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Intuitive Learnability of Touch Gestures for Technology-Naïve Older Adults

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Touch-based interactions, if intuitive and natural, should be highly learnable. However, the learnability of touch gestures as a computer interaction modality cannot be taken for granted and should be evaluated empirically. This is especially true when technology-naïve older adults are concerned, given the psychological and physical constraints associated with this age range. To investigate this issue, we conducted a study with 17 technology-naïve older adults, whose experience with technology was mostly limited to making calls with mobile phones. Specifically, the participants were presented with three simple digital games on an interactive tabletop surface and asked to play the games on their own with minimal instruction or help. The first two games required the use of a drag gesture whereas the third game required the use of a rotate gesture. The main research question was whether the older adults could learn the gestures effectively and efficiently. A set of variables such as task duration and gesture accuracy were measured. Results showed that the learnability of a drag gesture was relatively high and that the participants could transfer this skill across the games. In contrast, the learnability of a rotate gesture was low and most of the participants failed to demonstrate any improvement over the tasks of the game. These findings partially corroborate those of earlier work. Implications for future work are drawn, especially exploring the potential of social interactions between older adults for enhancing the learning effects.

RESEARCH HIGHLIGHTS

- We research the intuitiveness of touch-gestures in older adults with very low technology adoption.
- The DRAG gesture is highly learnable and retainable without specific training or instructions.
- The ROTATE gesture has lower learnability, with a wider specter of incorrect interpretations.

Keywords: intuitive interaction, learnability, gestural input, touch-screen, interactive surface, senior users

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1. INTRODUCTION

In recent years we have witnessed a great demographic change in society where the proportion of elderly population has significantly increased and will continue to grow. The increasing use of digital technology in all aspects of daily life holds the promise of increased quality of life, especially for older people. However, when using contemporary consumer products with complex interfaces, older people face significant problems due to the cognitive and perceptual demands such products placed on the user (Czaja and Lee, 2007). Hence, the critical factor for the successful use of technology by older adults is systems that are tailored specifically to the needs and preferences of this user group. These systems must be designed and implemented with an approach that considers all age-related challenges in functional abilities.

In the last decade much attention has been devoted to understanding and accommodating the needs of elderly citizens with respect to interacting with technology. Additionally, there is an increased popularity of gesture-based applications where users use the movements of fingers, hands, head, face and other parts of the body to interact with digital objects (Amini *et al.*, 2001; Fitzgerald *et al.*, 2007; Sawada and Hashimoto, 1997).

As gesture-based interfaces have the advantage of simplicity by omitting the intermediary input device, older users who operate traditional input devices with limited speed and accuracy may find gestures attractive and applications more accessible (Chen, 2013).

Designing products that are more intuitive for older users can alleviate the negative experience caused by their cognitive and perceptual impairments. An intuitive technological product normally requires minimal learning as it should be contingent on the user's prior experience and familiarity with the technology (Blackler *et al*., 2010b). Furthermore, the advent of touch-based technologies has an accruing potential for improving human–technology interaction and adoption for older adults by introducing natural movements to the interaction process. The focus of this research is to evaluate the naturalness of touch-based gestures and assess whether the intuitiveness (or prior experience) of using similar hand motions for performing daily activities are transferable to the touch-based user interface. Specifically, we evaluated the learnability of a natural user interface (NUI) for older adults in empirical studies with users who had *no* experience with the interface and technology under evaluation. By implementing a gesture-based NUI on a familiar tangible table-top surface, we encouraged the users to use their prior experience of interacting in a natural environment.

In the following sections, we first discuss and elaborate the design and development of three tabletop games, where the user is required to master two basic touch gestures—drag and rotate—in order to accomplish the game goals. In the following text, we describe the experimental approach where 17 individuals with an average age of 67 years played the gesture-based games. The collected data are qualitatively and quantitatively analyzed through a defined set of variables on task performance. We conclude the paper with a discussion on the implications from the empirical results for the design of NUIs for technology-naïve older adults.

2. RELATED WORK

2.1. Intuitive interaction

The work on intuitive interaction design was initiated by Blackler *et al*. (2003) where intuition is defined as a cognitive process that utilizes knowledge gained through prior experience. Intuition does not simply rely on instinct and innateness, but it depends on experiential knowledge accrued over time. Over the past years this definition has been supported by several experimental designs (Blackler *et al*., 2010b; Hurtienne and Blessing, 2007; Naumann *et al*., 2007) where prior experience and familiarity have been identified as the main factors for intuitive use. Despite the increasing penetration of digital technology into almost all sectors of life, the older members of the analogue age have remained with decrepit technological paradigms (Westerman and Davies, 2000). Age-related decline in cognitive skills and physical abilities prevent older adults from learning new technologies efficiently (Blackler *et al*., 2005). Older people's interaction with modern technology is less intuitive even with prior experience where interfaces are used more slowly (Lewis *et al*., 2008). Using contemporary products and interfaces is generally less intuitive for older people than for their younger counterparts, as evident by longer task times and more erroneous results (Langdon *et al*., 2007). The reasons for the affected performance have been identified as older adults' lower familiarity with the new technologies (Lawry *et al*., 2010) and decline in their central executive function (Blackler *et al*., 2010a), implying that they are less able to process information in working memory. This difference is evident even with middle-aged users (Lawry *et al*., 2011) who are disadvantaged by their lower familiarity with a novel interface.

Blackler *et al*. (2012) investigated redundancy and simplicity as design approaches for making interfaces more usable for older people. The redundancy approach was shown as less effective for the oldest age group (73+), showing faster task times and better intuitiveness only for middle aged people (40–59). In the simplicity approach, older people took less time to complete the task in an interface that used a flat structure when compared with an interface with a nested structure. Reporting on the same experiment, Gudur *et al*. (2013) showed the same results when comparing the interface structures in a touch-based environment. In their study, older age groups performed better under anxious conditions and did not make significantly more errors compared with younger age groups on either interface structures.

