

Mouse Behavioral Patterns and Keystroke Dynamics in End-User Development: what can they tell us?

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ABSTRACT

Studying human behavior is of particular interest within the field of Human-Computer Interaction (HCI) as it can provide insight into human performance. Prior HCI research suggests that mouse and keyboard monitoring may provide a more complete picture of user behavior under high cognitive loads like decision making and developing tasks. In this exploratory study we investigate the potential correlation between a set of End-User Development (EUD) behavioral attributes and mouse behavioral patterns and keystroke dynamics. We conduct a field test on 30 end-users interacting with a modern web-based EUD tool for the construction of simple web forms. Our findings reveal the existence of several significant correlations between end-users' behavioral attributes and mouse pattern metrics or keystroke dynamics during the development process. Mouse pattern metrics like random and straight movements, mouse hovers, etc., can be associated with perceived ease use, perceived usefulness, self-efficacy, willingness to learn or risk-perception. Similarly, some keystroke dynamics like key press speed and down-to-down time can be associated with perceived ease of use or self-efficacy.

KEYWORDS

End-User Development (EUD); mouse tracking; mouse behavioral patterns; keystroke dynamics; end-user behavior

1. INTRODUCTION

Modern computing advocates the idea of end-users using mobile and web applications to accomplish their daily tasks. This has given rise to the need for web-based development activities by the end-user. End-User Development (EUD) activities are considered cognitively demanding since they demand non-professional end-users to develop their own artifacts without getting trained and without knowing programming languages and logic.

Understanding end-users' behavior under high cognitive loads, like developing and decision making activities, has become a major focus in Human Computer Interaction (HCI) research (Djamasbi et al., 2008; Payne, et al., 1988; Svenson, 1993) as it can provide insight into user performance. One class of behavior that is of interest within HCI research is mouse and keyboard behavior and therefore, techniques for studying mouse movement behavior and keystroke dynamics have been considered an effective means of HCI. In the area of web-user interaction mouse and keyboard monitoring is a vital

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part since it can implicitly and dynamically provide useful information about the users' state of mind, their perceived user experience and the system usability.

Mouse movement can be thought of as a series of moves, i.e. gestures, and each gesture is a specific and continuous physical process initiated and concluded by the user (Arapakis et al., 2014). Hence, several mouse-tracking studies suggest the existence of a typology of users based on observed cursor behavior (Leiva et al., 2008; Rodden and Fu, 2007; Rodden et al., 2008). Researchers estimate that mouse features can reflect specific user behavior patterns regardless of the task and the environment and can be used to model users' behavior (Hinbarji et al., 2015). Common mouse behavioral patterns, such as hesitation pattern, straight pattern, random pattern, etc. have been identified in many research works (e.g. Atterer and Lorenzi, 2008; Ferreira et al., 2010; Lee and Chen, 2007; Mueller and Lockerd, 2001; Rodden et al., 2008) but their characterization is generally vague, and their identification remains a largely visual process and is mainly based on qualitative analysis. Mouse pattern related metrics remain undefined and hence mouse patterns have not been quantitatively measured and analyzed in some important HCI behavioral research areas like EUD-user behavior.

Recently, keystroke dynamics (i.e. the timing information describing key press and release events), an approach from user authentication research, has also been used in HCI research to detect user cognitive and affective states, like mood and emotions (e.g. Khanna and Sasikumar, 2010, Epp et al. 2011). Similarly to mouse behavior, keystroke dynamics seem promising for modeling user behavior (Epp et al., 2011). However, despite their easy and useful applicability, keystroke dynamics have not been broadly studied in HCI behavioral research and we notice their complete absence from the EUD field.

Triggered by the above-described situation, this exploratory study examines whether end-users' mouse and keystroke behavior is associated with well known EUD behavioral attributes including perceived ease of use, perceived usefulness, self-efficacy, willingness to learn and risk perception. Our main objective is twofold: i) first to divide each 'popular' mouse behavioral pattern in a set of measurable mouse metrics and examine the potential correlations between these 'pattern-derived' attributes and EUD-user behavioral attributes, and ii) to examine the potential association between a set of common keystroke dynamics and EUD behavioral attributes.

The central goal of our research is to identify possible connections between mouse movements and/or keystroke dynamics and a set of EUD user behavioral attributes, like self-efficacy, risk-perception, etc. and understand how mouse behavioral patterns and keystroke dynamics are related to user behavioral states during EUD task execution.

The findings of this work seem promising and may provide the EUD research community with background knowledge and a motivation to study further and understand end-user developer mouse and keyboard behavior in today's web-based EUD systems.

This paper is organized as follows. The second section presents the literature background, including an overview of the End-User Development field, the behavioral EUD-user attributes we plan to measure, the mouse behavioral patterns and keystroke dynamics as well as similar past works. The third section presents the research objectives and questions that need to be examined. The fourth section describes the research methodology which is composed of four parts: i) the prototype web EUD tool that was used for the field test, ii) the monitoring mechanism and the data extraction method, iii) the field test implementation including: the participants and procedure, the given user task, the performance measure design and the questionnaire survey and finally ix) the data analysis method. The fifth section presents the results and the sixth section discusses the main findings and explains the study's possible issues and limitations. The last section presents the main conclusions and some future research directions.

2. THEORITICAL FRAMEWORK

2.1. End-User Development

According to Lieberman et al. (2006), EUD is ‘a set of methods, techniques and tools that allow users of software systems, who are acting as non-professional software developers, at some point to create, modify or extend a software artifact’. What characterizes end-user developers is that they express a need to modify on their own the computer systems they use and to gain more control over their computer applications (Lieberman et al., 2006; Repenning and Ioannidou, 2006).

EUD is inherently different from traditional software development. Burnett and Scaffidi (2011) declare that trying to support EUD by simply mimicking traditional development approaches will possibly lead to unsuccessful outcomes.

Fortunately, there are many remarkable EUD approaches, most of them presented in details in the work of Spahn et al. (2008) and Paternò (2013). Indicatively, such approaches include programming using visual attributes, programming by demonstration (PBD), programming by specification, programming with text, interface customization, natural programming, visual programming, spreadsheets, etc.

Many EUD technologies have been designed according to the abovementioned approaches. For instance, PBD-based tools are available for creating animations and are often used in combination with visual or textual languages. According to programming by specification, Liu and Lieberman (2005) implemented a system that accepts specification in natural language and generates a corresponding program written in Python. Some systems, like the Topes System of Scaffidi et al. (2008) provide a forms-based visual interface, restricting the user’s specifications to only those that can be handled by the tool. The CoScripter (Scaffidi et al., 2010) tool is a good example of combining visual with textual specifications, since it uses a textual language to represent a web macro, which is a script that directs a web browser to navigate the web and manipulate websites in a particular way (Burnett and Scaffidi, 2011).

While the first EUD tools were mainly focused on desktop graphical applications, in recent years a considerable amount of work has been carried out to apply the EUD approach to web environments (Paternò, 2013). According to Rode et al. (2005), web EUD tools can be categorized to three main categories: database-centric tools that are primarily intended to help end-users put databases online for viewing and editing purposes, form-centric tools that are intended to help end-users create forms for collecting data and website-centric tools whose primary purpose is assisting the user with the creation of static or dynamic websites. Some examples of database-centric EUD tools are PhpClick (Rode et al., 2005; 2006), FORWARD (Ong, 2010), Visque (Borges and Macías, 2010), XIDE (Litvinova, 2010), CRIUS (Qian et al., 2010) and Simple-Talking (Protogeros and Tzafilkou, 2015). There are also some query-centered approaches for mobile systems, such as Query by Zoom (Silveira, 2010) and Query- by-Object (Akiyama and Watanobe, 2012).

2.2. User Behavioral Attributes In End-User Development

End-users follow different approaches and reasoning strategies to modeling, performing and documenting the tasks to be carried out in a given application domain (Blackwell and Morison, 2010; Costabile et al., 2008). In this context, research in Human-Computer Interaction (HCI) has put considerable effort over the past decades to build theories and models which attempt to explain end-users’ perception while using computer software to customize, program and/or develop artifacts.

A series of end-user behavioral theories that shed behavioral attributes in HCI and EUD research have been developed. Some of the most dominant theories in the EUD community are: Self-Efficacy Theory (Bandura, 1977; 1986), Attention Investment Theory (Blackwell, 2002), Information gap Theory (Lowenstein, 1994) and Technology Acceptance Theory (Davis, 1989). These theories have

shed light on the significance of several EUD/HCI behavioral attributes such as Self-Efficacy, Risk-Perception, Willingness to Learn, Perceived Usefulness and Perceived Ease of Use. These variables are important to be measured for the analysis of end-users' behaviour since they tend most of the time to influence their performance (Tzafilkou et al., 2017).

Following we briefly present each one of them.

