Learning to Drag: The Effects of Social Interactions in Touch Gestures Learnability for Older Adults

Martin Mihajlov
Jozef Stefan Institute
Ljubljana, Slovenia
martin@eccf.ukim.edu.mk

Mark Springett
Middlesex University
London, United Kingdom
m.springett@mdx.ac.uk

Effie Lai-Chong Law
University of Leicester
Leicester, United Kingdom
lcl9@le.ac.uk

ABSTRACT

Considering the potential physical limitations of older adults, the naturalness of touch-based gestures as an interaction method is questionable. Assuming touch-based gestures are natural, they should be highly learnable and amenable to enhancement through social interactions. To investigate whether social interactions can enhance the learnability of touch gestures for older adults with low digital literacy, we conducted a study with 42 technology-naïve participants aged 64 to 82. They were paired and encouraged to play two games on an interactive tabletop with the expectation to use the drag gesture to complete the games socially. We then compared these results with a previous study of technology–naïve older adults playing the same games individually. The results of the comparisons show that dyadic interactions had some benefits for the participants in helping them to become comfortable with the drag gesture by negotiation and imitation. Further qualitative analysis suggested that playing pairs generally helped learners to comfortably explore the digital environment using the newly acquired skill.

Author Keywords

Natural user interface; older adults; touch gesture; learnability

ACM Classification Keywords

Human-centered computing → Touch screen; Human-centered computing → User studies

INTRODUCTION

Ageing populations are an increasingly worldwide phenomenon, as indicated by the recent surveys in different continents such as North America [40] and Europe [5]. As ageing comes with different cognitive and physiological changes, information and communication technologies (ICT) such as smartphones offer beneficial solutions for the improvement of health and quality of life for older adults [8,38]. While a variety of assistive technologies have been developed to help older adults in their daily life, there are still severe limitations and obstacles that older adults encounter when dealing with ICT [11].

For many older adults, negative perceptions of digital technology and their ability to master it is a significant barrier to digital adoption [2] and much of this negativity may be attributed to perceived difficulties in mastering intermediary input devices like mice and keyboards [43]. These devices require learning of a skillset that is unique to them, which do not allow learners to draw upon and redeploy skills acquired from interaction in the non-digital world.

While recently older adults have shown increased familiarity with digital technologies [47], technology acceptance requires the acquisition of specific skills. Since many older adults did not use ICT in their workplace before retiring, these skills are often limited [2]. As older adults are mostly familiar with analogue technologies [10], the potential naturalness of touch-based interaction should lead to the development of NUI which could ease the transition process to the digital world.

The number of studies on understanding how older adults with no relevant experience learn the basic touch gestures and what factors can facilitate the learning process remains small, despite the increasing use of touch-based technology in everyday lives. Existing studies on touch gestures typically involve older adults with technology experience [12,32] or older adults with specific health-related constraints [1]. To address this gap of understanding, we conducted an empirical study where we recruited subjects who did not have any experience with digital technology and would have to learn the manipulations for the first time on the touchscreen.

In the following sections, we first present the literature reviews on related topics. Then we elaborate the design of two tabletop games requiring one basic touch gesture, DRAG, to achieve the game goal. Next, we describe the experiment setup where these games were played by 21 dyads with an average age of 67 years and then present our comparisons with the results of a previous study involving 17 individuals with similar characteristics [27], based on a set of variables on task performance we have identified. We

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analyze the collected data and conclude the paper with a discussion on the implications from the empirical results.

RELATED WORK

Three strands of research work are relevant to our study: the learnability of touch-based interaction for older adults; the role of social interaction in older adults in learning technological skills; and the relation between learnability and naturalness. In this section, we present the reviews on these three related topics that have informed us to design our empirical study, analyze the data, and interpret the findings.

Touch-based Interaction for Older Adults

Touch-based interaction has the potential to support relatively swift learning and mastery for older adults. A majority of previous studies suggest that touch-based interaction has advantages in learnability, ease-of-use and acceptability [3,23,39]. Further studies suggest that touch screens are tolerant of motor issues typically associate with ageing [26] and relatively comfortable to master [22].

Dragging as a specific focus of research of touch-based interaction for older adults has been included in several studies. Findlater et al. [12] found that dragging was the slowest gesture on touchscreen when compared with a mouse. Stößel et al. [41] reported that dragging distances require a higher amplitude of movements which in turn causes deviation during the interaction. Dragging has also been proposed as an interaction technique for motor impaired users [9] as the continuous screen contact affects finger oscillation, which in turn increases the accuracy of the interaction.