The touch screen has been suggested as a suitable input device for elderly users because it is easy to learn and operate (Yarnold *et al*., 1996). Taveira and Choi (2009) observed that older users found touch-based input devices easier to use than other alternatives. Older users can also use touch-based products successfully, regardless of their age-related functional deficiencies (Häikiö *et al*., 2007). According to Umemuro (2004) even the influence of the anxiety factor declined significantly in a study of older people's performance in a touch-screen environment.

Gesture-based interfaces are considered more user-friendly to older users than windows, icons, menus and pointers (WIMP) interfaces because they are natural and intuitive. Rather than forcing users to acquire a set of manipulation skills peculiar to the technology, they allow users to apply a range of skills that have evolved through years of interaction with the real environment (Saffer, 2009). This goes beyond the 'naturalness' of using visual metaphors, or mimicking aspects of the real-world that is sometimes attributed to WIMP systems (Widgor and Wixon, 2011). They therefore require minimal learning time and they lead to a high degree of user satisfaction. Indeed, the related research studies of the last two decades lend support to the assumption on the naturalness and intuitiveness of gesture-based interaction. For instance, dated back to 20 years ago Abowd and Mynatt (1994) advocated using common means of human communication such as speaking and gesturing as input to ubicomp systems. A decade later, Karam and Schraefel (2005) concluded, based on their reviews of 40 years of literature on gesture-based interaction, that 'much of the research on gesture based interactions claim that gestures can provide a more natural form of interacting with computers' (p. 26). Similarly, Saffer (2009) argued that a natural system is the one that allows its users to act and communicate in the ways they naturally do in their everyday life. Other recent work, including Jacob *et al.*'s (2008) reality-based interaction as well as Widgor and Wixon's (2011) touch- and gesture-based NUIs, can further substantiate the notion of leveraging existing repertoire of naturally evolved human actions to enhance interaction design of computing technologies.

2.2. Naturalness

How *natural* are NUIs? Various stances on the notion of naturalness can be identified in the literature with some arguing from the more technical perspective (Biswas and Langdon, 2011; Widgor and Wixon, 2011) and some from the more philosophical one (O'Hara *et al.*, 2013). Norman (2010) offered an unambiguously negative answer to this question, claiming that most gestures are acquired rather than given. Nonetheless, it is critical to identify (un)natural to *whom* and to understand *why*. A NUI may appear intuitive for the generation of technology-savvy 'digital natives' (Prensky, 2007) such as contemporary teens, but inaccessible to the generation of technology-naïve 'digital aliens' such as older adults who have minimal experience with computer technologies. If an NUI is perceived by older people as unnatural, a concomitant question should be: how *learnable* are NUIs for this specific user group?

Evolved from WIMP, NUI is a computer interaction methodology exploiting human abilities such as touch, vision, voice and motion (Mann, 2002). Examples of more recent NUI-based systems are touch-gesture tablets, gaze-controlled remote control and motion-sensing games. As an alternative to their predecessors—command-line interfaces and graphical user interfaces—NUIs are deemed more desirable and inclusive as they aim to utilize the power of a much wider range of communication modalities, leveraging skills people acquire through ordinary activities in everyday life (Widgor and Wixon, 2011). Another critical feature of NUI is high learnability relative to WIMP interfaces. Grossman *et al.* (2009) define learnability as '*The ability to perform well during an initial interval and the ability to achieve eventually optimal performance, for a user with no experience with the interface*'. As suggested by Saffer (2009), NUIs facilitate the use of a range of evolved skills rather than technology-specific procedures that are typical of WIMP-style interfaces. This implies that initial learning and the acquisition of manipulation skills have fewer barriers to overcome, accelerating good performance. Therefore, the two notions—naturalness and learnability—would seem to be closely related.

An NUI may not be natural in the sense that it draws on our innate abilities to use it, rendering any form of learning or training unnecessary. Nonetheless, an NUI should be highly learnable and therefore can lower the barrier to digital technology acceptance for older adults, many of whom experience computer anxiety (Segrist *et al.*, 2004). Playing simple games on a touch-gesture tabletop can support older adults to overcome their reluctance and fear of using digital devices. Although touch-based interaction has been shown to have some efficacy beyond WIMP systems for learnability, ease of manipulation and likeability (Biswas and Langdon, 2011), mastering core manipulation skills and recognizing often non-textual cues requires adoption, exploration and practice. These seemingly simple skills can be challenging for older adults, because of the compounding issues engendered by their lack of computing experience and declining cognitive, perceptual and motor skills (Fisk *et al.*, 2009).

O'Hara *et al.* (2013) remarked that the word 'natural' in the context of NUI is loosely associated with concepts such as ease of use, learnability and intuitiveness (Norman, 2010), and that the positivist view of NUI has been widely adopted (Abowd and Mynatt, 1994; Karam and Schrefel, 2005; Saffer, 2009). Specifically, it defines the aim of NUI as leveraging people's actions used to communicate and to manipulate objects in everyday life. However, O'Hara criticized this so-called representational account of naturalness, for narrowly focusing on the objective aspect of human actions and gestures, and thus underplaying the importance of the subjective and social aspect.

