gaze of the user, i.e., the eye movements are tracked and the point to where the user is looking is captured to be further mapped to points on the screen [17]. However, these approaches generally emulate just the cursor-movement part of the computer mouse. The click function itself is normally implemented alongside the tracking techniques using a dwell time: given that the cursor is kept stagnant over an area for a specific amount of time, the click is automatically performed.

Dwell time usually works well, but it can be a problem if the executed task does not require a constant movement of the mouse pointer, such as watching a video or typing a text, especially if these tasks extend for a long time, due to fatigue caused by the mouse cursor control method [22]. Since dwell time method stays always active, automatic clicks would then occur whenever the user's head was stationary, which would turn the interaction quite cumbersome. In addition, the task execution time may be higher compared to other alternative click methods, because there is a need to wait for a certain amount of time to perform the click and this can adversely affect the user experience.

In this context, this work presents two devices developed to be used as alternative methods for clicking, which are based on electromyography and mouth-puffing. Electromyography (EMG) is a technique that allows the monitoring of the signals produced by the muscles. In this work, the signal produced when eyebrows are raised is used as an action to perform the click. The proposed puff-based device uses a piezoelectric disc as a pressure sensor that is responsible for detecting the user's puffing. An Arduino is responsible for receiving the signal produced by the developed devices and converting them into left click. Additionally, in order to integrate the alternative interfaces based on mouth-puffing and EMG into a complete mouse-like system, the head-tracking feature provided by the eViacam software was used, allowing the user to move the mouse cursor with head movements.

The main objective of this work is to perform a comparative study between three alternative click methods commonly used in the literature. The devices based on mouth-puffing and EMG have been developed, since the tools available in the market are quite expensive. The eViacam free software already implements the dwell time method as its standard click method, so the development of this functionality was not necessary. The methods were evaluated in two different scenarios with volunteers, where the execution time and the number of errors of each task were collected. A quantitative analysis was performed through statistical tests to verify if the time to perform the tasks and the number of errors are influenced by the type of method used. In addition, a qualitative analysis was performed considering the opinion of the volunteers who participated in the test stage in order to compare the level of satisfaction for each method.

The remainder of the paper is organized as follows. Section 2 discusses related works with respect to alternative methods and techniques applied as device control. Section 3 then provides details of the main resources used to build the system. Tests with volunteers are detailed in Section 4. The statistical tests applied are presented in Section 5, while respective results from the tests are discussed in Section 6. Finally, Section 7 presents the conclusions and plans for future works.

2 RELATED WORKS

This section presents papers that use non-conventional interactions as a method of control. Although this work focuses on devices used specifically as alternative methods of click, some works reported here might use these interactions for other purposes.

A sip-and-puff device was built in [23] to help people affected by tetraplegia to autonomously control a wheelchair. With a series of combinations of sips and puffs (similar to a binary combination of zeros and ones), it was possible to execute five basic actions: go forward and backwards, turn left and right, and stop. In another work focused on powered wheelchairs, a computer was placed in front of the user to assist in the controlling tasks [4]. The sip-and-puff module could be chosen among all modules (eye blinks; head, facial, and eye movements; and brain waves) to pick on a screen menu which action to execute on the wheelchair.

The work proposed in [32] used potentiometers together with a sip-and-puff module to help people with disabilities to guide the yaw spin rotation of a remote-controlled toy helicopter. For other movements, like up or forward, other types of control devices were used.

The FlipMouse, described in [1], allows a person to control the mouse cursor, as well as the click functions, using only the mouth. A joystick is used to move the mouse cursor. A switch inside the joystick allows the user to perform the mouse left click, while a puff sensor is responsible for catching the right click. The communication with the computer is established through a microcontroller, which manages the communication protocol required by the USB interface to use the mouse commands.

In [30], an accelerometer was used to emulate the mouse click when the occlusion action (clenching teeth) was performed. A wireless device was proposed, in which the transmitter module was placed behind the user's ear in order to detect the occlusion and send the information to the receiver part, which was connected to a USB port on the computer. In another proposal, the click function was implemented with the help of EMG circuits [25]. Electrodes were placed in the middle of the forehead and the user had to contract the frontal muscles by raising the eyebrows to perform the click. EMG was also used in [9] and [8] to perform the mouse clicks, as well as to control the mouse cursor through six different patterns of signals. Electrodes were now placed on the user's forearm in order to aid people who cannot use their hands. The work described in [3] also used the idea of emulating both click and movement of a mouse via electroencephalographic biosignals, which were in turn captured from the cerebrum's occipital lobe.