There have been several studies of older adults where the participants had no previous touch-screen experience [30,44]. Among them, one study about smartphones recruited subjects who didn't use a mobile phone [19]. A survey of literature relating to studies of older adults using touchscreen devices, including performance analyses and comparisons of interaction devices, was conducted by Motti et al. [31]. They reported that older adults' performances are affected by target sizes, spaces between targets, targets location on the screen, provided feedback and presentation aspects as font size. In a study of older users playing puzzle games on touchscreens, several common errors related to the device, input technique and user manual dexterity were identified [33]. These included problems with identifying and pushing small buttons, detecting accidental touches, and problems in pushing objects to the intended location.

Social Interaction and Digital Games for Older Adults

Many new technologies utilize the proven effect of social interactions to encourage older adults to use them [7]. Furthermore, the benefits of social interactions for older adults' learning can be reinforced with games [45]. Academic research in gaming for older adults has been mainly focused either on the preventive or rehabilitative benefits of playing games [4]. Playing digital games can promote positive health outcomes associated with alleviating depression, feelings of loneliness, and isolation [25]. Furthermore, digital games provide innovative and engaging activities for enhancing older adults' aging processes [21]. Through group or online play, games offer opportunities for social interaction [16], which in turn provides a venue for developing social capital that strengthens strong social ties [42]. Gajadhar et al. [13] found that for older adults social playing with physical presence provides a greater level of satisfaction over online playing, with the least positive experience noted as playing against a virtual opponent. Social interaction is also an important factor for time spent on gaming for older adults [29].

Naturalness and Learnability of Touch-based Interaction

The notion of a 'natural' user interface as something inherent in a style of interaction has been criticized as misconceived in recent articles [34,35]. Natural interaction can be well supported by third generation interfaces, but this is not a given as naturalness may be viewed as an outcome of appropriate design rather than intrinsic to the design itself.

Using real-world metaphors and cues with the directness of touch table interaction allows for relatively rapid experimentation and exploratory action from the user. Users do not need to familiarize themselves with technology-specific procedures such as mouse operation and can apply real-world knowledge in a more direct way. The process of conceptual blending [6,20] in which users integrate new concepts (in this case interfaces tools and affordances) with prior experience is therefore better supported. Examples from these studies show some participants initially failing to blend concepts effectively, but rapidly acquiring game and interaction concepts. This is indicative of the way in which prior knowledge and experience, which may not be directly related to interaction tasks and objects of interest, can be recruited and used in exploration.

It is noted that learnability has several potential definitions emphasizing different aspects [15], only some of which refer to the initial acquisition of core skills, our focus in the current work. The notion of learnability that we use in our work is similar to Leung et al. [24], as given above. Our focus is on the initial learnability of a basic manipulation skill - the drag gesture.

EMPIRICAL STUDY

Participants and Equipment

Through a retirement community we recruited 42 participants (20 male, 22 female), with a mean average age of 68.12 years (age range 64-82). The participation in the study was voluntary with a small compensation for travelling to the venue where the study took place. All the participants had a very low exposure to interaction with modern technologies, with experiences mostly limited to making calls on a keypad-based mobile phone. None of the participants had ever used a personal computer or operated a computer-based device. They were in good health with a few negligible complaints on infirmities that cause slight discomfort with active use of their extremities.

For the purpose of the study we used a SMART Table 230i®, a multi-touch interactive learning tabletop from Smart Technologies that allows for simultaneous interaction of multiple users. To record the experiment sessions, we used a Canon Vixia HF R20 camcorder.

Experiment Design

To motivate the technology-naïve participants to engage in touch-based interaction, we deployed two simple mini-games requiring a specific touch gesture to complete. To evaluate how collaborative gameplay can encourage touch-based interactions and enhance the acquisition of proper touch gestures, we divided the participants into dyads who played the games as a team. Except for one dyad the participants in all other groups were familiar with each other before participating in the study. Additionally, all dyads were mixed gender except for one that consisted of two female participants.

The experiment was set up in a large, spacious room at a retirement community center. Each of the 21 sessions lasted 25 to 30 minutes and consisted of two parts. In the first part, each participant filled out a short questionnaire that collected data about technology use and personal health. In the second part the participants were asked to consecutively play the two games, which were ordered in terms of their complexity level. The participants received no instructions on how to play the games in order to better simulate the naturalness of how technology-naïve people would acquire touch gestures. The entire gameplay was videotaped, resulting in about 10 hours of video data. The video data was transcribed, time-stamped and coded into variables in parallel by two independent parties, whereas all discrepancies in the coded data were jointly resolved. The coding scheme consisted of determining gesture types and time durations which was captured in accordance with the definitions noted in the Variables section.