2.3. Learnability

One possible definition of learnability is the ease with which a person learns to use an interactive system to achieve a goal. Several attempts to define learnability have been undertaken, and a consensual definition is still lacking. After reviewing the related 88 papers published since early 1980s, Grossman *et al.* (2009) proposed a taxonomy of learnability with two aspects: *scope* and *user definition*. Specifically, learnability can be scoped based on the timeframe in which performance is considered, ranging from a short usage episode of an hour or less to a longer one of weeks or months during which performance may change. With regard to users, relevant metrics include their experience with computers, interfaces and similar software, and quality of their domain knowledge. Grossman *et al.* (2009) identified seven categories of learnability metrics: task performance, command usage, mental cognitive processes, subjective user feedback, documentation usage, usability and specific rules. Depending on the evaluation context, a subset of such learnability measures are selected, and adapted, if necessary. For instance, in our study, more relevant measures are task performance (e.g. task time, errors) and usability (e.g. quality of use). As an extensive measurement process would very likely arouse negative feelings in older adults, who are prone to fatigue (Fisk *et al.*, 2009), the use of questionnaire or any form of obtrusive intervention should be minimized; lest participants may misattribute their unpleasant experiences holistically to computer technologies. Moreover, interpretations of the learnability measures need to be contextualized with respect to the characteristics of older adults.

Previous work, though limited, has investigated touch gesture interfaces of applications that support older adults in activities such as remote communication (Leonardi *et al.*, 2010) and photo sharing (Apted *et al.*, 2006). Some work suggested that touch-screens might be beneficial for older adults (Lee *et al.*, 2009; Findlater *et al.*, 2013; Schneider *et al.*, 2008), who could complete a range of touch gestures including point, drag and pinch (Kobayashi *et al.*, 2011). However, some studies found that a touch-screen was more difficult than a mouse for older users to manipulate (Florines *et al.*, 2007; Wood *et al.*, 2005). In general, older adults were found to be slower than their younger counterparts in touch gestures but not more error-prone (Stößel and Blessing, 2010). Furthermore, Mertens *et al.* (2010), based on their work on touch-table design for users with kinetic tremor, argued that ease-of-use is critical for promoting confidence in older users (including those with minor physical impairments) to interact with digital devices. If users could recognize their natural motion patterns as the required input, it would help mitigate their anxiety with computer technologies.

To understand further the relationship between naturalness and learnability in the context of NUI, it is relevant to look into *exploratory learning skills* (Rieman, 1996). The main characteristics of such skills are recognition-based search for features, direct manipulation of objects, reactive planning by recognition and understanding of system feedback and incremental learning through trial-and-error. Players motivated to engage with games are effectively engaging in incremental learning about, for example, the behavior of digital objects, the principles of object and area selection and the relationship between analogue metaphors and degrees of movement on digital space. However, this can be difficult for many older users for several reasons (Chin and Fu, 2012). These individuals tend to have no prior competence on which they can draw to initialize learning other than awareness of analogue metaphors to identify objects and (if supported by the system) simple movements associated with those objects. Older adults are familiar mostly with analogue technologies, and in many cases are not comfortable with the concept of exploratory learning through trial-and-error (Fisk *et al.*, 2009). Also, older people typically acquire physical and perceptual impairments that cause difficulties in specifying actions and performing intricate hand and finger actions to manipulate pointing devices (Biswas and Langdon, 2011).

In summary, the findings from the existing work on the learnability of touch gestures for older adults are inconsistent. One main reason is that the number of studies is relatively small considering the large variance in digital literacy of older participants. For instance, in Findlater *et al.* (2013), 9 of 20 older adults used touch-screen devices on a daily basis and 3 had never used such devices; in Piper *et al.* (2010), 17 out of 20 older adults used computer daily, but in Leonardi *et al.* (2010) only 2 of 15 older participants had some computer experience and the others had none. Besides, the number of participants varies with the studies, and it tends to be small. Acquiring digital literacy is often an issue of overcoming reluctance. Games, when well-designed, can be very motivating and engaging, and thus have high potential to address the issue of aversion to unfamiliar interactions. An increasing number of studies show that digital games can encourage older adults to adopt computers as well as improve their quality of life (Gabrielli *et al.*, 2008; Wang and Burton, 2010).

Our current study aims to build on the previous work by recruiting a more homogeneous sample of older adults who had no experience with touchscreen devices and very limited experience with digital technology in general. This allows us to draw coherent conclusions on the learnability of touch gestures. Furthermore, we aim to enrich the body of applied knowledge in this specific area, enabling a meta-analysis to be conducted later for deriving a coherent understanding of this research area.

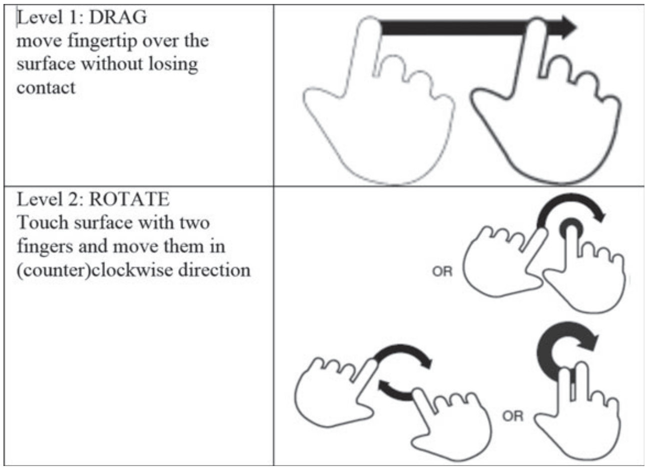
3. EMPIRICAL STUDY

3.1. Participants

The studies were conducted in Republic of Macedonia, a Balkan country where enhancing digital literacy in adult citizens has been one of the key development areas to address (UNESCO, 2011). Altogether 17 participants were recruited through a retirement community: 4 males and 13 females (mean age: 67.32 years; age range: 54–82). All their participation was voluntary with a small compensation for traveling and daily expenses. All participants were technology-naïve and their interaction experiences were mostly limited to making calls on a keypad-based mobile phone. None of them have ever used a computer. All were in good health with minor complaints concerning ailments that cause slight discomfort with active use of their hands.