Self-Efficacy

According to Self-Efficacy theory studies, self-efficacy (SE) conveys an individual's level of confidence to execute courses of action in a given situation. Self-efficacy has been studied in depth by Bandura (1977; 1986) who found that it can be influenced by environmental situations, cognitive and personal factors as well as demographic characteristics. Social cognitive theory (Bandura, 1977; 1986) posits self-efficacy as a key determinant of skill acquisition and task performance.

Computer self-efficacy is an extension of self-efficacy that is specifically related to computer usage (Compeau and Higgins, 1995). Pajares (2002) argues that self-efficacy can affect task effort, persistence, expressed interest, and the level of difficulty of goals users will strive to attain. Stated in Blackwell et al. (2009) point out that being a challenging task, software development renders a person with low self-efficacy may be less likely to persist when a task becomes challenging. Moreover, self-efficacy is tightly linked to positive physiological and emotional states in the aftermath of a successful execution of certain behavior (Shea and Bidjerano, 2010).

Risk-Perception

Analyzed in Blackwell's Attention Investment Model theory (Blackwell, 2002), Risk-Perception (RP) is considered as a factor that strongly influences the end user's behavior through their cost/benefit evaluation. According to Blackwell (2002), risk is the probability that no pay-off will result, or even that additional future costs will be incurred from the way the user has chosen to spend attention. If users decide that the costs and/or risks are too high in relation to the benefits they may choose not to follow through with the action. Perception of risk thus plays an important role in a user's decision making about whether to use particular application features (Beckwith and Burnett, 2004). The Attention Investment Model predicts that higher perception of risk can lead to differences in actual behavior. Risk-Perception can strongly influence computer related behavior (e.g. Willingness to learn, Self-Efficacy, etc.) since it determines the whole 'confidence and security' the end-user feels while interacting with the computer environment.

Low Risk-Perception has been shown to be positively related to performance during computer related tasks. High Risk-Perception renders users less likely to make use of unfamiliar features (Beckwith et al., 2005) eliminating their 'high performance' possibilities and the successful task completion. High perceived risk results in avoidance behavior (not using features that might help them in their task), then the result could be lower task performance, or a higher cost (in time) to accomplish the desired computer task (Beckwith and Burnett, 2004).

Willingness to Learn

Willingness to Learn and use new features (Grigoreanu et al., 2008; Burnett et al., 2010) is a EUD behavioural attribute affecting the end-users' overall performance since it reveals the user's motivation power, determines the amount of effort the user makes and the perspectives of his/her future performance enhancement. It is included among the main behavioral attributes GenderHCI studies since many times it tends to affect male and female end-users' differently while interacting with EUD tools (Beckwith and Burnett, 2004).

Willingness to learn can also be seen as a type of exploratory behavior. Exploratory behavior is directly associated to learning and has been proved to be ‘used’ in a different way by end-users. In particular, some end-users tend to ‘explore’ much more than others (Burnett et al., 2008).

According to Loewenstein’s information gap theory (1994), willingness to learn is also highly associated with self-efficacy since a user needs to have a certain level of self-efficacy in order to reach a useful level of curiosity. This curiosity will leverage the levels of their exploratory behavior and hence willingness to learn, enhancing at last their performance (Burnett et al., 2011). Willingness to Learn is an important attribute because it can ‘predict’ the end-user’s willingness to try, persist, tinker and even search for guidance or study to learn how to use new features and EUD technologies.

Perceived Usefulness and Perceived Ease of Use

The original Technology Acceptance theories, developed by Davis (1989), do not necessarily focus on end-users as their primary audience, and the technologies studied are general software technologies. Nevertheless, there are strong ties to the more specific research of end-user problem solvers (Beckwith and Burnett, 2007).

The main purpose of Technology Acceptance Model (TAM) (Davis, 1989), is to explain and predict information technology (IT) acceptance and facilitate design changes before users have experience with a system. TAM is considered one of the well-known models related to technology acceptance and use since it has shown great potential in explaining and predicting user behavior of IT (Park, 2009).

According to TAM, when users are presented with a new technology, two key factors influence their decision about how and when they will use it: perceived usefulness and perceived ease of use (Davis, 1989; Venkatesh and Morris, 2000). TAM suggests that perceived ease of use and perceived usefulness are the two most important factors in explaining system use. Additionally, the End-User Computer Acceptance (EUC) theory introduces the most relevant human factors affecting the end-users’ overall behavior and performance including perceived ease of use and usefulness (Chen and Corkindale, 2008; Cyr et al., 2007; Sun and Zhang, 2008).

Following we describe the meaning and terminology of the two above mentioned key acceptance attributes:

- Perceived ease of use is defined as the degree to which a person believes that using the system would be free of effort (Davis, 1989). Given that effort is a finite resource, an application perceived to be easier to use than another is more likely to be accepted by users (Davis, 1989). Its role is crucial in EUD tasks and it can affect users’ performance, as mentioned in many researches (e.g. Beckwith, et al, 2006; 2007; Beckwith et al., 2005; Burnett, 2009, Burnett et al., 2008; 2010; 2011).
- Perceived usefulness is determined as the degree to which a person believes that using a particular system will enhance his/ her job performance (Davis, 1989). Davis (1989) describes a system high in Perceived Usefulness as one for which a user believes in the existence of a positive user-performance relationship. The user perceives the system to be an effective way of performing the task(s).

2.3. Mouse Behavioral Patterns in HCI and Related Work

Like most of the web tracking technology, the main goal of mouse tracking is a deeper understanding of the user behavior for inferring user intentions. In recent years, research focus has turned to whether mouse tracking could offer a scalable alternative to eye tracking for measuring usability of web pages, search relevance, user attention, cognitive processes, psychological or affective states and

more. Compared to eye-tracking, mouse tracking is cheaper, simpler to implement and can be used for massive studies without the need of test monitor presence (Arroyo et al., 2006; Atterer et al., 2006; Chen et al., 2001; Cooke, 2006; Leiva et al., 2008).

In the area of Human Computer Interaction (HCI) researchers have been trying to quantify the movement of humans who perform pointing tasks on computers and other devices. Mouse cursor movement is a vital part in this field and has been used in many studies. One of the initial and main measurements used in those studies is Fitts' law for movement time (Fitts, 1954; Fitts and Peterson, 1964). This law originated from the desire to quantify the pointing behavior of humans and is currently most used to measure the efficiency of an interface's layout. The efficiency is measured in the time period that is needed to use the interface i.e. to click the buttons or to navigate within the interface. Since Fitt's law, many researchers have used mouse movement analysis to deeper understand users' cognition process, psychological aspects (such as frustration), perception, level of difficulty, etc.

In 2001, Mueller and Lockerd proposed the use of cursor patterns behavior as input for deliver personalized content to users. Unfortunately, the identification of patterns has not advanced significantly since then. Mouse patterns characterization is generally vague, and their identification remains a largely visual process and qualitative analysis.

There are not many research works that clearly attempt to detect users' behavioral attributes via mouse behavior. One example of research close to the diagnosis of user behavioral state is the research of Khan et al. (2008) who correlated mouse and keyboard usage to the outcome of personality tests. Also, Zimmerman et al. (2003) examined mood through mouse and keyboard input and recorded both mouse clicks and mouse coordinates. Dijkstra (2013) investigated the diagnosis of self-efficacy levels in simple question-based e-learning environments using as mouse metrics the distance and time differences as well as the mouse pauses. Tzafilkou et al. (2014) attempted to diagnose users' self-efficacy and hesitation levels in order to improve user experience in web-based activities. Navalpakkam and Churchill (2012) demonstrated that mouse movement patterns can predict whether the experience of a user is perceived as pleasant or not. Arapakis et al. (2014) analyzed the frequency of common mouse metrics like speed, distance, acceleration, direction, etc. to diagnose well-known user engagement items like focused attention and effect.

Although its significant usefulness to analyse user behavior in HCI tasks, mouse tracking has not been studied yet in common everyday web-based activities like web-based End User Development. Mouse behavior in EUD could be monitored and analyzed to measure user intention and engagement, diagnose perception and acceptance states, predict user performance, etc. User modeling implementations based on implicit mouse and keyboard input could also be used to personalize and adapt the EUD system developing approach or interface elements and assist end-users perform better in their developing tasks.

There is a number of studies that have identified some common patterns of cursor movements, such as reading patterns, direct movements, random movements, hesitation patterns, fixed and guide patterns. These patterns have been identified in different web contexts like search engine result page, interaction with web forms and web site navigation (Atterer and Lorenzi, 2008; Hornbæk and Frøkjær, 2003; Magnuson, 2005; Mueller and Lockerd, 2001; McKinstry et al., 2008; Freeman et al., 2011). These works are of significant HCI contribution, since identifying mouse behavioral patterns allow us to infer the activity performed by the user, for example, usability problems and user experience (Navalpakkam, et al., 2013).

Following we briefly present the most common mouse behavioral patterns suggested in the reviewed literature. We also attempt to conclude (based on previous research findings) on which EUD-user behavioral attribute(s) every pattern could reflect on.