Game Selection

It is claimed that technology-naïve older users can perform basic tasks with no prior training if they are provided with familiar visual objects that can be manipulated like their real-world counterparts [17]. Based on this principle of "familiarity" we used two suitable mini-games containing a touch-based interface that replicates physical table interaction. Their suitability was identified according to the principle of concrete metaphors [48], playfulness [37] and the guidelines for interactions in games for older people [14] which deal with issues such as physical and cognitive impairments, adaptation to individual differences, and natural mappings to support gesture recall.

HotSpaces (Game 1) is a game where the touchscreen displays a simple outline of a world map. Requiring minimal geographical knowledge, the participants are expected to place six city names in a continent (Figure 1). Considering that the actual goal of the game was not to teach or test the subjects on geographical, the correctness of city placement was disregarded. Instead, any placement of a city label on a continent was considered as correct, and consequently was regarded as one task. The game consisted of a total to six tasks over the complete gameplay. The goal of the game was to evaluate how players learn the DRAG gesture.

Figure 1. A dyad playing the game HotSpaces

HotSpots (Game 2) is a game where six pairs of playing cards are displayed on the touchscreen and six loose cards are displayed in the center of the table. Each card pair has a number-10 card, an overturned card with an unknown value and a large two-digit number displaying the sum of the card values. The participants had to match the six loose cards to an appropriate overturned slot with the DRAG gesture in order to make up the indicated sum. Identically to the previous game, a game task was considered as complete when a card was placed in any slot that the player considered as correct, irrespective of the accuracy of the sum. The actual goal of the game was to evaluate how the learned DRAG gesture is transferred from one game to another.

Variables

Due to the nature of the games we identified two specific constructs as relevant for the analysis: goal recognition (GR), the moment in which the player identifies the goal of the game such as placing the label of a city in an appropriate continent for Game 1; and interaction discovery (ID), the moment in which the player discovers the gesture needed to achieve the goal. The variables related to these constructs were defined as follows:

- GR time: The time passed between the start of the game and goal recognition.
- ID time: The time passed between the start of the game and interaction discovery (i.e. the first DRAG gesture).
- Gestures before GR: The number and type of gestures attempted by a player before goal recognition.

- Gestures before ID: The number and type of gestures attempted by a player before the discovery of the correct interaction.

Additionally, we defined the following variables in order to evaluate the learnability of the DRAG gesture in the first game, namely, HotSpaces, and its retention in the second game, HotSpots:

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

The correctness of the drag gestures performed by the participants has been derived from the relevant literature as well as from our empirical observations. Correct gestures include a typical DRAG and what we refer to as a semi-DRAG, which we define as a suboptimal drag where the finger(s) of the participants touching the object of interaction move over a surface for a distance shorter than intended. For most tasks of the two games, the participants performed semi-DRAGs repeatedly in order to move the object to its destination. The weaker sensorimotor control of older adults can account for this gesture. Incorrect gestures are TAP and PRESS. TAP denotes a brief touch of a surface with a fingertip, while PRESS is referred to as touching the surface for an extended period (Villamor et al., 2010).

Research Goals and Hypotheses

We have identified three research goals and six related hypotheses (H).

Our first research goal was to determine the learnability of the DRAG gesture in a collaborative environment. For this goal, with Game 1, we evaluated the changes in three variables – task time, the number of correct gestures and the number of incorrect gestures - across six subtasks requiring the same touch gesture (i.e., dragging each of six different city labels to a continent). We tested the following hypotheses:

H1: There are significant differences in task time among all the six tasks of Game 1.

H2: There are significant differences in number of correct gestures for among all the six tasks of Game 1.

H3: There are significant differences in number of incorrect gestures for among all the six tasks of Game 1.

Our second research question was to estimate to what extent the learnability of the DRAG gesture could be retained and transferred to different tasks. For this purpose, with Game 2 we evaluated how participants used their knowledge and skills gained in Game 1 to resolve similar tasks. We formulated the following hypotheses:

H4: A learned DRAG gesture would have better interaction discovery time and lower number of gestures before interaction discovery for the second game.

H5: There is significant improvement in task duration for each task between the games.