In [16], two optical sensors (an infrared emitter LED and a receiver LED) are used to allow the user to click by eye blinking. Both sensors are positioned close to one of the user's eyes in order to capture the voltage difference on the receiver LED pins more accurately when the user opens and closes the eyelid. The time between two voltage peaks was then translated into a click event. There is also a voice-controlled mouse device [7], in which a numbered grid is shown on the screen. When the user speaks a number, the grid is reduced to the respective number's rectangular subregion and the task is repeated until the grid cannot be further reduced.

According to the revised literature, none of the papers presents a comparative study between alternative methods of control. Only a device that uses some unconventional interaction as a control method is presented. Quantitative (based on statistical tests) and qualitative analysis, respectively, are fundamental to verify whether there is a significant difference between methods, considering the performance — time of accomplishment of tasks and amount of errors — and user satisfaction.

Therefore, this works aims at comparing three alternative methods for the mouse click event: puff-based device, an EMG circuit and the dwell time method. All of them use a head tracking software for the mouse cursor movement control.

3 MATERIALS AND METHODS

This Section presents the tools used in this work, showing the devices developed to be used as an alternative method of click and also the software used as control of the mouse pointer.

As an alternative method of mouse control, Enable Viacam (eViacam) head tracking software [10] was used. eViacam is a multiplatform program that captures the movements of the user's head, with the help of a webcam, and transforms into mouse cursor movements. Apart from being a free, open-source software, the main reason for the selection of eViacam are the customizable settings that can be adapted for each user.

The dwell time method is enabled by default on eViacam to perform the mouse click, but this feature can also be turned off, which leaves open the possibility of using other alternative methods of click.

EViacam also allows the user to receive visual feedback through the facial detection module, as shown in Figure 1. When the recognition is active, the rectangle around the user's face is represented in red with green dots inside. At times, during an interaction, the square may change to blue, meaning the face is no longer being detected.

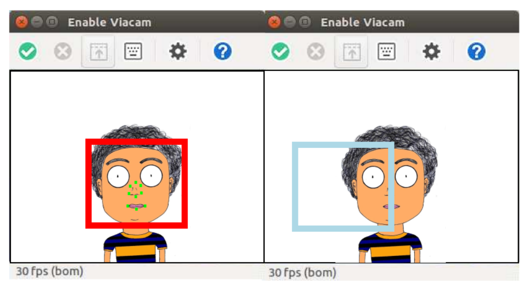

Figure 1: eViacam face recognition feedback.

Puff-Based Device

The puff-based device uses a piezoelectric sensor as the central component and is responsible for the perception of the user's breath. The device is divided into two modules: transmitter and receiver. The transmitter module is responsible for sending, through an Arduino [2] in conjunction with a radio frequency (RF) module, the signals produced by the piezoelectric sensor. The receiver module also has an Arduino in conjunction with an RF module and is responsible for receiving the signals and classifying them. It is important to note that the communication between the two modules is wireless and the receiver module is connected to the computer via USB.

The transmitter module is located in a custom headset based on the prototypes developed in [6, 28] which is responsible for always keeping the sensor in front of the user's mouth, regardless of the position of the head. Figure 2 shows how the headset is used and how the electronic components are arranged inside it.

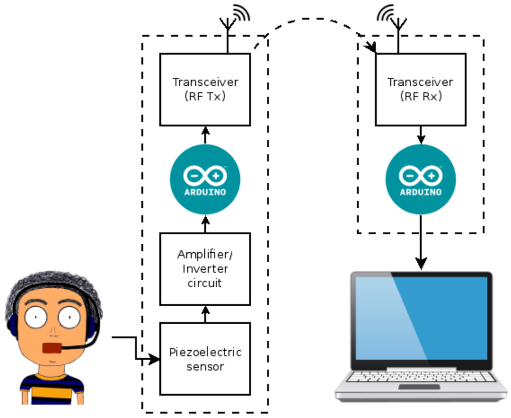

Figure 2: Mouth-puffing based method architecture.

EMG Device

The EMG-based device uses biopotential signals produced by the contraction of the muscles located in the region above the user's eyebrows. Figure 3 shows the architecture of the modules present in the EMG-based method.