Straight Pattern

Defined as "straight pattern" (Lee and Chen, 2007) else the 'direct mouse movements' (contradictory to the random ones), the users' 'confident movements' are characterized by a pause before a direct movement towards a target since "once traced the desired feature users move the mouse straight to it" (Lee and Chen, 2007). According to Rodden et al. (2008), this pattern defines direct movements that occur once the user has decided which action to take and this could reveal certainty and task-oriented self-efficacy.

On presence of this pattern, researchers infer that there is an earlier decision and the user feels certain about his/her movement and hence they associate this pattern to the user's self-efficacy levels. A direct movement pattern may reveal that an activity is easy and simple, reflecting an earlier decision making.

In the context of interaction with web applications, direct movement is characterized by "a direct movement with no big pauses" (Ferreira et al., 2010).

Hence, drawing from the related literature review, mouse trajectory (e.g. straight lines) or selected targets (i.e. clicks) after direct movements may measure the end-user's self-efficacy level or perceived ease of use when interacting with computer applications.

Hesitation Pattern

'Hesitation' pattern is first explicitly defined in Cheese project (Mueller and Lockerd, 2001). According to the authors "hesitation on links or text could potentially provide information about what else interests the user on the page". This hesitation could be expressed by the cursor as a mouse hover over the under decision item (i.e. element to click).

Other studies which focused on the analysis of movements of the cursor in web forms refer to the pattern of hesitation as movements between "two or more answers while trying to decide which one to choose" (Ferreira et al., 2010). There have also been identified hesitation patterns during interaction with navigation menus (Atterer and Lorenzi, 2008).

Hesitation pattern may suggest doubt, difficulty and decision-making activity. Generally, via the hesitation pattern the user reflects a doubt about the option to choose. For instance, in the case of forms the greater the degree of difficulty, the more hesitation patterns are observed (Ferreira et al., 2010). In commercial applications of mouse tracking, as ClickTale (2010), the pattern of hesitation is defined as "the average time from the beginning of a mouse hover to the moment of the mouse click". There is a clear distinction between those who believe that the hesitation may occur on a single target, as a pause before the click (ClickTale, 2010) and among those studies that consider the hesitation as a pattern of doubt among many possible targets (Ferreira et al., 2010).

Hesitation pattern could hence be used to infer users' perceived difficulty, risk-perception levels (since the user evaluates the cost benefits of choosing an action among others), or even the perceived usability from his/her interaction with the system.

Reading Pattern

The reading pattern can be divided into two different types of behavior: the horizontal reading pattern that is characteristic but not so common among users (Rodden et al., 2008) and the vertical reading pattern where the mouse path traces a vertical line, with small or large pauses. In Ferreira et al. (2010) the horizontal reading pattern is characterized by a "smooth mouse movement trails horizontally across paragraphs. In comparative studies with eye-tracking it is defined as a movement that follows the eye horizontally (e.g. Rodden et al., 2008).

The vertical reading pattern is defined as a movement of "following the eye vertically" (Rodden et al., 2008). This pattern is observable in the vertical lists reading like a menu where the users "use the mouse as a marker when they are looking through a list of links" (Mueller and Lockerd, 2001).

Random and Fixed Pattern

According to Ferreira et al. (2010) the random pattern is characterized by movements "without any specific intention, just playing around and doing random movements with short pauses or not". The authors noted that the random movements often arise when the difficulty level of the task increases (in contrary to the straight pattern movements).

Hence, on presence of a random pattern we can infer doubt, difficulty, low self-efficacy, anxiety, etc.

Described in Lee and Chen (2006), the fixed pattern refers to the areas where the users mostly used for "repose" the cursor. For Lee and Chen (2006) these areas usually are on the right-side of the page. This area is also mentioned as "White space" (Ferreira et al., 2010) and research indicated that a large number of users use whitespace to rest the mouse, thus avoiding accidentally clicking a link. Fixed pattern could be expressed via long or shorter mouse pauses on 'neutral' web-page areas. During this time users may reflect on the task, read (eye tracking could only reveal reading behavior during mouse pauses) or evaluate the costs and benefits of making particular decisions (e.g. clicks, actions). Hence, fixed pattern could measure risk-perception or usefulness levels.

Guide Pattern

According to Lee and Chen (2006), the guide pattern defines a behavior of continuous movement of the cursor. According to the authors this pattern seems to reflex and "exploratory" role that suggest a relationship between mouse and eye movement" and hence this pattern may give us an idea of the user expectations. Hence, guide pattern may be associated with users' acceptance, i.e. perceived usefulness and ease of use and also willingness to learn.

However, guide pattern is very similar to the reading pattern since it can be expressed via 'smooth' (i.e. slow) cursor movements identifying horizontal or vertical reading.

2.4. Keystroke Dynamics in HCI and Related Work

Keystroke dynamics have been typically used in biometrics and user authentication (Bergadano et al., 2003; Monroe and Rubin, 2000). As defined in Monroe and Rubin (2000) "keystroke dynamics is the process of analyzing the way a user types at a terminal by monitoring the keyboard inputs thousands of times per second in an attempt to identify users based on habitual typing rhythm patterns".

In a more 'HCI-friendly' and generic approach, Epp et al. (2011) describes keystroke dynamics as 'the study of the unique timing patterns in an individual's typing, and typically includes extracting keystroke timing features such as the duration of a key press and the time elapsed between key presses".

Recently, keystroke dynamics have been used in affective computing research to detect user affective states like mood and emotions (Epp et al. 2011; Khanna and Sasikumar, 2010).

In Khanna and Sasikumar (2010) the authors successfully modeled three emotional classes (positive, neutral, negative). Attributes used in Khanna and Sasikumar (2010) are: typing speed, mode, standard deviation, standard variance, range, total time taken, number of backspaces used and interval between typing (if any).

Epp et al. (2011) used keyboard dynamics in emotion detection and showed the classification of 15 emotional states and could identify six emotions (confidence, hesitation, nervousness, relaxation, sadness and tiredness). They also showed promising results for anger and excitement.

Nahin et al. (2014) have presented a method of determining user emotion by combining both keystroke dynamics and text pattern analysis.

There is not much research in analyzing keystroke dynamics and end-users behavioral (like perception and acceptance) states.

Some related research may concern personality detection through keyboard and mouse input. For instance, in Khan et al. (2008) the authors suggest that some of the main traits and sub traits of personality can be measured from keyboard and mouse use. The keyboard attributes measured in two exploratory studies were 'key-up' and key-down'. Their findings revealed some limited significance since only recording the standard deviation of the average time between events gave some insight into a user's activity level, a sub trait of extraversion.

In Vizer et al. (2009) the authors used keystroke timing features of free text in conjunction with linguistic features to identify cognitive and physical stress.

In a more related study of Dijkstra (2013) the author examined the correlation between mouse or keyboard input and self-efficacy levels. Although mouse input showed some promising results for detecting self-efficacy levels, no correlations were found between typing keyboard behavior and self-efficacy.

3. AIMS AND RESEARCH QUESTIONS

Since EUD has some important differences from other HCI areas where mouse tracking has been researched, we should consider some constraints before formulating our research objectives.

First, a web-based EUD system does not consist of static web pages (like most mouse tracking studied environments); instead it is composed of dynamic web pages and in some cases it is a Single Page Application (SPA). Thus, we will not define any areas of interest (AOIs) in the web page and our mouse metrics will be context and region-independent, ignoring the interface layout. Our approach will be suitable to be used in other similar EUD research works.

Second, we will measure the average mouse-behavior during the time needed by a user to complete a development task. This time may be different for each user and is defined as 'task duration time'. For this reason the time related mouse metrics (e.g. average pause time, average time between clicks, etc.) are divided by the task duration time for each user and this ratio is used as the main mouse metric. This gives the analogy of the measured mouse time variable to each user's EUD completion time.

Also, to quantitatively examine mouse patterns in EUD activities we have first to find a measurable manner. That is to subdivide each mouse pattern (from the ones described in the literature) in a set of measurable mouse metrics. In Churrua (2011) the author subdivided each mouse pattern in a set of mouse movements but measured them using only visual representation via video recording. In the current research we attempt to subdivide every mouse pattern in a set of measurable mouse metrics and examine them separately to see which ones are met in end-user developers' mouse behavior and which ones of them are significantly correlated to one or more of their EUD behavioral attributes. Our main research objective is to examine the bivariate potential correlations between the pattern-related mouse attributes (direct moves, number of clicks, number of hovers, etc.) and end-users' behavioral attributes (perceived ease of use, perceived usefulness, self-efficacy, willingness to learn and risk perception).

We also plan to measure the activity level of mouse movements, i.e. the relationship between movement of the cursor and the duration time of the EUD session. We will then examine the correlation between activity level and EUD behavioral attributes.