H6: There is significant improvement in gesture score for each task between the games.

Our third research goal concerns the demonstration of the positive effect of social interactions on the learning of the DRAG gesture. Hence, we compared the results of this study to the results of our earlier study [28]. For consistency, the earlier study followed the same experimental setup at the same retirement community center and utilized participants from the same demographic and technological awareness group.

The following comparison hypotheses were formulated:

H1c: There are significant differences in game completion time between single and dyadic participants.

H2c: There are significant differences in interaction discovery time and number of gestures before interaction discovery between single and dyad participants.

H3c: There are significant differences in task duration for each task between single and dyadic participants.

H4c: There are significant differences in number of correct gestures for each task between single and dyadic participants.

H5c: There are significant differences in number of incorrect gestures for each task between single and dyadic participants.

RESULTS

Analysis of Game 1

On average the 21 dyads completed the game in 212.7 seconds (SD=130.5). The time to complete Task 1 was the longest (M=106.4, SD=125.4), while the time to complete Task 6 was the shortest (M=11.4, SD=11.2). The participants used a lower number of correct gestures (M=7.8, SD=8.5) and a higher number of incorrect gestures (M=11.7, SD=17.1) during the first task, with the trend reversing as the game reached the last task (M=7.9, SD=11.6 and M=0.8, SD=1.1, respectively).

	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	
	Neg.	**Pos.**	**Neg.**	**Pos.**	**Neg.**	**Pos.**	**Neg.**	**Pos.**	**Neg.**	**Pos.**
Task duration	11.82	3.25	10.87	3.5	11.44	5.17	12.22	3.63	11.92	5.5
Incorrect gestures	9.97	1.5	9	0	10.34	2.75	11.16	3.83	11.74	3.5

Table 1. Ranked scores for task duration and incorrect number of gestures from the Wilcoxon-signed rank test.

The Kolmogorov-Smirnov test was significant across all tasks for *task duration*, $D(21) \in (0.209, 0.352)$, $p<0.05$, *number of correct gestures*, $D(21) \in (0.197, 0.301)$, $p<0.05$, and *number of incorrect gestures*, $D(21) \in (0.255, 0.363)$, $p<0.05$, which violates the assumption of normal distribution. Consequently, Friedman's ANOVA test was performed. The results showed a significant difference in task duration between the tasks ($\chi^2(5)=25.444$, $p<0.05$), and a significant difference in *number of incorrect gestures* between the tasks ($\chi^2(5)=30.712$, $p<0.05$). This confirmed the hypotheses H1 and H3. The lack of significant difference in *number of correct gestures* across tasks ($\chi^2(5)=1.352$, $p>0.05$) supports the alternate hypothesis to H2. Consequently, all post-hoc tests were performed for *task duration* and *number of incorrect gestures* in order to understand the nature of this significance.

In order to measure the noted significant changes in *task duration* and *number of incorrect gestures* the mean values for these variables were compared between each task using the Wilcoxon signed-rank test. Task 1 was used as a control group as the means ($M_{duration}=106.43$, $M_{gesture}=11.67$) and the ranked scores ($R_{duration}=5.31$, $R_{gesture}=5.26$ for this task are variably different from other tasks. Because of the multiple comparisons, all post-hoc tests are reported at a 0.01 level of significance with a Bonferroni correction.

Table 1 presents the ranked scores for *task duration* and *incorrect number of gestures*. There is an evident lean towards positive ranks, implying that the trend of the measured variables is decreasing across tasks. Task duration was significantly higher for Task 1 when compared to Task 2 ($z=-3.790$, $p<0.001$), Task 3 ($z=-3.790$, $p<0.001$), Task 4 ($z=-3.342$, $p<0.001$), Task 5 ($z=-3.379$, $p=0.001<0.01$), and Task 6 ($z=-3.442$, $p<0.001$). Conversely, the number of incorrect gestures was significantly higher for Task 1 when compared to Task 2 ($z=-3.663$, $p<0.001$), Task 3 ($z=-3.626$, $p<0.001$), Task 4 ($z=-3.488$, $p<0.001$), Task 5 ($z=-3.363$, $p<0.001$), and Task 6 ($z=-3.530$, $p<0.001$).

To compare the dyadic participant results of this study with the single participant results of our previous study we compared the differences between the measured values. The results of the Mann-Whitney test showed that there were no significant differences for most of the variables between single and dyadic participants: game time, interaction discovery time, number of gestures before interaction discovery, and problem recognition time. This confirmed the alternate hypotheses to H1c and H2c. However, the number of gestures before recognition for single participants differed significantly from the number of gestures before recognition for dyadic participants ($U=133.0$, $z=-1.681$, $p<0.05$).