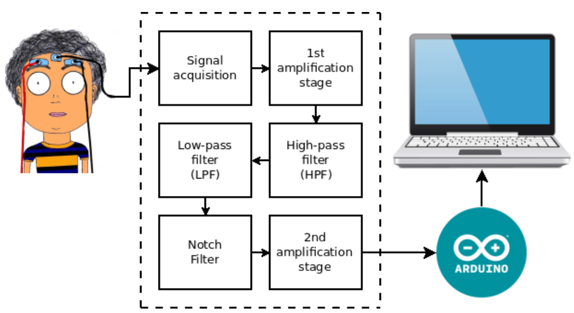

Figure 3: EMG architecture.

There are a few steps of analog signal processing performed in the EMG circuit. After the acquisition, the signal is amplified using a specific component (instrumentation amplifier) for low-intensity signals such as biopotential signals. The amplified signal is filtered to only allow the passage of desired frequencies (low-pass and high-pass filters) and to attenuate noise caused by power line (notch filter). After filtering, the signal is again amplified, allowing the Arduino to correctly classify it [13] [20].

Signals Classification

The output of the circuits (puff and EMG) is connected directly to the analog port of the Arduino. The binary classification of the signals into click and not click is performed using the algorithm shown in Figure 4. The signal is read on the analog port of the Arduino and when the amplitude of the signal is greater than 0.5 Volts, the left mouse click is performed. When the click occurs, one second is waited before performing further signal readings.

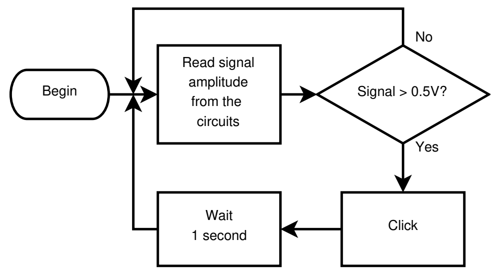

Figure 4: Algorithm used to classify the signals.

4 TEST ENVIRONMENT AND PROCEDURES

An overview of the physical environment in which the volunteers performed the tests is shown in Figure 5. A laptop was positioned in front of the participant to capture, through the integrated webcam, the real-time frames of the user's face. The tests were performed individually with all participants in the same environment during daylight. The illumination of the test environment was controlled in order to not interfere negatively in the facial detection of the mouse pointer control software.

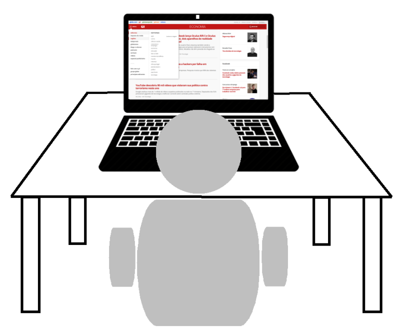

Figure 5: Test environment overview.

Tests were performed in YouTube (https://www.youtube.com/) and G1 (https://g1.globo.com/) websites, shown in Figures 6 and 7, respectively, with their respective areas of interest highlighted in color and labeled as A1, A2, etc. These websites were chosen because they were not adapted to the type of alternative methods investigated in this paper. When using the dwell time method, for example, watching a video in YouTube becomes quite a challenge because the user is forced to keep the cursor in movement in order to avoid executing the click action unintentionally. However, navigation in YouTube does not require great precision, as can be seen in Figure 6, the clickable elements are relatively large and spaced from each other, preventing clicks on unwanted elements occur. G1's interactive menu, on the other hand, is also a problem for eViacam head tracking module, since the items on the navigation bar expand and change accordingly by just hovering the cursor over the menu's item. In addition, the clickable elements in G1 are small and very close to each other, as seen in Figure 7, requiring great user precision to avoid unwanted clicks.

Figure 6: Areas of interest in YouTube webpage.

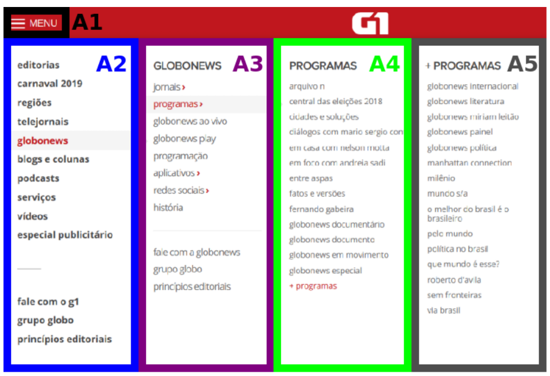

Figure 7: Areas of interest in G1 webpage.