Finally, we will examine the potential correlations between a set of main keystroke dynamics (dwell time, flight time, etc.) and the measured EUD behavioral attributes. Although web-based EUD activities do not include a lot of text typing tasks, users still have to provide some important input

through the keyboard (e.g. form fields' names, options values, object's names and descriptions, etc), and although limited, this input could still reveal a meaningful contribution.

Hence our main research questions are the following:

RQ1: Are straight pattern attributes associated with end-users' behavioral attributes?

RQ2: Are hesitation pattern attributes associated with end-users' behavioral attributes?

RQ3: Are random pattern attributes associated with end-users' behavioral attributes?

RQ4: Are fixed pattern attributes associated with end-users' behavioral attributes?

RQ5: Are guide pattern attributes associated with end-users' behavioral attributes?

RQ6: Is the activity level of mouse movements associated with end-users' behavioral attributes??

RQ7: Are any keystroke dynamics associated with end-users' behavioral attributes?

This is an exploratory study and we do not construct any hypotheses regarding which pattern reflects which behavioral attribute since every pattern is a composition of different mouse metrics and some metrics could reflect one behavioral state while some others could reflect another one. Also metrics of different patterns could be associated with the same behavioral states.

To examine the above-presented research questions, as explained, we have first to subdivide every behavioral mouse pattern into a set of measureable mouse attributes (mouse metrics). Following we present the mouse metrics for each one of the presented mouse patterns and argument on their selection. We exclude the reading pattern from our study since its metrics are really close to the guide pattern and there are not many reading tasks (except some instructions or wizard-based guidance text) in the EUD environments.

Straight pattern attributes

According to Lee and Chen (2006), "in straight pattern (or else direct pattern), the mouse movement starts from an initial region, while users are presumably visually browsing other regions of the page. It is surmised that once users spotted the link that they were asked to find, they moved the mouse straight to it, and usually terminated the action with a click".

Based on the above conclusion, in Churrua (2011) visual interpretation, the straight pattern can be expressed through direct movements that may or may not include a pause and they usually move toward a target, that is, they end up in a mouse click.

Hence, the mouse metrics-attributes we plan to examine in regards to the straight pattern include the following:

- Direct movements (i.e. straight lines);
- Clicks in the end of straight lines (e.g. direct movements towards a target that was clicked) ;
- Average time passed between straight lines (e.g. time elapse between direct movements; this could also show how often a user makes a decision to trace a direct trajectory).

We note that it is not necessary all the attributes to exist in order the straight pattrer be expressed. The existence of only some of them could represent the straight pattern in a measurable way. The same rule concerns all the below patterns as well.

Hesitation pattern attributes

As mentioned, in ClickTale (2010) the pattern of hesitation is defined as "the average time from the beginning of a mouse hover to the moment of the mouse click".

In other research works hesitation may occur on a single target, as a pause before the click or it regards a dilemma between two or more choices and hence can be expressed through mouse hovers between at least to items in the same sequence (Guo et al., 2008).

In a more generic term we could also link hesitation to mouse hovers, pauses before clicks and average time between clicks as well.

Hence, the mouse metrics-attributes we plan to examine in regards to the hesitation pattern include the following:

- Hovers that turned into clicks;
- All hovers in general;
- Average time from mouse hover to mouse click;
- Average time of pauses before clicks;
- Average time between clicks.

Random pattern attributes

According to Ferreira et al. (2010) a movement is random when it occurs without apparent intention, that is, not between targets. Also it may or may not include short pauses.

Random movements may reveal user anxiety and doubt (Churruca, 2011) and hence they should be clearly different from straight pattern movements.

The random related metrics we plan to examine are:

- Curved (i.e. not direct or random) movements;
- Clicks that occurred outside direct movements;
- Total number of movements (since a large amount of mouse movements could include a large percentage of movements with no intention).

Fixed pattern attributes

In Lee and Chen (2006), the fixed pattern refers to the areas where the users mostly used for "repose" the cursor. That is that except from the area where the mouse is reposing, it stays there for a 'long' time. In our case, this can be translated into 'long pauses'.

Different studies use different time thresholds to characterize a pause as long or short. Since this is a EUD exploratory study, and because of the nature and the cognitive load of a developing task, we consider as long pauses those over 4 seconds. Short pauses (or else pauses) remain 200ms as underlined in the related literature (Dijkstra, 2013).

Also, as explained, we do not plan to explore the position of cursor in the page (i.e. the area) where the mouse reposed, since the EUD interface page layout is different than search related and other web sites where previous work (e.g. Lee and Chen, 2006), was conducted.

Hence, our fixed related metrics include the following:

- Long pauses;
- Average time of long pauses;
- Average time of all pauses (including short pauses).

Guide pattern attributes

The guide pattern (Lee and Chen, 2006) defines a behavior of continuous movement of the cursor and it seems to reflex an "exploratory" role that suggests a relationship between mouse and eye movement (Leiva and Hernando, 2008). Hence, guide pattern is similar to the reading pattern since it implies that the mouse traces slow or long movements following the eye.

In our study, as long movements we consider direct movements with distance more than 10 pixels and as slow movements we consider movements that their time interval exceeds 3seconds.

Hence, the guided related metrics we plan to examine are the following:

- Long movements;
- Slow (smooth) movements.

In figure 1 below we summarize the measurable mouse attributes we gathered for each mouse behavioral pattern that we plan to examine.

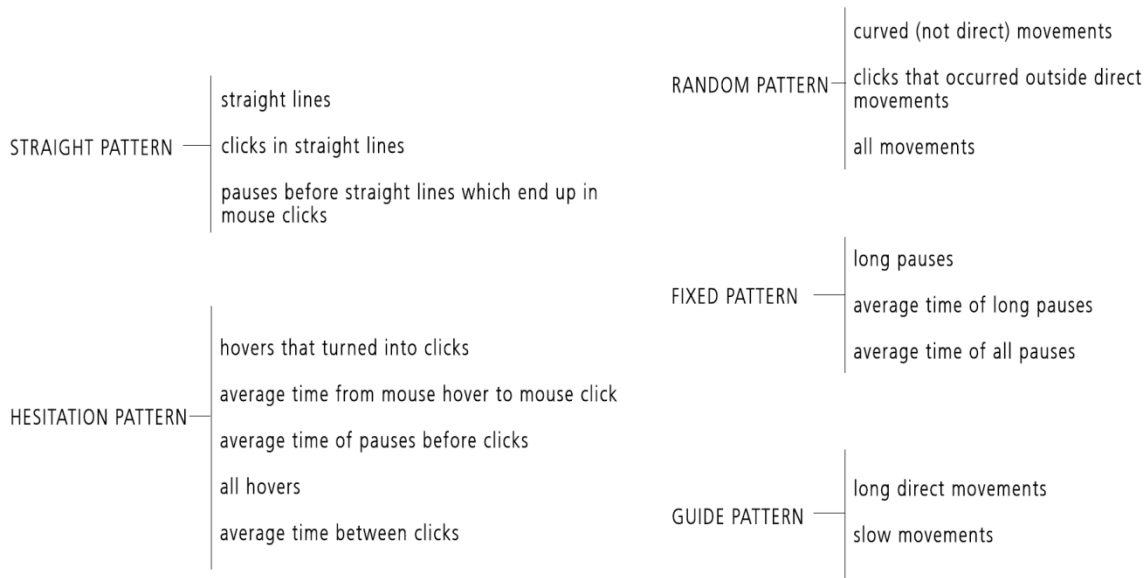


Figure 1. Chosen measurable mouse attributes per mouse behavioral pattern

Keystroke attributes

Since there are not similar behavioral EUD or other related research on keystroke dynamics, we will ‘borrow’ some typical keystroke metrics from other HCI related studies like emotion recognition.

The main keystroke dynamics-attributes we plan to analyse are depicted in Figure 2 and they are based on key press speed, duration (dwell time), latency (flight time) and down-to-down time as proposed in Khanna and Sasikumar (2010), Nahin et al. (2014) and in Epp et al. (2011).

In our exploratory field test we will examine the potential correlations between these typical keystroke dynamics and the measured EUD behavioral attributes of self-efficacy, risk-perception, willingness to learn, perceived usefulness and ease of use.

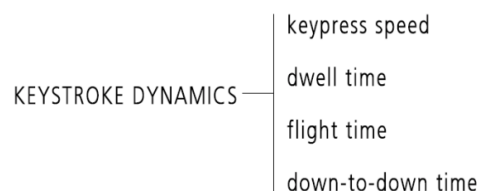


Figure 2. Chosen measurable keystroke dynamics attributes

4. RESEARCH METHODOLOGY

The research methodology follows a four-step approach to examine potential mouse/keyboard and perception/acceptance correlations in a prototype web-based EUD environment for creating simple web forms to store data for particular objects (entities).