3.2. Instrument

The SMART Table 230i®, a multi-touch interactive learning tabletop from Smart Technologies, was deployed for the purpose of this study. The Table allows multiple users to interact with the interface simultaneously and is able to register up to 80 simultaneous gestures. The display of the table uses a XGA short-throw lens to project on a 27.5” screen with a 4:3 aspect ratio. The interactive table runs the SMART Notebook® software on a Windows OS. The game software used in the study was developed with the SMART Table Toolkit. All the experimental sessions were recorded with a Canon Vixia HF R20 camcorder.


Level 1: DRAG
move fingertip over the surface without losing contact

Level 2: ROTATE
Touch surface with two fingers and move them in (counter)clockwise direction

Figure 1. Illustrations of the three main gestures (Vilamor *et al*., 2010).

3.3. Experiment design

An increasing number of multi-touch tabletop applications promote entertainment and social interactions among elderly people (Loureiro and Rodrigues, 2011). Hollinworth and Hwang (2011) used ‘familiarity’ as a design principle and showed that providing familiar visual objects that can be manipulated by finger gestures similar to their real-world counterparts allows older users to perform basic tasks with no prior training. Hence, we selected three simple and intuitive mini-games which were particularly suitable for touch-gesture interfaces. In the process we adopted the guidelines for encouraging appropriation (Harley *et al*., 2010) and for interactions in games for elderly people (Gerling *et al*., 2012). Specifically, these adopted guidelines deal with issues such as physical and cognitive impairments, adaptation to individual differences, natural mappings to support gesture recall and implementing easy routines to encourage independent play.

To evaluate the acquisition of proper touch gestures, the participants played the games individually. Based on the complexity of the gestures to be acquired in the games, the gestures are classified as two levels (Fig. 1).

A mixed factorial design was used for this study with the within-subject variable being the game requiring a specific touch gesture to complete (DRAG, ROTATE).

The 17 evaluation sessions took place in a spacious room with the experiment setup where each session lasted approximately 20 minutes. A session consisted of two parts. First, each participant was asked to fill out a paper-based short questionnaire about their technology use and personal health. Second, the participants were asked to play the three games consecutively in the order of complexity on the tabletop, and the entire gameplay part was videotaped, resulting in about 8 h of videos.

As the main goal of the study was to understand how technology-naïve people acquired different touch gestures, no instruction or demonstration how to play the game was provided. At the beginning of a session, the participants were told that they were going to play with a new device in order to improve their isolation from technology and that they were free to explore the games on the device. No time limit was imposed and no unsolicited help was given.

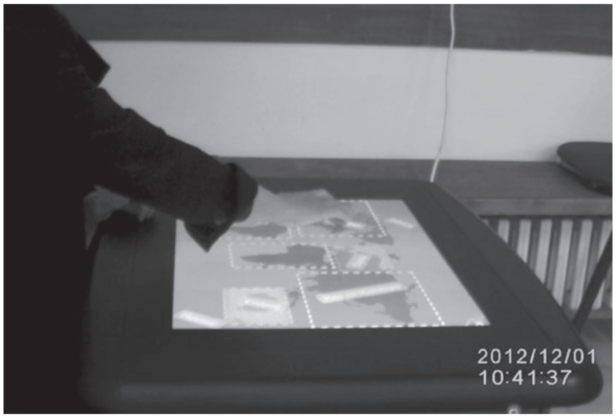


Figure 2. Participant playing Game 2–Hot Spaces.

Throughout all these sessions, two researchers were present as observers. One of them was a local academic, who communicated with the participants and took note of their specific verbal behaviors. The other was a visiting researcher who co-designed the study. To facilitate the expert analysis, all the videos were transcribed and time-stamped, and the dialogues were translated from Macedonian into English. The audiovisual data were coded into variables in parallel by two independent parties, whereas all discrepancies in the coded data were resolved by a joined recode. The coding scheme consisted of determining gesture types and time durations and was performed in accordance with the definitions explained in the Variables section.

3.4. Game design

3.4.1. Game 1: Hot Spaces

Hot Spaces is a map-based game requiring minimal geographical knowledge. The touch-screen displays a simple outline of a world map along with six city names placed in rectangular boxes (Fig. 2). The game was completed after the player had placed each of the six given cities in a continent, regardless of its location correctness. The actual (hidden) goal of the game was not to evaluate the participants’ knowledge of geographical facts, but to evaluate how the players learned DRAG when using touch-based technologies. Each city placement was one task, totaling to six in all.

3.4.2. Game 2: Hot Spaces

Hot Spots is a number game that requires very basic arithmetic knowledge. The touch-screen displays six pairs of playing cards;

Figure 3. Game 3–moving the jigsaw pieces in the central red square to the surrounding white shapes.

each has a number-10 card and an overturned card (with an unknown value). A large two-digit number indicating the sum of the 10 and unknown value was displayed at the junction between a pair of cards (Fig. 2). The participant had to drag a loose card from the center of the tabletop to a slot where the overturned card was to make up the indicated sum. There were six such matching tasks to complete. Similar to Game 1, the task was considered completed when a card was placed in a slot, irrespective of the accuracy of the sum. The actual goal of the game was to evaluate the transfer of the learned DRAG from Game 1.