The selection of the click method used by the participant was performed randomly. After the method selection, the tasks shown below were presented to the users with a brief description and in order of execution. For G1's webpage, the menu started unexpanded, while YouTube's webpage initial state was a paused video in full-screen mode.

- Test in YouTube webpage (see Figure 6):
  - Click on the play button. (A1)
  - Click on the subtitles button. (A2)
  - Set the volume to 50%. (A1)
  - Return the video to the initial 10 seconds. (A1)
  - Click to select the next video. (A1)
  - Click on the exit full-screen button. (A2)
- Test in G1 webpage (see Figure 7):
  - ∗ Subtask 1:
    - Move the cursor to the menu icon. (A1)
    - Move to "*editorias*". (A2)
    - Move to "*economia*". (A3)
    - Click on "*tecnologia*". (A4)
  - ∗ Subtask 2:
    - Move the cursor to the menu icon. (A1)
    - Move to "*editorias*". (A2)
    - Move to "*natureza*". (A3)
    - Click on "*desafio natureza*". (A4)
  - ∗ Subtask 3 :
    - Move the cursor to the menu icon. (A1)
    - Move to "*globonews*". (A2)
    - Move to "*redes sociais*". (A3)
    - Click on "*globonews*". (A4)
  - ∗ Subtask 4:
    - Move the cursor to the menu icon. (A1)
    - Move to "*globonews*". (A2)
    - Move to "*programas*". (A3)
    - Move to "*+programas*". (A4)
    - Click on "*globonews política*". (A5)

Each time the participants completed a task, they were asked to respond to a questionnaire of six multiple choice questions about the aspects of the task performed. Besides, the users responded to three subjective questions in which they were free to give opinions and suggestions.

Regarding the tasks, the time to complete the task and the number of click errors were collected. The volunteer was instructed to always start with the mouse pointer in the center of the screen before each task, to have a pattern at the time of performing the task execution count. The count of click errors was based on involuntary clicks, caused by the click methods used, and also by clicks that were not part of the pre-established routine.

5 STATISTICAL TESTS

The samples related to the number of click errors and to the execution time of a given task (dependent variables), obtained through the data collection in the test stage, were submitted to two statistical tests to verify if there is influence of the click method used on the dependent variables. The Chi-Square and one-way ANOVA tests were applied to analyze the data concerning the time samples and errors, respectively. These tests were applied because they better fit to the data characteristics, as will be shown in Section 6.

The level of significance used in this work was $\alpha = 5\%$ and statistical analyses were done using the Python programming language [27] with the help of the StatsModels [31] and SciPy [29] libraries.

Chi-Square Test

The contingency coefficient C was used to determine the magnitude of the association between errors and click methods. This coefficient is obtained from the Chi-Square (X^2) test under the null hypothesis (H_0), which tests whether the independence between the variables is true [11]. The X^2 test statistic is obtained from Equation 1.

$$X^2 = \sum_{i=1}^{l} \sum_{j=1}^{c} \frac{(O_{ij} - E_{ij})^2}{E_j} \quad (1)$$

The rows and columns are represented by the variables l and c, respectively, O_{ij} is the frequency observed at the intersection of the i^{th} category of the first variable with the j^{th} category of the second variable. The expected frequency (E_{ij}) at the intersection of i^{th} with the j^{th} category of the two variables is obtained from Equation 2.

$$E_{ij} = \frac{n_j n_i}{N} \quad (2)$$

The total frequency observed in the i^{th} category of the first category i represented by n_i, whereas n_j is the total frequency observed in the second category. It is desired that the expected frequencies are greater than five [11]. The number of degrees of freedom (df), for the Chi Squared statistic, is $df = (l - 1)(c - 1)$. The contingency coefficient (C) for the sum of all categories N is given by Equation 3.

$$C = \sqrt{\frac{X^2}{N + X^2}} \quad (3)$$

Analysis of Variance

In order to verify if the methods investigated this work influence the average time of execution of the tasks, the single-factor ANOVA (one-way ANOVA) was used. The technique assumes, in addition to the independence of the data, that the means follow a normal distribution with common variance σ^2. The tests used to evaluate these two assumptions were the Shapiro-Wilk and Levene tests, respectively [21].

Since the result of analysis of variance (F-value) is significant, it is necessary to use a Post-Hoc test [24], to identify which samples are different because the ANOVA test shows only that there is a difference between the means but does not indicate which means are different.