First we present the prototype tool that was used for the field test. Then we present the mouse and keyboard monitoring mechanism and explain its implementation as well as the data extraction method. After, we describe the field test including the sample and procedure details, the user-task, the performance calculation and the measured dependent variables and questionnaire. Finally, we present the data analysis process.

4.1. Prototype Web EUD Tool

The prototype EUD tool was designed to assist end-users in creating simple web forms. The tool interface was user friendly and easy to use with many and clear ‘click elements’ (buttons, links, fields, etc) so that the mouse tracking implementation and later analysis would be easy and efficient. The participants had to create a set of objects (i.e. the entities they wish to store data for) and build the corresponding web forms by constructing and editing one by one the various types of form fields (see Figure 3). They could also edit some design elements (colors, font sizes, button styles, etc.) and preview the result.

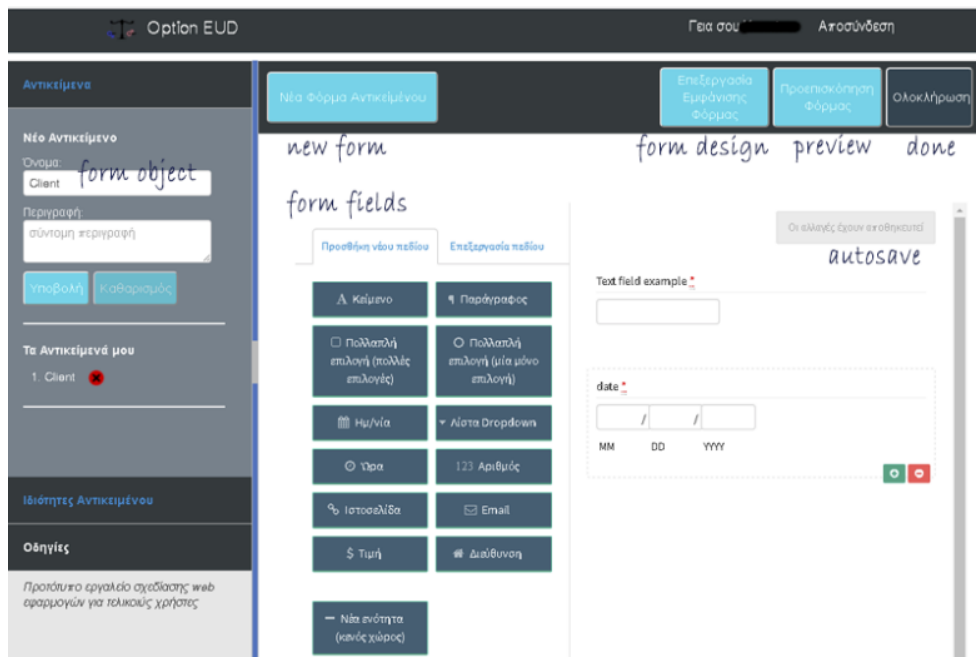


Figure 3. EUD tool interface (some translation in English is provided in hand-written fonts)

The participants’ high performance results (4,6 out of 5) and their high levels of perceived ease of use (4,09 out of 5) as depicted in table 4 indicated the efficiency of the tool as well as a positive user experience.

4.2. Monitoring Mechanism and Mouse/Keyboard Data Extraction

For the purpose of the mouse and keyboard tracking work we designed a prototype monitoring tool that, based on the reviewed mouse patterns, captures user mouse and keyboard behavior and stores every event in a MySQL database. An important feature is that the tool displays graphs and statistics in real-time at any website connected via Javascript file in the central server. Hence, we connected

the monitoring tool to the EUD prototype tool to implicitly monitor the end-users' mouse and keyboard behavior while working on their developing task.

The raw mouse data consisted of mouse clicks, moves and hover events, their coordinates, their time intervals and a timestamp of when every mouse event occurred.

The raw keystroke data consisted of key press and release events, unique codes for each key, their time intervals, and a timestamp of when the key event occurred.

We stored all the recorded mouse and keyboard data in the following relational database tables:

- mouse clicks;
- mouse moves;
- mouse hovers;
- key press;
- key release.

To extract the examined metrics we used a set of PHP algorithms and SQL queries. Thus, we could retrieve from the database the desired mouse and keyboard behavior for every user.

To link the questionnaire answers to each user's mouse and keyboard behavior we generated a unique client id for every user and we stored it in every database table and in a questionnaire's answer field.

Table 1 below describes the mouse attributes (as they presented in section 3) that we plan to extract.

Table 1. Extracted mouse attributes

Feature	Type	Meaning
num-mv	Count (units)	Number of mouse movements in a session
num-crv	Count (units)	Number of non-direct (curved) movements in a session
num-outlineClks	Count (units)	Number of clicks outside direct movements (lines) in a session
num-inlineClks	Count (units)	Number of clicks in the end of direct movements (lines) in a session
num-longPauses	Count (units)	Number of mouse long pauses (>5sec) in a session
avg-longPauses	Time (ms)	Ratio of average time of long pauses to the task duration time
num-dirMv	Count (units)	Number of direct movements in a session
avg-timeBtwDir	Count (units)	Ratio of the average pauses time between direct movements to the task duration time
num-hvrToClk	Count (units)	Number of mouse hovers in a session
avg-hvrToClk	Count (units)	Average time from mouse hover to mouse click on the same element
avg-btwClk	Count (units)	Ratio of average time between clicks to the task duration time
avg-pause	Count (units)	Ratio of average time of pauses (>200ms) to the task duration time
avg-pauseBfrClk	Count (units)	Ratio of average time of pauses (>200ms and <10sec) before clicks to the task duration time
num-longDirMv	Count (units)	Number of long (>10px) direct movements in a session
num-slowMv	Count (units)	Number of slow (>2sec) movements in a session
num-hvr	Count (units)	Number of all mouse hovers in a session
task-dur	Time (ms)	The EUD task total duration (completion) time (which is different for every user)
acl-mv	Time (%)	Activity level for mouse movements (i.e. time of movements in a session/task-dur)

As already explained, the time mouse features (avg-longPauses, avg-hvrToClk, avg-btwClk, avg-pauseBfrClk, avg-pausesBtwDir and avg-pause) are taken into account along with the EUD task duration (task-dur) time which is different for every user. That is, where ‘avg-shortPause’ is the ratio $\text{avg-shortPause} / \text{task-dur}$, and so on.

Table 2 below describes these keystroke attributes we plan to extract. As already mentioned, the main keystroke attributes we extracted were based on key press (character) speed, dwell, flight and down-to-down time as proposed in Khanna and Sasikumar (2010), Nahin et al. (2014) and in Epp et al. (2011).

Table 2. Extracted keyboard attributes

Feature	Type	Meaning
speed-char	Count (units)	Number of characters pressed every 4 seconds
dwell-time	Time (ms)	Time elapsed between key press and key release
flight-time	Time (ms)	Time elapsed between a key release and the next key press
d2d-time	Time (ms)	Time elapsed between the characters pressed every 4 seconds

Regarding speed-char (key press speed) we used a threshold of 4 seconds instead of 5 seconds proposed in the reviewed literature (e.g. Nahim et al., 2014), since as explained web-based EUD is not a typing task hence we need shorter time thresholds to measure users’ keyboard activity.

4.3. Field Test

4.3.1. Participants and Procedure

The experiment was conducted in an introductory e-commerce course, in the Department of Accounting and Finance in a Greek University. The participants’ population was 42 end-users and the final sample consists of 30 end-users, 18 male and 12 female. There were no significant age and expertise differences among the participants. To confirm the sample EUD representation, i.e. the participants’ similar level of computer and developing experience, an expertise pre-test was conducted (see figure 4).

The participants were given a EUD task to solve, in the form of an exercise demanding the construction of a simple web form. The use of the prototype tool was simple and the interface text was in Greek. Instructors made a basic presentation of the EUD tool at the beginning of the field test and did not give any other special instructions, apart from the exercise (i.e. the requested development task). Few students who were not very comfortable with the use of the system and asked help received some further information and instructions. In the end, participants could be informed about their performance and discuss their experience and difficulties or ask any further questions.

The conducted field test did not take into account the students’ large population but the EUD generic population which according to Costabile et al. (2003a; 2003b) ‘it is not a uniform population, but divided in no mutually exclusive communities characterized by different goals, tasks and activities. The EUD population can be different according to cultural, educational, training, and employment background, experience in computer use, age (the very young and the elderly), types of (dis)abilities, etc.’ (Costabile et al., 2003b). Based on the EUD terminology given by Lieberman et al. (2006), that end-users act as are non-professional developers to build or modify applications, we require from our participants to belong to the generic end-user developer population. That is, they should be familiar enough with web and computer software’s and concepts but they should not to be experts and of course not programmers.

Drawing from all these, the targeted EUD group population is young (age 18-25) users from a European country (Greece), with no disabilities, having the regular computer skills and experience (e.g. computer use and web surfing) but they are not professional developers, meaning that they do not have any programming or web development skills.