3.4.3. Game 3: Puzzle

In this game the player has to move eight jigsaw pieces, which were coalesced as a square in the center of the tabletop, to some predefined shapes (Fig. 3). To complete this game the participant had to perform two different gestures—DRAG and ROTATE. As tasks in this game could not be as well-defined as those in Game 1 or Game 2, we propose an alternative unit of analysis—trial. A trial refers to the episode from the moment a player starts interacting with a jigsaw piece with various gestures till she stops doing so. She may revisit this jigsaw piece, which is, however, counted as a new trial.

3.5. Variables

Given the open-nature of the games, two specific constructs are identified: goal recognition (GR; i.e. the moment when the player recognizes the goal of the game) and interaction discovery (ID; i.e. the moment when the player discovers the interaction needed to achieve the goal). The related variables are operationalized as follows:

- *GR time*: The time between the start time and the moment a player understands the goal of the game (e.g. placing cities onto the continents in Game 1).
- *ID time*: The time between the start time and the moment a player visibly makes the first DRAG gesture.
- *Gestures before GR*: The number and type of gestures attempted by a player before realizing the goal of the game, exhibiting exploratory learning behavior.

The key variables for evaluating the learnability of DRAG in Game 1 and its retention in Game 2 are as follows:

- *Task time*: The time between the moment a player touches an object (a city label/a playing card) and the moment the object is positioned, and the interaction with the object is discontinued.
- *Gesture*: Types of (in)correct gesture performed, number of each gesture type.

In Game 3, the learnability of ROTATE was evaluated. The following variables are measured per trial (interacting with a single jigsaw piece) rather than per task:

- *Gesture:* Types of (in)correct gesture performed, number of each gesture type per trial.
- *Trial time*: Duration of interacting with a jigsaw piece.

3.6. Research questions and hypotheses

The purpose of the evaluation of Game 1 was to determine the learnability of the DRAG gesture. The primary source of data was the game session videos which were coded systematically to answer the following research question (RQ):

> *RQ1: What is the learnability of the DRAG gesture for the players as indicated by the changes of their performance over a set of six similar tasks with the tabletop?*

Specifically, we measured the change in time duration, number of correct gestures and number of incorrect gestures across all the six tasks to evaluate the following hypotheses (H1, H2 and H3) derived from RQ1. They were formulated based on the assumption that the participants could learn from practicing the tasks sequentially and thus improve their performance by reducing the task completion time and increasing the gesture accuracy.

> *H1: There is a significant decrease in task duration over the six tasks.*
> *H2: There is a significant increase in the number of correct gestures over the six tasks.*
> *H3: There is a significant decrease in the number of incorrect gestures over the six tasks.*

With Game 2 we aimed to determine how well the DRAG gesture learned from Game 1 could be transferred to deal with the tasks in this game. Our second RQ is thus formulated as follows:

> *RQ2: How do players benefit from their knowledge and skills gained in Game 1 to resolve tasks in Game 2?*

To address RQ2, it is necessary to compare the values of different variables, including (i) *ID time*—how much time it takes the participant to find out what interaction is required for playing the game; (ii) *gestures before ID*—how many exploratory gestures, which might be simply trial-and-error or be experience-driven, were performed by the participants; (iii) *task duration*—time (in seconds) expended in completing an individual task of the game; (iv) *GR time*—how much time it takes for the participant to identify the goal of the game; (v) *number of gestures* and (vi) *normalized scores for correct and incorrect gestures.*

To enable the comparisons between the two games, we transformed the data for the number of correct and incorrect gestures into one variable—*gesture score* (GS) defined as the percentage of correct gestures over the total number of gestures performed by a participant in one task [$\mathrm{GS} = (\mathrm{Gc}/\mathrm{Gc} + \mathrm{Gi}) \times 100$]. This provides normalized values across all the tasks of Game 1 and Game 2 on a scale of from 0 to 100, allowing for the comparison of gestural performance between the two games which rely on the same gestural requirement, but different cognitive strategies.

Based on the assumption about the high learnability of the drag gesture, we formulate the following hypotheses:

> *H4: The ID time for Game 1 is significantly longer than that for Game 2.*
> *H5: The ratio of correct gesture count to the total gesture count for Game 1 is significantly lower than that for Game 2.*
> *H6: There is a significant decrease in task duration for each task between games.*

With Game 3 we aimed to evaluate whether the participants could learn the correct rotate gesture as they progressed in their game-play. The participants needed to perform four different rotate gestures to complete the game. Gestures were considered as incorrect when the system did not respond because a shape was rotated in an unexpected manner.

> *RQ3: What is the learnability of the ROTATE gesture for the players as indicated by their interactions with the jigsaw pieces on the table top?*

Correspondingly, we formulate the following hypotheses:

> *H7: The number of correct rotate gestures increases significantly from the beginning towards the end of the game.*
> *H8: The number of incorrect rotate gestures decreases significantly from the beginning towards the end of the game.*

4. RESULTS

As Games 1 and 2 were similar to each other in terms of goal, structure and touch gesture required and quite different from Game 3, we have analyzed the first two games with the same methods and used a different approach for the last game. The results are grouped accordingly.

Table 1. Use of technology metrics

	Frequency of use[a]	Ease of use[b]
Mobile calls	3.76	5.00
Mobile SMS	2.00	2.29
Digital camera	1.76	2.24
Computer	1.25	1.09
Internet	1	1

[a] 1 = never, 5 = always; [b] 1 = very difficult, 5 = very easy

4.1. Participant profile

The participant profiles were identified through the analysis of the data captured with the demographic questionnaire. The Kolmogorov–Smirnov test indicates that the variable *age* is normally distributed. Further, the results of the independent t-test show that there is no significant difference in age between males and females ($t(15) = 1.64$, $P > 0.05$). For the other demographic variables with a non-normal distribution, the Mann–Whitney tests also show no significant differences between genders (Table 1).