The Tukey HSD (honestly significant difference) is the selected Post-Hoc in this work. This test is used to determine which of $K \geq 3$ sample means are significantly after ANOVA test has indicated there is sufficiently strong evidence to reject the overall null hypothesis that all population means are equal [18]. The Tukey HSD is a conservative test (low false positive rate) and uses comparisons between pairs to determine which method is different.

6 RESULTS

The click methods investigated in this work were compared through quantitative and qualitative analysis. For the former, statistical tests of significance, for the task execution time and the number of errors, were used. The qualitative analysis, on the other hand, was carried out based on the volunteers opinions. For this, the data were collected through a questionnaire that contained six multiple-choice questions about the method used and also three subjective questions, where the participants could express their own considerations about the tasks and the click method employed.

The study was conducted with 14 females and 26 males, totaling 40 participants. All volunteers are students of a public university. The invitation of the participants occurred simply and by convenience. Table 1 shows the number of participants organized by type of method used in the tests.

Table 1: Number of participants for each method.

Method	Females	Males	Total
Dwell	6	9	15
Puff	4	11	15
EMG	4	6	10
Total	**14**	**26**	**40**

Statistical Analysis for the YouTube Task

Table 2 presents the frequency of errors by the method to obtain the contingency coefficient C and obtain the test of independence between the methods and the amount of error for the case of YouTube. It is important to note that Y is the number of errors. The Chi-Square test showed that there is no association between the method and the click errors ($X^2(2) = 0.55, p = 0.758 > 0.05$). Through the Chi-Square test, the contingency coefficient was obtained with the value $C = 0.12$.

Table 2: Frequencies of errors for the YouTube case.

Method	Y=0	Y≥1	Total
Dwell	5	10	15
Puff	7	8	15
EMG	4	6	10
Total	**16**	**24**	**40**

Figure 8 shows, using boxplot, the distribution of the data regarding the time of the test in YouTube. The boxes represent the middle half of the distribution. The red line represents the median of the data. The ends of the dashed vertical lines represent the lower and upper limits of the distribution and all points outside the ends are considered outliers. Since the samples are small, none outlier has been removed from the analysis.

Table 3 shows the descriptive statistics of the time taken in YouTube. It is possible to observe that the average times — in

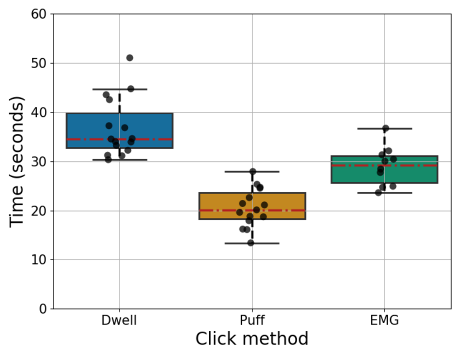

Figure 8: Distribution of data for YouTube time.

seconds — of the methods are different, which presented average and standard error, respectively, equal to $36.71s; 1.56s$ (dwell), $20.55s; 1.02s$ (puff-based method) and $28.98s; 1.26s$ (EMG).

Table 3: Descriptive statistics for YouTube time.

Method	N	Mean	Median	Std. deviation	Std. error
Dwell	15	36.71s	34.5s	6.02s	1.56s
Puff	15	20.55s	20.1s	3.95s	1.02s
EMG	10	28.98s	29.2s	3.99s	1.26s

Applying the Shapiro-Wilk and Levene tests, the prepositions of normality ($p = 0.06$) and homogeneity ($p = 0.577$) of the residues, respectively, were satisfied. Therefore the ANOVA test can be applied to the samples. The one-way ANOVA test showed that there is an effect of the click method used on the time required to perform the clicks ($F(2, 37) = 41.628, p = 0.00 < 0.05$). The Tukey HSD Post-Hoc test was used to verify which means are different.

The Post-Hoc test showed that, on average, users needed less time to perform click tasks in YouTube using the puff-based method (see the means column in Table 3), since there is a significant difference ($p < 0.05$) across all pairs of methods, as shown in Table 4. It is important to note that the EMG-based method was the second best in terms of performace and the dwell time was the method in which users needed more time to complete the task.

Table 4: Post-Hoc test for YouTube time.

Methods compared	Mean difference	Std. error	Sig.
Puff-Dwell	±16.16s	1.77s	.000
Puff-EMG	±8.42s	1.98s	.000
EMG-Dwell	±7.73s	1.98s	.001

Given the results obtained through statistical analysis of the data collected in the YouTube task, it is possible to affirm that the methods of clicks analyzed did not interfere in the amount of errors. However, the time to perform the click tasks is significantly different among all click methods, with an advantage to the puff method, since, on average, users who used this method took less time to complete the task.