To confirm these criteria, some personal information (sex, age, educational background) was collected and as mentioned, prior to the EUD task the participants were also asked to answer a short questionnaire regarding their experience level on database concepts, programming, World Wide Web and overall computer use. Their experience level was measured in a scale from 1 to 5, as depicted in figure 4.

Εγγραφή νέου χρήστη

Personal data

Στοιχεία

Όνομα *name*

Όνομα κι επώνυμο

Φύλο *sex*

☐ Γυναίκα

☐ Άνδρας

Ηλικία *age*

Διάλεξε ηλικία

Τμήμα *department*

Λογιστική και Χρηματοοικονομ.

Πρώτο πτυχίο *other degree*

Αν υπάρχει

User account

Λογαριασμός

Διεύθυνση Email

Διεύθυνση Email

Κωδικός

Password

Επιβεβαίωση Κωδικού

Ξανά το Password

Experience

Εμπειρία (1-5)

computer experience

Εμπειρία στη χρήση Ηλεκτρονικού Υπολογιστή:

Διάλεξε

web experience

Εμπειρία στη χρήση Διαδικτύου:

Διάλεξε

database experience

Εμπειρία στη χρήση Βάσεων Δεδομένων:

Διάλεξε

programming experience

Εμπειρία στον Προγραμματισμό:

Διάλεξε

1: Καθόλου

2: Λίγο

3: Μέτρια

4: Καλά

5: Πολύ καλά

Register

Εγγραφή

Figure 4. Web questionnaire prior to EUD task, regarding the user personal info and computer experience (translation in English is provided in hand-written fonts)

The measured mean value of the participants' database familiarity was 1,45, revealing that they could be 'safely' considered as non-professional/non-expert end-users in database-development tasks. Additionally, their programming experience was 1,30, their familiarity with web was 2,97 and their general familiarity with computer use was 2,78 (see table 3 and diagram in figure 5). These mean values satisfy our target group (end-user developers) requirements, i.e. users that are non-experienced programmers, with no or limited knowledge on database concepts but with efficient familiarity with web interaction and computer use in general. This information could allow us to generalize the results from a small sample and make broad claims about web-based EUD behavior of similar EUD populations.

Table 3 Descriptive statistics of participants' experience level

Measured Item	Mean (0-5)	St. Deviation	St. Error
Computer Experience	2,78	0,81	0,11
Web Experience	2,97	0,80	0,11
Database Experience	1,45	0,75	0,32
Programming Experience	1,30	0,69	0,10

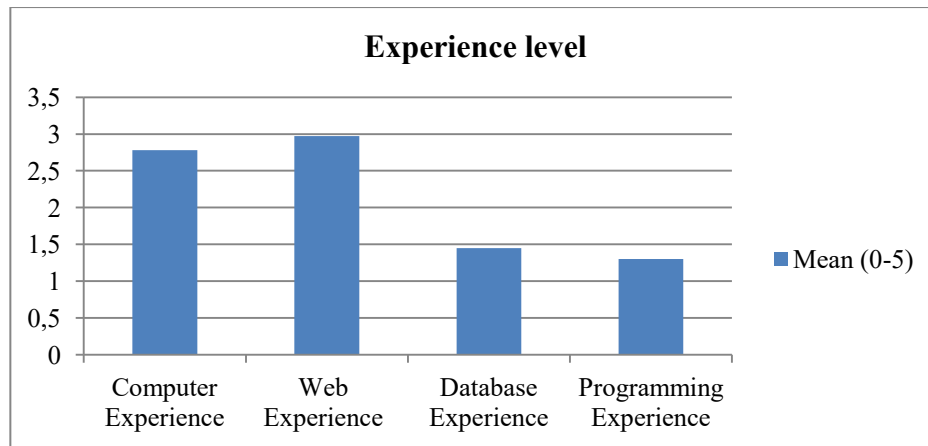


Figure 5. Diagram of participants' experience level (N=30)

4.3.2. User Task and Performance Measure

The exercise (user task) needed to be small enough to be solved in a limited time by the participants, and as comprehensive as possible in order to capture a logic amount of mouse movements and keystroke events. The example of a web form is simple and comprehensive, since forms and fields are familiar to most end-users and its construction encompasses a set of items such as field types (text, number, list, etc), choice options, length and design elements (fonts, colors, button styles, etc.) as well. So, the exercise given to the participants was to create a simple web form to store a set of customer data.

First, the end-users had to create an object named 'customer' and give it a description. Then, for this object they had to create a form and construct the following form fields:

- a text type field to store the customer name and last name;
- a dropdown type field with two options to store the customer age;
- an email type field to store the customer email address.

The participants could also set the fields as required or not, define their length and some other form aspects.

To calculate user performance for every participant we used a score scale from 1 to 5 and assigned a relative weight of importance to each constructed item as the following equation (1) shows:

$$P = o * 1.0 + f * 1.0 + t * 0.5 + d * 0.25 + e * 0.25 \quad (1)$$

Where, P=Performance, o=Object, f=Field name, t=Field type, d=Dropdown list option (in the dropdown type field) and e=Extra (i.e. unnecessary) field. The relative weights reflect the importance of each item of the above equation.

After completing the above-described user task, each participant had to answer a self-report questionnaire-based survey consisted of 22 items measuring a set of EUD behavioral variables (see Annex A). The questionnaire was provided to the users as an online survey form, embedded in the last page of the EUD application.

4.3.3. Dependent Variables and Questionnaire

The following list contains the set of user-oriented (EUD behavioral) variables measured for each user from the post-task questionnaire survey.

EUD behavioral (dependent) variables:

- Self Efficacy (SE)

- Risk Perception (RP)
- Willingness To Learn (WL)
- Perceived Usefulness (PU)
- Perceived Ease of Use (PEOU)

Performance was excluded from the list of the dependent variables since the paper focuses on the variables of EUD behavioral attributes, and performance was calculated only to reinforce the tool's efficiency and the research validity.

The questionnaire survey was consisted of 22 questions (items) which measure the five independent above-listed variables. A five point Likert-type scale with 1 = “strongly disagree” to 5 = “strongly agree” or 1 = “never” to 5 = “many times” was used to measure the items. Our questionnaire structure was based on previous research of computer perception and acceptance related questionnaires (e.g. Compeau and Higgins, 1995; Davis, 1989; Moon and Kim, 2001; Venkatesh et al., 2003; Thompson, et al. 1991; Wang et al., 2009) but we adjusted and extended the questions in order to cover all the under survey attributes. The original questionnaire was in a Likert scale form consisted of a prompt, “during the usage of the EUD tool I felt that I was totally confused, or I was confident” etc.

As presented in Annex A, five items were used to measure Self-Efficacy, Risk-Perception and Perceived Ease of Use, three were used to measure Willingness to Learn and four items were used to measure Perceived Usefulness. The internal validity of the questionnaire is presented in Table A1 in Annex A.

4.3.4. Data Analysis

Sample Characteristics

A normality distribution test was conducted to test whether the values of every measured dependent variable were approximately normally distributed for the whole sample.

A Shapiro-Wilk's test ($p > 0.05$) (Shapiro and Wilk, 1965) and a visual inspection of box plots (see Table B1 and Figure B1 in Annex B) showed that the values of Perceived-Usefulness, Perceived-Ease of Use, Willingness to Learn, Self-Efficacy and Risk-Perception come from a normal distribution.

The fact that the sample size is normally distributed reinforces the validity of the statistical results.

Data Analysis Method

Since our data is approximately normally distributed we can use a parametric analysis method. Hence, in order to measure the bivariate correlations between the measured variables we used the Pearson correlation analysis since it is an appropriate method to define the strength of the association among a set of continuous variables.

To present the general results concerning every measured variable we used descriptive statistics.

To evaluate the questionnaire internal consistency we calculated the value of Cronbach alpha (α).

Later, in the Discussion section we highlight our main findings and discuss a number of potential limitations of the current experimental design.

5. RESULTS

Construct validity has been tested to ensure that the results are reliable and consistent. By calculating Cronbach's alpha coefficient we tested the construct reliability. This measures the internal consistency by indicating how a set of items are closely related and forming a group (Moola and Bisschoff, 2012). Nunnally (1967) suggests that a Cronbach's alpha (α) value of 0,70 is acceptable, were a slightly lower value might sometimes be acceptable as well.

In Table A1 in Annex A Cronbach's α values for all factors are above 0,70, indicating that all measures employed in this study demonstrate a satisfactory internal consistency and the measurement model is supported.

Table 4 below presents the descriptive statistics for the EUD behavioral measured items for the whole sample. Performance statistics are also included since performance calculation was used to reinforce the EUD prototype tool's efficiency.