Using Friedman's ANOVA we tested whether there were significant differences in *frequency of use* and *ease of use* between different technology usages (i.e. mobile phone for calls, mobile phone for SMS, digital camera, the internet and computer). The results of the tests show that there are significant differences in frequency of use ($\chi^2(4) = 41.319$, $P < 0.05$) and in ease of use ($\chi^2(4) = 49.271$, $P < 0.05$) between mobile phones for calls and the other technology usages as reported by the participants These results indicate that the participants tended to use a relatively simple technology (i.e. mobile phone) for a simple task (i.e. talking).

4.2. Definition of gesture types

With videos as the main data source, the correctness and frequency of each type of gesture performed by the participants were derived. Specifically, correct gestures include 'drag' and 'semi-drag'. A 'semi-drag' is defined as a suboptimal drag where fingers move over a surface for a distance shorter than required. The weaker sensorimotor control of older adults can account for this gesture. For most of the tasks, semi-drags were performed repeatedly in order to move the object to its destination. Incorrect gestures are: 'tap', 'hold' and 'w-rotate'. 'Tap' denotes a brief touch of a surface with a fingertip, 'hold' refers to a suspended finger movement, and 'w-rotate' stands for 'wrong rotate' when two or more joined fingers are used to rotate an object with the wrist. This occurred often when a player intended to re-orientate an object to improve its readability

Table 2. Ranked scores from the Wilcoxon-signed rank test.

	Task 2 over Task 1		Task 3 over Task 1		Task 4 over Task 1		Task 5 over Task 1		Task 6 over Task 1	
Mean rank	Neg.	Pos.	Neg.	Pos.	Neg.	Pos.	Neg.	Pos.	Neg.	Pos.
Task duration	10.17	3.50	9.50	2.00	9.68	3.38	9.88	2.50	8.97	1.50
Correct gestures	8.64	8.20	8.11	7.83	8.75	5.00	7.86	8.38	8.96	7.13
Incorrect gestures	7.96	1.50	8.73	3.25	9.96	2.17	8.77	3.00	8.00	1.00

(e.g. a city label was upside down). This rotate gesture, albeit incorrect, can be a precursor for a proper one required for Game 3.

4.3. Results of Game 1: Hot Spaces

The mean task completion time for the 17 participants was 260 s (SD = 121.6). The duration of Task 1 was longest (M = 104.8; SD = 97.7) whereas the duration of Task 6 was the shortest (M = 9.3, SD = 5.7). The participants made less correct gestures (M = 16.2; SD = 20.6) and more incorrect gestures (M = 27.2; SD = 40.1) in the first task. But this trend reversed when the game reached the last task (correct gesture: M = 6.3, SD = 6.5; incorrect gesture: M = 0.5, SD = 1.3).

In the exploratory analysis of the data, the Shapiro–Wilk test was used to test for the normal distribution of the data, as it is a more precise test for samples with <20 participants. The test was significant across most tasks for task durations $[D(17)$ € $(0.676, 0.892), P < 0.05]$, numbers of correct gestures $[D(17)$ € $(0.410, 0.828), P < 0.05]$ and numbers of incorrect gestures $[D(17)$ € $(0.454, 0.747), P < 0.05]$, thus violating the assumption of normal distribution. Friedman's ANOVA test was performed using task as a coding variable and task duration, number of correct gestures and number of incorrect gestures as dependent variables. The results of the test reveal that there is a significant change in task duration between the tasks ($\chi^2(5) = 27.267$, $P < 0.05$), a significant change in the number of correct gestures between the tasks $\chi^2(5) = 13.366$, $P < 0.05$ and a significant change in the number of incorrect gestures between the tasks $\chi^2(5) = 25.825$, $P < 0.05$. These results are in support of hypotheses H1, H2 and H3.

Furthermore, in order to understand the nature of the significant differences, all post-hoc tests were performed for task duration, number of correct gestures and number of incorrect gestures. To measure the change, the mean values for these variables were compared between each task using the Wilcoxon signed-rank test. In the analysis, Task 1 was used as a control group as the means (M) and the ranked scores (R) for the task duration (M = 104.81, $R = 5.00$), for the number of correct gestures (M = 16.19, $R = 4.53$) and for the number of incorrect gestures (M = 27.19, $R = 5.25$). To avoid the accumulation of Type 1 errors, a Bonferroni correction was applied, therefore all post-hoc results are reported at a 0.01 level of significance.

The results of the tests presented in Table 2 show a tendency to positive ranks which implies that the trend of the measured variables is decreasing across tasks. The task duration was significantly higher for Task 1 when compared with Task 2 ($z = -2.793$, $P < 0.01$), Task 3 ($z = -3.068$, $P < 0.01$), Task 4 ($z = -2.642$, $P < 0.01$), Task 5 ($z = -3.129$, $P < 0.01$) and Task 6 ($z = -3.439$, $P < 0.01$). The number of correct gestures was significantly higher for Task 1 when compared with Task 4 ($z = -2.560$, $P < 0.01$). Finally, the number of incorrect gestures was significantly higher for Task 1 when compared with Task 2 ($z = -3.204$, $P < 0.01$), Task 3 ($z = -3.039$, $P < 0.01$), Task 4 ($z = -3.182$, $P < 0.01$), Task 5 ($z = -3.068$, <0.01) and Task 6 ($z = -3.235$, $P < 0.01$).

An additional Wilcoxon-signed rank test was performed for task duration using Task 6 as a control variable, since the means (M = 9.25) and the ranked scores ($R = 1.81$) appear different than the means for the same variables in the preceding tasks. The results of the test show a lean to negative ranks which implies that the trend of the measured variables is increasing across tasks. Task duration was significantly lower for Task 6 when compared with Task 2 ($z = -3.416$, $P = 0.00 < 0.01$), and Task 4 ($z = -3.185$, $P = 0.003 < 0.01$). The findings are in support of hypotheses H1 and H3, and in partial support of H2 as there is a significant difference, but with a decreasing trend.