Regarding the execution time, the dwell time was outperformed by the two other methods. This was already an expected result, since the dwell time naturally increases the task execution time due to the need to wait a certain number of seconds for the click to be activated. The independence of click methods on the number of errors was also expected, as the YouTube task does not require much accuracy to perform the click action because the clickable items are not very close to each other.

Statistical Analysis for the G1 Task

Table 5 presents the frequency of errors for each method, which were used to calculate the contingency coefficient C and obtain the test of independence between the methods and the amount of error for the case of G1. The Chi-Square test showed that the amount of errors depends on the click method used ($X^2(2) = 7.81, p = 0.02 < 0.05$), although this test was compromised because one of the expected frequencies was less than five [11]. Through the Chi-Square test, the contingency coefficient was obtained with the value $C = 0.40$.

Table 5: Frequencies of errors for the G1 case.

Method	Y=0	Y≥1	Total
Dwell	4	11	15
Puff	11	4	15
EMG	7	3	10
Total	**22**	**18**	**40**

The distribution of the data regarding the execution time of the test in G1 is shown in Figure 9. It is possible to observe that the puff-based method, which had the lowest error rate (27%), also presented a shorter time on average. Table 6 shows the descriptive statistics of the time taken in G1. It is possible to note that the means of the EMG and dwell time methods are not so different from each other ($64.31; 2.12$ e $57.44; 3.75$, for EMG and dwell time, respectively).

Shapiro-Wilk ($p = 0.993$) and Levene ($p = 0.207$) tests showed that the means are normally distributed and are homogeneous, thus not violating the assumptions of normality and homogeneity of residues, respectively. In other words, the ANOVA test can be applied to the data collected from G1 with respect to the task time.

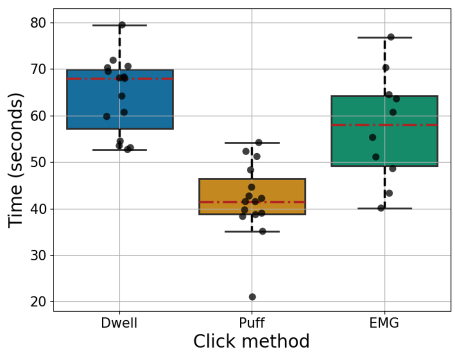

Figure 9: Distribution of data for G1 time.

Table 6: Descriptive statistics for G1 time.

Method	N	Mean	Median	Std. deviation	Std. error
Dwell	15	64.31s	68s	8.20s	2.12s
Puff	15	42.02s	41.5s	8.08s	2.09s
EMG	10	57.44s	58s	11.86s	3.75s

The ANOVA one-way test showed that there is an effect of the click method used on the time required to perform the click tasks in G1 ($F(2, 37) = 22.90, p = 0.000 < 0.05$), as well as in YouTube. The Tukey BSD test was applied in the samples to determine which means are significantly different, showing that only the mean time of the puff-based method is different from the others ($p < 0.05$) as can be seen in Table 7.

Table 7: Post-Hoc test for G1 time.

Methods compared	Mean difference	Std. error	Sig.
Puff-Dwell	±22.29s	3.35s	.000
Puff-EMG	±15.42s	3.75s	.000
EMG-Dwell	±6.87s	3.75s	.173

Given the results of the statistical tests for the G1 task, it is possible to state that the type of method used influences the occurrence of click errors. In the case of the execution time of the task performed in G1, there is a significant difference between the puff-based device and the other methods. Therefore, the puff-based method was the best to perform the click tasks on both websites.

The significant difference, on the time to execute the tasks, was not expected only for the puff-based method, since the EMG, due to the autonomy to perform the click, should have been better than the dwell time. The influence of the click methods on the amount of error was expected, since the clickable items in the G1 interactive menu are very close to each other, so this task required more accuracy than YouTube. Consequently, the dwell time was the method with the higher number of errors on average.

Qualitative Analysis

In this section, the results of six multiple-choice questions answered by the volunteers at the end of each task, which are shown in Table 8, and a discussion about the subjective questions on the click method used, is addressed.

Figure 10 shows an overview of the questionnaire responses. The answers are shown using treemap, a visualization technique that allows mapping hierarchical data to a rectangular region [15] [14]. The data hierarchy is organized by click method, task, and questions, respectively. The size and colors represent the amount of a given answer and the response itself, respectively. The colors are represented by a Likert scale, which in this case varies from 1 to 5. The colors red, orange, yellow, light green and dark green represent answers 1, 2, 3, 4 and 5 respectively.