Table 4. Descriptive statistics of user questionnaire measured items and performance (N=30)

Measured item	N	Mean (1-5)	Std. Deviation
Perceived Usefulness	30	3,78	0,60
Perceived Ease Of Use	30	4,09	0,70
Self-Efficacy	30	3,96	0,78
Risk-Perception	30	2,42	0,75
Willingness To Learn	30	3,70	0,82
Performance	30	4,60	0,66
Valid N (listwise)	30		

Diagrams in figure 6 below show the mean values of the recorded mouse and keystroke attributes. Mouse time related metrics (average pauses, etc.) are not depicted.

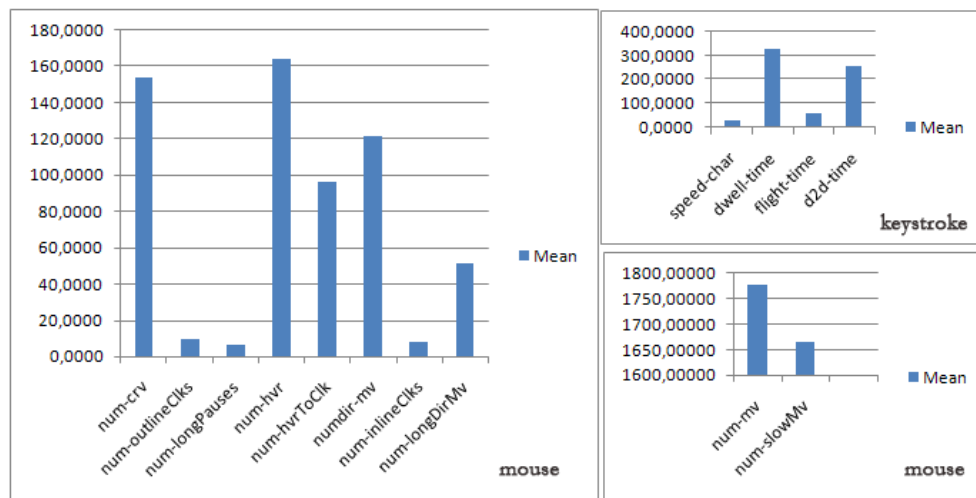


Figure 6. Diagrams of participants' mouse and keyboard actions' values (N=30)

Table 5 below shows the Pearson correlations (r) between every extracted mouse metric and EUD behavioral attribute. As depicted, several significant correlations have been revealed. Last row depicts the Pearson correlation between activity level of mouse movements and behavioral variables.

Table 5. Correlation analysis between mouse metrics and user behavioral attributes (N=30)

Pattern category	Mouse attribute	PU (r)	PEOU (r)	SE (r)	WL (r)	RP (r)
Random	num-mv	-0,43*	-0,41*	-0,31*	-0,20	0,18

	num-crv	-0,36*	-0,38*	-0,29	-0,28	0,16
	num-outlineClks	-0,22	-0,38*	-0,304	-0,18	0,16
Fixed	num-longPauses	-0,21	-0,32	-0,43*	-0,44	0,27
	avg-longPauses	0,32	0,34	0,44*	0,27	-0,87
	avg-pause	0,39*	0,24	0,21	0,32*	-0,31*
Straight	numdir-mv	-0,36*	-0,37*	-0,24	-0,28	0,14
	avg-timeBtwDir	-0,25	-0,06	-0,12	0,31*	-0,29
	num-inlineClks	-0,15	-0,28	-0,27	-0,28	-0,37
Hesitation	num-hvrToClk	-0,26	-0,44*	-0,28	-0,16	0,15
	avg-hvrToClk	0,25	0,28	0,29	0,50**	-0,17
	avg-btwClk	0,61	0,25	0,22	0,35*	-0,31*
	avg-pauseBfrClk	0,38*	0,21	0,18	0,33*	-0,27
	num-hvr	-0,31*	-0,28	-0,16	-0,23	0,11
Guide	num-longDirMv	-0,31*	-0,34*	-0,19	-0,24	0,12
	num-slowMv	-0,36*	-0,36*	-0,25	-0,28	0,15
-	acl-mv	-0,38*	-0,24	-0,20	-0,30	-0,30

**Correlation is significant at the 0.01 level

*Correlation is significant at the 0.05 level

Table 6 below shows the Pearson correlations (r) between every extracted keystroke metric and EUD behavioral attributes. As depicted, some significant correlations have been found.

Table 6. Correlation analysis between keystroke attributes and user behavioral attributes (N=30)

Keystroke Attribute	PU (r)	PEOU (r)	SE (r)	WL (r)	RP (r)
speed-char	-0,17	-0,35*	-0,34*	-0,14	0,23
dwell-time	0,19	0,24	0,22	0,23	-0,40
flight-time	0,13	0,01	0,08	0,28	-0,06
d2d-time	-0,23	-0,29	-0,37*	-0,20	0,17

*Correlation is significant at the 0.05 level

6. DISCUSSION

The field test results are encouraging for the future of mouse and keyboard monitoring for EUD behavioral analyses. Initial exploratory findings have given us key insights since various correlations have been revealed between mouse/keyboard behavior and EUD behavioral attributes. Most of our research questions have been answered in a contributing way since the findings reinforced the usefulness of mouse and keyboard behavioral analysis in web-based EUD activities. Following we summarize the main findings that came up for every research question formed in section 3.

RQ1: Are straight pattern attributes associated with end-users' behavioral attributes?

Results in table 5 show that one of the straight pattern's metrics (the number of direct movements) is significantly associated with perceived ease of use and perceived usefulness, and one metric (the metric of average time between direct movements) is significantly associated with willingness to learn.

We notice that number of clicks inside direct movements showed no correlation to EUD behavioral attributes. One would also expect, based on the reviewed literature, the existence of some significant correlations between straight pattern attributes and self-efficacy since straight pattern implies user confidence. The absence of a self-efficacy correlation could mean that self-efficacy and straight pattern related mouse metrics should be studied more in the field of EUD and a deeper behavioral analysis is needed to understand which mouse behavior (if any) can clearly reveal EUD self-efficacy levels.

RQ2: Are hesitation pattern attributes associated with end-users' behavioral attributes?

Results in table 5 show that hesitation pattern related metrics are significantly associated with all the measured behavioral attributes, i.e. perceived ease of use, perceived usefulness, willingness to learn, self-efficacy and risk-perception. In particular, hesitation pattern metrics revealed the following EUD correlations:

- Number of hovers that turned into clicks is significantly correlated to perceived ease of use;
- Average time from mouse hover to click is significantly correlated to willingness to learn and self-efficacy;
- Average time between clicks is significantly correlated to willingness to learn and risk-perception;
- Average pause time before clicks is significantly correlated to perceived usefulness and willingness to learn;
- Number of hovers is significantly correlated to perceived usefulness.

RQ3: Are random pattern attributes associated with end-users' behavioral attributes?

Results in table 5 show that random pattern related metrics are significantly associated with perceived ease of use, perceived usefulness and self-efficacy. In particular, random pattern metrics revealed the following EUD correlations:

- Number of movements is significantly correlated to perceived ease of use, perceived usefulness and self-efficacy;
- Number of curves (not direct movements) is significantly correlated to perceived ease of use and perceived usefulness;
- Number of clicks outside direct movements (straight lines) is significantly correlated to perceived ease of use.

RQ4: Are fixed pattern attributes associated with end-users' behavioral attributes?

Results in table 5 show that fixed pattern related metrics are significantly associated with perceived usefulness, self-efficacy, willingness to learn and risk-perception. In particular, random pattern metrics revealed the following EUD correlations:

- Number of long pauses (> 5sec) is significantly correlated to perceived ease of use, perceived usefulness and self-efficacy;
- Average time of long pauses (> 5sec) is significantly correlated to self-efficacy;
- Average time of all pauses (both long and shorter >200ms) is significantly correlated to perceived usefulness, willingness to learn and ease of use.

RQ5: Are guide pattern attributes associated with end-users' behavioral attributes?

Results in table 5 show that guide pattern related metrics are significantly associated only with the two acceptance attributes, i.e. perceived usefulness and perceived ease of use. In particular, random pattern metrics revealed the following EUD correlations:

- Number of long direct movements (>10px) is significantly correlated to perceived ease of use and perceived usefulness;
- Number of slow (smooth) movements (>2sec) is significantly correlated to perceived ease of use and perceived usefulness.

RQ6: Is the activity level of mouse movements associated with end-users' behavioral attributes?

As results in table 5 show, activity level for mouse movements is associated only with perceived usefulness in web-based EUD activities.

RQ7: Are any keystroke dynamics associated with end-users' behavioral attributes?

As results in table 6 show, only two out of four keystroke dynamics (keypress speed and down-to-down time), revealed some significant correlations to EUD behavioral attributes. In particular, keystroke dynamics attributes revealed the following EUD correlations:

- Keypress speed (threshold = 4sec) is significantly correlated to perceived ease of use and self-efficacy;
- Down-to-down time (threshold = 4sec) is significantly correlated to self-efficacy.