4.4. Results of Game 2: Hot Spots

The mean task completion time for all participants was 159.12 s (SD = 120.35). The mean GR time was 65.88 s (SD = 60.95), and the mean ID time was 40.18 s (SD = 29.27). The participants made more correct gestures (M = 31.3; SD = 73.1) and more incorrect gestures (M = 6.5; SD = 13.1) in the first task with a decrease as they progressed with the other tasks (correct gesture: M = 4.3, SD = 4.0; incorrect gesture: M = 0.4, SD = 0.6). The same decreasing trend was observed for task duration with Task 1 having the longest (M = 38.1; SD = 50.1) and Task 6 having the shortest duration (M = 5.3, SD = 4.0).

As the Shapiro–Wilk test was significant across all the variables, showing a violation of the normal distribution assumption, to compare the data between Games 1 and 2, the Mann–Whitney significance test was used. A summary of the

Table 3. Results of the Mann–Whitney test for general game variables between Games 1 and 2.

	Single group		
	U	*Z*	Sig.
Game duration	56.00	−2.714	0.006
Problem recognition time	127.00	−0.038	0.978
ID time	35.50	−3.488	0.000
Gestures before problem recognition	101.50	−1.003	0.325
Gestures before ID	64.00	−2.441	0.014

Table 4. Results of the Mann–Whitney test for task duration and GS between Game 1 and Game 2.

	Duration for single group			GS for single group		
Task	*U*	*Z*	Sig.	*U*	*Z*	Sig.
1	64.00	−2.413	0.01	57.50	−2.699	0.01
2	82.00	−1.737	0.04	117.00	−0.443	0.67
3	65.00	−2.378	0.02	114.00	−0.573	0.58
4	40.00	−3.324	0.00	111.50	−0.657	0.52
5	52.00	−2.870	0.00	125.00	−0.143	0.95
6	47.00	−3.064	0.00	123.50	−0.200	0.57

results for general game variables is presented in Table 3, while a summary of the results for task duration and GSs is presented in Table 4.

Regarding the general game variables, the results of the test show a significant difference between the two games in game duration ($U = 56.00$, $z = -2.74$, $P < 0.05$), ID time ($U = 35.50$, $z = -3.488$, $P < 0.05$) and number of gestures before ID ($U = 64.00$, $z = -2.441$, $P < 0.05$), suggesting that the participants made fewer exploratory gestures after they had gained some experience in Game 1. Furthermore, there is no significant difference for GR time or the number of gestures before GR. These results support the hypotheses H4, H5 and H6.

The results of the Mann–Whitney test show a significant difference in task duration between the two games for all tasks. The significant difference in GSs is present only for Task 1 ($U = 57.50$, $z = -2.699$, $P < 0.05$). These findings are a partial support for hypotheses H5 and H6.

4.5. Findings for ROTATE: Game 3

Rotate gestures are classified as correct when the tabletop responds to a jigsaw piece being rotated so; otherwise, incorrect. Four types have been identified from the data:

- *f-rotate*: using two or more disjointed fingers of the same hand (correct);
- *h-rotate*: using two or more fingers of both hands (correct);
- *s-rotate*: using a single finger to make a rotation (incorrect);
- *w-rotate*: using two or more joined fingers, essentially trying to rotate with the wrist (incorrect);

Table 5. Multiple regression results for individual learning behaviors in a sample of modeled participants.

	B0	B1	B2	S (B0)	S (B1)	S (B2)
srotate	1.00	−1.00	0.00	0.31	0.45	1.00
wrotate	2.50	−2.50	−2.50	0.00	0.01	0.01
rotate	0.13	0.76	0.25	0.13	0.76	0.25
rotateh	0.50	−0.50	−0.50	0.12	0.25	0.25

A total of 17 single participants started playing the Puzzle game. However, as 2 participants had no interactions with the table, data from 15 participants were collected and evaluated in the further analysis. They performed a mean total of 16.73 interactions (SD = 6.87), where 7.6 interactions (SD = 4.32) included rotational gestures. They played the game for 124.87 s (SD = 62.53), needing 10.2 s (SD = 8.39) to initiate the first rotate gesture and 71.2 s (SD = 60.35) to make the first correct rotational gesture. To further explore the learning behavior of participants it was necessary to observe how the means of each rotate gesture change throughout the game. For this reason, the play sessions for each participant were divided in three phases of equal time duration: beginning, middle and end. To build the learning model for each participant, we used multiple regression analysis using the defined phases as categorical predictors. The beginning phase was used as a constant, and we compared the values in this phase with the middle and end phases. The sample of the condensed results of each model presented by the coefficients and their significance is presented in Table 5.

5. DISCUSSION

In this section we discuss the empirical findings by revisiting the three main RQs raised earlier.

> RQ1: *What is the learnability of the DRAG gesture for the players as indicated by the changes of their performance over a set of six similar tasks with the tabletop?*

The answer to RQ1 is that the learnability of the DRAG gesture is generally high, as evident by the empirical findings. O'Brien (2010) showed that prior experience was the most common reason for successful technology use by older people. Dragging a physical object across a smooth surface is a common action familiar to all. The transition of this prior experience from the real world to the use of the DRAG gesture in a touch-based interface was attained by the appearance of intermittent semi-drag gestures. As the results show, to 'solve' the first game (i.e. Game 1) the players discovered the DRAG gesture during the first task where they spent most of their playing time. Once the gesture was learned, the players could 'breeze' through the subsequent tasks with relative ease. This was supported by the decrease in the number of incorrect gestures as the participants made fewer mistakes after every completed task. Additionally, the decrease in the number of correct gestures across the tasks implies that the participants made less semi-drag gestures and quickly approached the optimal full drag gesture. The decrease in semi-drags during game-play was fast and effortless without conscious reasoning, which aligns with the definition of Blackler *et al*. (2005) for intuitive use.