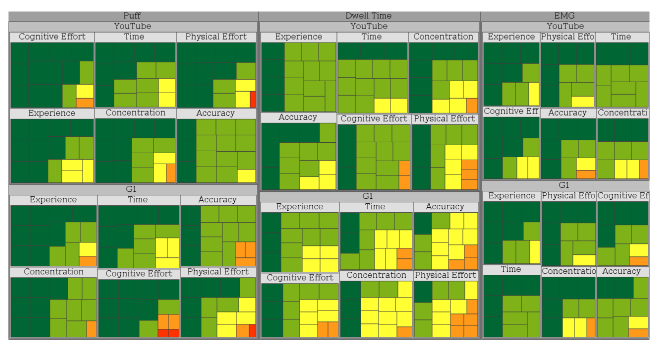

Figure 10: Overview of multiple-choice questions.

The criterion considered to measure the satisfaction level for each question is based on the amount of dark green and light green ratangles. Generally, it is possible to observe that the participants who used the dwell time were less satisfied than the volunteers who used the other two methods investigated in this work.

Experience. According to answers, participants who used the dwell time method had a less satisfactory experience than the other volunteers. This happened due to the lack of autonomy at the time of the click, since it is made automatically and several times this made difficult the execution of the tasks, generating undesirable clicks, mainly in the G1, that required a greater precision.

Time. Regarding the execution time of the tasks, the participants who used the devices based on mouth-puffing and EMG are more satisfied than the other method. The dwell time method presented an expected low performance, since the need to wait for the click occurrence naturally increases

Table 8: Questions used in the multiple-choice questionnaire.

	Question	Answer	
1	How was your **experience** using this alternative method?	1 – insufficient	5 – excellent
2	What did you think of the **time** to accomplish the task?	1 – slow	5 – fast
3	How **accurate** was the task?	1 – insufficient	5 – excellent
4	How was the **cognitive effort** to accomplish the task?	1 – high	5 – low
5	How was the **physical effort** to perform the task?	1 – high	5 – low
6	Did you **focus** more on the task or on the click method?	1 – on the click method	5 – on the task

the execution time of the task, directly influencing the satisfaction level of the participants. This can be perceived mainly in the G1 task, where there is a higher frequency of responses in yellow and orange.

Accuracy. The accuracy to perform clicks was directly influenced by mouse cursor control software, because in many cases facial detection did not work correctly when it was necessary to move the pointer to the corners of the monitor, making it difficult to perform the clicks on the specified items. This fact can be noticed by the lower occurrence of dark green responses (5), especially the dwell time, which was the method most affected by this problem, since this failure in facial detection often lasted long enough for the activation of the click, causing clicks on unwanted elements.

Cognitive effort. In the study of the question related to cognitive effort, the methods based on mouth-puffing and EMG presented a higher level of contentment, despite the task performed in G1, where two participants (puff-based) reported the difficulty in focusing on the desirable elements, since the tabs alternated as the mouse cursor moved between the menu items.

Physical effort. The method that most users showed to have been disturbed by the physical effort was the dwell time. This can be perceived by the number of yellow and orange rectangles. This happened because users had to move the cursor at all times to avoid undesirable clicks, causing physical discomfort.

Concentration. For the case of the concentration factor, the majority of participants who used the puff-based and EMG devices reported that they focused more on the task than on the method used, since these methods allow a certain autonomy for the realization of clicks.

On the other hand, many participants who used the dwell time reported that they had to concentrate on the operation of the click method to avoid that involuntary clicks occurred, since this method does not provide autonomy like the other evaluated methods. It is possible to perceive these facts by the quantity of yellow and orange rectangles of the dwell time method in contrast with the superiority of rectangles in light and dark green of the methods that use physical devices (puff and EMG).

Discussion About the Subjective Questions

At the end of the tests, each participant answered in a virtual questionnaire with the following questions:

- *"What positive points can you cite about the click method used?"*
- *"What negative points can you cite about the click method used?"*
- *"Based on your experience, what suggestions would you give about the click method used?"*

Participants were encouraged to answer all three questions, but to feel themselves free to respond them or not. All answers have been read and are synthesized below.