Table 7 summarizes the results of tables 5 and 6, presenting a clearer image of the bivariate correlations between the measured mouse/keyboard metrics and EUD behavioral attributes. As we see, every mouse behavioral pattern can be correlated to many user behavioral attributes since every mouse metric reveal its distinct particularities regardless the pattern it 'belongs to'. Thus, we notice that many mouse pattern metrics are correlated to more than one EUD behavioral attributes. This was the main reason we could not construct any particular hypotheses on the correlations between mouse patterns and particular behavioral attributes. However, we can notice some clear common behavioral correlations of patterns. For instance, we observe that fixed pattern is mainly associated to self-efficacy, whereas guide and random patterns are mainly oriented to perceived usefulness and ease of use. Hesitation pattern expresses a multi-item orientation since hesitation mouse metrics are more in number plus not so close (in terms of mouse action) one to another.

Regarding keystroke dynamics correlations, we notice that both key press speed and down-to-down time are correlated to self-efficacy, revealing a strong relationship between user's self-efficacy and keystroke dynamics in EUD tasks. Key press speed also reveals a relationship with perceived usefulness. Dwell and flight time did not show any meaningful contribution in the current web-based EUD behavioral research.

Table 7. Summary of significant correlations between EUD behavioral attributes and mouse/keyboard metrics

Mouse/Keystroke Attribute	Mouse Behavioral Pattern	User Behavioral Attribute
<i>Mouse metrics</i>		
num-mv	Random	PU, PEOU, SE
num-crv	Random	PU, PEOU
num-outlineClks	Random	PEOU
num-longPauses	Fixed	SE

avg-longPauses	Fixed	SE
avg-pause	Fixed	PU, SE, WL, RP
num-dirMv	Straight	PU, PEOU
avg-pausesBtwDir	Straight	WL
num-inlineClks	Straight	-
num-hvrToClk	Hesitation	PEOU
avg-hvrToClk	Hesitation	SE , WT
avg-btwClk	Hesitation	WL, RP,
avg-pauseBfrClk	Hesitation	PU, WL
num-hvr	Hesitation	PU
num-longDirMv	Guide	PU, PEOU
num-slowMv	Guide	PU , PEOU
al-mv	-	PU

Keystroke metrics

speed-char	PEOU, SE
dwel-time	-
flight-time	-
d2d-time	SE

As a conclusion we could say that we cannot detect particular behavioral attributes from one single mouse behavioral pattern. Mouse pattern ‘translation’ and division in measurable mouse metrics is necessary before conducting a EUD-related correlation analysis. Additionally, different research works could enrich or differentiate these metrics resulting in some different or more/less correlations. As already mentioned, mouse behavioral patterns have not yet matured in the HCI behavioral research and their mouse metrics remain vague. However, steps like the current study are contributing to the evolution of mouse behavioral patterns and their broader application in user-oriented HCI and EUD research.

6.1. Possible Issues and Limitations

Since this research is the first in the area of mouse tracking in EUD environments it comes with certain limitations.

First, the approach involves a limited number of behavioral variables, mouse and keyboard metrics and there are a number of other important end-user behavioral attributes (e.g. curiosity, pleasure, willingness to learn, exploratory behavior, etc.) and mouse metrics (e.g. distance travel, speed of movement, etc.) or even keyboard events that could be added in future studies.

A second possible limitation is the generalizability issue. The current field test is conducted on a generally small sample size and this can possibly affect the ability to generalize the findings. The current study does not take into account the generic users' or students' population but a EUD subset and based on this, it evaluates the sample representation. As mentioned, we refer to a EUD subpopulation since according to Costabile et al. (2003b), EUD population is not uniform and is divided in a set of communities characterized by different goals, tasks and activities. EUD population can be different according to cultural, educational, training, and employment background, experience in computer use, age, types of (dis)abilities, etc.

Finally, there may be another possible limitation involved by the SPA (single page application) design of the prototype EUD tool. Other design paradigms such as the wizard-logic have been proved to be preferred by female users (Beckwith et al., 2005; Burnett et al., 2010) and it can positively affect their perception, acceptance or performance. Also, this can possibly lead to differentiated results in future web-EUD research that will be conducted on multipage or wizard like interface designs.

7. CONCLUSIONS AND FUTURE WORK

In this exploratory study we examined the correlation between a set of EUD behavioral attributes and mouse behavioral patterns and keystroke dynamics. Our aim was to find out whether end-users' behavioral attributes can be reflected on their mouse and keyboard behavior during web-based EUD activities.

The measured EUD behavioral attributes were self-efficacy, risk perception, willingness to learn, perceived ease of use and perceived usefulness. The mouse behavioral patterns we examined were the straight pattern, the hesitation pattern, the fixed pattern, the random pattern and the guide pattern. Reading pattern was excluded due to the dynamic nature of EUD activities and their limited 'content to read'. The measured keystroke dynamics that were chosen were the four main ones, as derived from the reviewed literature, including key press speed, dwell time, flight time and down-to-down time.

A set of research questions were formed to structure the research objectives and distinguish the measured variables. Except mouse pattern-related variables we also measured mouse activity level of movements and included it in our correlation research.

To explore our research questions we conducted a field test using a prototype web-based EUD tool to assist end-users in creating simple web forms, and we monitored their mouse behavior via a prototype mouse tracking mechanism. Mouse and keyboard monitoring data from 30 participants (from an initial population of 42 end-users) was analyzed.

The conducted field test showed that there are several significant correlations between mouse measurable attributes and EUD behavioral states. Keystroke dynamics also revealed some significant correlations to perceived usefulness and self-efficacy. Summary conclusions in table 7 show that mouse and keyboard monitoring is a useful mean of gathering real time implicit feedback in EUD activities.

The main contribution of this work is to provide HCI and EUD research community with a basic research background and a motivation to study further and to understand the end-user behavior in web-based EUD environments, as well as the correlation between mouse and keystroke actions and end-users' behavioral items while interacting with these systems' environments.

We believe that mouse behavioral patterns should be 'back in action' and studied further in web environments to analyze end-users' behavior. As already mentioned, there are a number of other important end-user behavioral attributes (e.g. curiosity, pleasure, willingness to learn, exploratory behavior, etc.) and mouse metrics or keyboard stroke attributes that could be added in future studies.

Another interesting future research direction could also be to examine the end-users' behavior by combining mouse/keyboard monitoring and eye tracking methodologies. In our future works we plan to conduct new web-EUD exploratory studies monitoring both eye and mouse movements to detect possible new perceptual and behavioral correlations and use them as implicit feedback in self-adaptive EUD systems. In particular, combined mouse and eye tracking data can help EUD researchers deeper understand what happened in between clicks and reveal more about the users' cognitive process. By capturing the users' development behavior, user-modeling techniques could be developed to adapt/personalize the EUD environments, aiming to enhance the end-user performance and experience.

It would also be useful to conduct a similar study on a larger sample size, to address generalizability issues and represent broader EUD populations (such as the student population).

Hopefully our research will shed light on the necessity of similar human-oriented behavioral analyses in the EUD evolution and encourage relative future work.

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ANNEX A. QUESTIONNAIRE

Table A1. Questionnaire survey and results for validity of the measurement model

Construct Item		Cronbach α (≥ 0.70)
Self-Efficacy		0,89
SE1	I felt confident while I was using the system	
SE2	I believed that I could perform well	
SE3	I felt I had the control of the task	
SE4	I felt that everyone else knew what to do but me	
SE5	I felt confused while using the system	
Risk Perception		0,70
RP1	It was taking me time to decide how to move while using the system	
RP2	I felt nervous every time I took an action (e.g. pressed a button)	
RP3	I checked well my actions before moving to the next steps	

RP4	I had no hesitation to take an action	
RP5	I had no difficulty to try which feature (among other) to use	
Willingness To Learn		0,81
WL1	I wanted to learn how to use the system while I was using it	
WL2	I d like to learn more how to use the system	
WL3	I d like to learn how to use other similar systems too	
Perceived Ease of Use		0,76
PEOU1	The system is easy to use	
PEOU2	I do not need to try too hard to use the system effectively	
PEOU3	I can use the system without written instructions	
PEOU4	I can learn how to use the system easily and fast	
PEOU5	I can easily correct my mistakes while I use the system	
Perceived Usefulness		0,71
PU1	The system is useful	
PU2	The system makes me more productive	
PU3	The system makes me save time	
PU4	The system satisfies my needs and requirements	

ANNEX B. NORMAL DISTRIBUTION TEST RESULTS

Table B1. Test of Normality (N=30)

	Shapiro-Wilk		
	Statistic	df	Sig.
Perceived Usefulness	0,956	30	0,248
Perceived Ease Of Use	0,934	30	0,065
Self-Efficacy	0,933	30	0,057
Willingness to Learn	0,959	30	0,289
Risk-Perception	0,967	30	0,453

Figure B1. Normal Q-Q Plots for the whole sample