The appearance of the 'semi-drag' gesture is a noteworthy occurrence. The effects of ageing on motor abilities generally include coordination reduction and a loss of flexibility which is a problem for many older people when using mobile phones or laptop computers with touchpads (Rogers *et al*., 1996). As reduced motor skills also cause more errors during fine movements, especially when other cognitive functions are required at the same time (Charness and Bosman, 1990), the semi-drag gesture emerges as a compensation mechanism for the precise uninterrupted motion required for a proper DRAG gesture. As reduced motor skills are a permanent condition, the number of semi-drags approaches an optimal constant by Task 5, beyond which there is no improvement. Hence, to further increase the 'ease of use' of a touch-based technology, it is necessary to improve the sensitivity of the touch surface for older adults.

> *RQ2*: *How do players benefit from their knowledge and skills gained in Game 1 to resolve tasks in Game 2?*

The knowledge of the learned gesture could be retained and easily retrieved for Game 2, as shown by the decrease in ID time and the number of gestures before ID. In addition, all of the tasks of Game 2 were performed significantly faster than the tasks of Game 1. The GS shows that the performance level was attained immediately after Task 1, with speed being the only significant improvement across the subsequent tasks. The familiar features between the two games enabled the participants to use the DRAG gesture more quickly and intuitively, which was initially confirmed by (Blackler, 2008) when evaluating familiar features in interfaces for cameras and remote controls. Similarly, it was shown that prior experience also enabled people to use cars (Langdon *et al*., 2007) and microwaves (Lewis *et al*., 2008) more quickly and with fewer errors.

> *RQ3: What is the learnability of the ROTATE gesture for the players as indicated by their interactions with the jigsaw pieces on the table top?*

Due to its increased complexity, the findings for the ROTATE gesture are not as straightforward. From the derived learning models we can identify three main game-play patterns:

- *Non-progressive playing*, when the player consistently uses a wrong rotate gesture throughout the game;
- *Active learning*, when the player begins playing the game with a wrong rotate gesture and over time starts using a correct rotate gesture;
- *Active unlearning*, when the player begins playing the game with a correct rotate gesture and over time starts using an incorrect rotate gesture;

The non-progressive playing model was predominant among participants with most participants using the w-rotate gesture variant intensely. There were some occurrences of s-rotate which diminished over time in most cases. The use of correct gestures was generally low and they were never performed by more than half of the players. This essentially shows that there has been no learning of the correct rotate gestures for this user group.

Of all the results obtained, those for w-rotate are rather peculiar and deserve deeper analysis, given the inherent complexity of this gesture. A w-rotate gesture contains subtle rotational affordances of which the player may not be aware. Specifically, when using joined fingers for w-rotate, during the rotation of the wrist the player may unconsciously separate the fingers and induce a small drag. Despite discomfort (Hoggan *et al*., 2013) and subjects finding it rather unrewarding (as no immediate effect on the orientation of the jigsaw piece could be observed), some players continued performing this gesture multiple times until, unintentionally, they would briefly separate the fingers and unknowingly perform a correct rotate gesture which was accepted by the system. This created a false impression for the participant that w-rotate was correct, resulting in continued use of this gesture during the game.

6. CONCLUSION

This paper contributes to a deeper understanding of the intuitiveness, naturalness and learnability of touch gestures—dragging and rotation—for technology-naïve older adults. It has improved on the previous work by involving a larger and more representative sample possessing minimal experience with the digital device under evaluation. This complies with the consolidated definition of learnability.

The results of our study show that simple touch gestures can be intuitive for older adults with no prior experience with touch-based technology. Familiarity and frequent use of similar hand gestures in everyday activities contributes to the high learnability of such technology. Specifically, the empirical findings indicate that the drag gesture is more natural for technology-naïve older adults and thus easier for them to learn, as shown by their significantly improved performance over two similar games within a short time span of less than on average 10 min. In contrast, the rotate gesture proved to be a challenge for these users, as shown by their limited improved or even persistently suboptimal performance in the game. These findings imply that different types of gesture can have (large) differences in their intuitiveness for older users, who are expected to draw on their repertoire of actions for everyday life to interact with modern technologies.

Methodologically, we avoid over-structuring the setting so as to facilitate the natural flow of interaction, and also avoid over-assessing the participants with a battery of tests so as to mitigate the risk of arousing their resistance. However, we have contributed to enhancing the digital literacy of technology-naïve older adults by enabling them to confidently experience and explore a novel technology. For our future work, we aim to investigate the extended learnability (Law and Sun, 2012) by tracking this specific user group up to several months to understand their performance and emotional changes with the use of touch-based technologies.

Presenting learning tasks as simple and enjoyable digital games can motivate older adults to explore computer technologies. A more exciting aspect is that digital games have the potential to address a common ageing issue—isolation—if they are played in a social context (Al Mahmud *et al*., 2008). In accord with the social constructivist theories, knowledge and skill building is a sense-making process through negotiating ideas with others (Dourish, 2004; Palincsar, 1998; Suchman, 1987). Arguing along this line, the learnability of touch gestures when playing a tabletop game may be enhanced when it is played collaboratively. Hence, as our future work we will investigate how technology-naïve dyads play games socially on touch-based devices and whether the social context can induce stronger learning effects than those in the individual context as described in this paper.

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