Regarding task performance, as evident from the results presented in Table 2, there was a significant difference for task duration between single and dyadic participants for Task 2 ($U=95.0$, $z=-2.244$, $p<0.05$), Task 3 ($U=89.0$, $z=-2.428$, $p<0.05$) and task 4 ($U=115.0$, $z=-1.626$, $p<0.05$) which is in favor of supporting hypothesis H3c. The number of correct gestures differed significantly between single and dyadic participants only for Task 1($U=107.5$, $z=-1.861$, $p<0.05$), which was in partial support of hypothesis

		Task 1	Task 2	Task 3	Task 4	Task 5	Task 6
Task Duration	**U**	143	95	89	115	151.5	164
	Z	-0.767	-2.244	-2.428	-1.626	-0.507	-0.123
	Sig.	0.23	0.01	0.01	0.05	0.31	0.45
Correct gestures	**U**	107.5	147	138.5	145.5	156.5	155
	Z	-1.861	-0.648	-0.91	-0.696	-0.354	-0.402
	Sig.	0.03	0.26	0.19	0.25	0.37	0.35
Incorrect gestures	**U**	133	164	131.5	150	143	130.5
	Z	-1.078	-0.133	-1.203	-0.616	-0.868	-1.336
	Sig.	0.14	0.45	0.12	0.28	0.20	0.11

Table 2. Significance results of the Mann-Whitney test for task-related variables.

	Game completion time	Goal recognition (GR) time	Interaction discovery (ID) time	Gestures before goal recognition (GR)	Gestures before interaction discovery (ID)
U	134.5	211.5	83.5	177	117.5
Z	-2.164	-0.226	-3.447	-1.103	-2.619
Sig.	0.03	0.83	0	0.28	0.01

Table 3. Results of the Mann-Whitney test for general game variables between Game 1 and Game 2 (all measures are in seconds).

		Task 1	Task 2	Task 3	Task 4	Task 5	Task 6
Task duration	**U**	151.5	220	194.5	199	111.5	174.5
	Z	-1.738	-0.013	-0.657	-0.542	-2.752	-1.162
	Sig.	0.04	1.00	0.62	0.60	0.00	0.25
Gesture Score (GS)	**U**	155.5	186.5	218	214	190	198
	Z	-1.639	-0.886	-0.07	-0.191	-0.864	-0.628
	Sig.	0.05	0.38	0.95	0.86	0.40	0.54

Table 4. Results of the Mann-Whitney test for task duration and Gesture Score (GS) between Game 1 and Game 2 (all measures are in seconds)

H4c. When testing the differences for incorrect gestures between single and dyadic participants, the results showed no significant difference for any of the tasks, which confirmed the alternate hypothesis to H5c.

Analysis of Game 2

In the second game, the participants completed the game on average with 125.90 seconds (SD = 78.12). The goal recognition (GR) time was 71.43 seconds (SD=65.03) while the interaction discovery (ID) time was 36.14 seconds (SD=27.27). Approximately, 27.19 gestures (SD=39.27) were initiated before the goal of the game was recognized and 3.76 gestures (SD=4.83) were performed before interaction discovery. In order to compare the activities in Game 1 with the activities in this second game more accurately, we transformed the data for number of correct and incorrect gestures as a single variable, gesture score (GS). This variable is computed as a percentage of correct gestures over the total number of gestures performed by a participant in a single task ($GS= (Gc/(Gc+Gi)*100)$, which provides normalized values across all tasks for both games on a 0 to 100 scale.

To compare the data between the two games we used the Mann Whitney significance test as the Kolmogorov-Smirnov test was significant for all variables. A summary of the results for general game variables is presented in Table 3 while a summary of the results for task duration and gesture score is presented in Table 4.

The Mann-Whitney test showed a significant difference between Game 1 and Game 2 in game duration (U=134.50, z=-2.16, $p<0.03$), interaction discovery time (U=83.50, z=-3.45, $p<0.05$) and number of gestures before interaction discovery (U=117.50, z=-2.62, $p<0.01$). Additionally, no significant differences were detected for goal recognition time or the number of gestures before goal recognition. This suggested that the participants made fewer exploratory gestures, given what they had learned in Game 1 which supports hypothesis H4. When applied to all tasks, the results of the Mann-Whitney test showed a significant difference in task duration and gesture score between Game 1 and Game 2 only for Task 1 (U=151.50, z=-1.74, $p<0.04$, and U=155.50, z=-1.64, $p<0.05$). These findings partially support hypotheses H5 and H6.