For the case of the dwell time method, the majority of participants reported the possibility of performing tasks easily and without the need to use their hands. For example, a volunteer reported: "*it is easy to use and you do not have to use your hand*". However, some participants have argued there is a need to become accustomed to the method in order to be able to use it easily. As negative points, many users commented on the discomfort of moving the mouse pointer to avoid involuntary clicks. One of these participants reported: "*the automatic click causes discomfort because it can not stop the mouse cursor, causing neck fatigue*". In addition, some volunteers reported that facial detection failures influenced click precision, since the software often took time to re-detect the user's face and this time was sufficient to perform the click. The suggestion for improvement was quite diverse. Some participants pointed to the need for slower pointer and click speed while others stated that they would feel more comfortable if the pointer and click speed was faster. Moreover, improvements in facial detection, the addition of a gesture to disable click and replacement of cursor control software have also been reported.

In the case of the puff-based method, many participants mentioned that the device is accurate enough to recognize the mouth-puffing and convert it into a click. One of the participants reported: *"I had never used an alternate click interface and my experience was very good because I really liked the precision of the click"*. Because the headset always keeps the sensor in front of the user's mouth regardless of the angle of the head, the click recognition rate is quite high, despite the occurrence of some cases where the volunteer was blowing insufficiently enough for click activation. The eViacam was indicated as a negative point by the majority of the participants, since the detection failed constantly. In addition, some volunteers did not like the headset used, as this tool was not adjustable for different head sizes. One participant said: *"The headset did not fit right in my head and that was kind of uncomfortable in some ways"*. Furthermore, the implementation of other mouse functions, such as the right click, was also suggested.

For the EMG-based device, reports such as *"easy to use"* and *"low physical effort to perform clicks"* were frequent among most participants. This ease according to the volunteers lies in the simplicity of performing the eyebrow lift movement to perform the click and this movement requires a relatively low physical effort. However, failures in face detection in many cases interrupted the execution of the tasks, frustrating the users. The need to use electrodes connected to the body also bothered some participants, since in some cases the user would bump into the wires connected to the electrodes causing involuntary clicks. Again the participants mentioned the replacement of eViacam as a suggestion for improvement. In addition, the decrease of elements connected to the body was also mentioned and classifying the action of blinking the eyes using the help of a webcam to capture this action was suggested as an alternative, thus eliminating the use of the EMG device.

7 FINAL CONSIDERATIONS

This work presented an evaluation of three click methods through quantitative tests and a qualitative analysis based on the opinions of the users. The source-code and hardware schematics are publicly available to the community on GitHub [5].

Statistical tests confirmed, for the case of YouTube, the hypothesis that the dwell time method would be inferior in performing the tasks compared to methods that offer greater autonomy for the accomplishment of the clicks. However, in the G1 task, there was only a significant difference in the mean execution time of the puff-based method. This was an unexpected result, since the need to wait a certain time for the click to occur should increase the mean execution time so that there was also a difference between the EMG-based method and the dwell time, especially for a task that requires a lot of accuracy such as the G1 scenario.

On the other hand, with regard to click errors, the results obtained were in agreement with the expected, since the influence of the click methods on the number of errors is more noticeable in scenarios that require greater precision to execute the clicks as the case of the G1.

According to the answers given in the questionnaire by the users, the devices based on mouth-puffing and EMG are the best methods to perform the proposed tasks. The level of satisfaction of the participants confirmed that the dwell time is not an ideal method to be used, since the lack of autonomy negatively influences the execution of the tasks.

Given these circumstances, it is possible to affirm that, in general, among the evaluated devices and scenarios, the methods based on mouth-puffing and EMG are the best to be used as alternative methods of click, due to the performance on the tasks and the level of satisfaction of volunteers. Despite the good results presented, participants were not entirely satisfied with the proposed devices in this paper, as problems related to the size of the headset and the need to use electrodes connected to the body, for devices based on mouth-puffing and EMG, respectively, were reported.

Future Works

The software that allows controlling the mouse cursor using the head movements did not please many participants, because several times the facial detection did not work correctly, negatively affecting the execution of the tasks. Therefore, it is necessary to search for alternative mouse cursor control applications. The tracking of eye movements could even be used for the control of the pointer, since the interaction by gestures of the head was considered tiresome for some users.

The development of an adjustable-size headset is also required to provide more comfort. Because the size of the headset is fixed, many people may not feel comfortable, since the headset may not fit properly on the user's head.

It is also important to carry out a study with more alternative methods of clicking to see if the performance of the puff-based method continues higher than other methods not tested. Increasing the number of participants is also necessary, as the more people test the methods, the results will be more significant.

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