The comparison of results between the single and dyadic participants revealed no significant differences. It seems that after playing the first game, all the participants reached an almost optimal level of understanding and performing the DRAG gesture. Consequently, the subsequent improvements were negligible and not influenced by the collaborative interactions of the participants.

DISCUSSION

The focus of our first research goal was determining the learnability of the DRAG gesture in a collaborative environment. The results of the analysis that tested hypothesis H1 showed that in the process of discovering the DRAG gesture, the participants spent most of their time on solving the first task of the first game. After this gesture had been performed correctly once, the participants would “breeze” through the subsequent similar tasks by completing them in significantly less time. This implies that the gesture was optimally learned after the first task. Thanks to the collaborative environment, for most of the dyads, irrespective which participant executed the correct DRAG gesture the other participant would mimic it almost immediately. Conversely, both participants exhibited similar performance in the subsequent tasks.

The “optimal learning after the first task” interpretation is further supported by the analysis of the number of correct and incorrect gestures. While the number of correct gestures remained relatively unchanged as suggested by the alternate hypothesis to H2, the number of incorrect gestures decreased across tasks. A decrease in number of incorrect gestures, which confirms hypothesis H3, implies that the participants made fewer mistakes after every completed task. The observation that the number of correct gestures had reached a plateau indicated that the number of semi-DRAG gestures remained relatively constant across tasks. Two reasons can be provided for the appearance of the semi-DRAG gesture, the physical limitations of the participants' finger mobility and technological limitations in terms of the sensitivity of the touch-based tabletop. As participants cannot improve on their mobility, an improved touch sensibility of the table for older adults is a desirable feature to be added for enhancing the accessibility of the system, just like there are features for increasing font size, displaying larger icons, etc. The successful acquisition of the DRAG gesture itself can be attributed to prior experience [18], especially considering that the action of dragging an object across a surface is a common and familiar task and as such naturally transferable from a physical to a virtual environment.

To determine the retention of the learned DRAG gesture and its applicability across tasks was our second research goal. As expected, hypothesis H4 was supported and interaction discovery time and the number of gestures before interaction discovery for Game 2 was significantly lower than for Game 1. This confirmed the notion that the DRAG gesture was successfully learned in Game 1 and that this retained knowledge was easily retrieved and applied in the subsequent game. When we observed task duration time and the Gesture Score, the correct/incorrect gesture ratio was different only for the first task, a partial support of hypothesis H5 and H6 as the significance was not evident for each task. Therefore, once the first task was completed an optimal performance level was reached, after which neither speed nor quality of performance increased. In our previous study with single participants, the task duration time for all Game 2 tasks was significantly lower than task duration time for Game 1. This point of difference between the single and dyad groups implies that dyadic participants reach the learnability limit faster than single participants.

To address the third research goal about the existence of an improved learning experience of the DRAG gesture in collaborative environments with social interactions it is necessary to supplement the analysis of the coded gestural data with the interaction data captured by videos. For Game 1, the results showed no significant differences for goal recognition time or for interaction discovery time between single and dyadic participants, although there was a significant difference in the number of gestures before goal recognition. Frequently, a dyad-pair would discuss strategies for gameplay for prolonged periods and thus interacted with the touchscreen less. They discovered the goal of the game through verbal turns and gestures, which are likely to have had a role in enhancing their cognitive and experiential strengths [46] to sustain the motivation to deal with the game’s challenges. In contrast, single participants discovered the game goal by interacting directly with the tabletop.

The number of correct gestures differed significantly between the dyads and the single players only for Task 1. This nonetheless suggests that dyads have a significant benefit in establishing initial competence. Given that this is a vulnerable point in terms of building confidence and negating reluctance, this suggests that there are key benefits in learning through dyadic interaction where reluctance and fear of technology may be factors. Also, the dyads completed in a significantly shorter time than singles for Tasks 2, 3 and 4. This suggests that once the initial gesture is learned the dyads are capable of exploring its use across tasks more fluently, becoming more conversant with the principle of exploratory learning.

Qualitative Analysis

Further analysis of the rich video data helped gain insights into the dynamics of dyadic interactions. While a detailed qualitative analysis is not the focus of this paper, we discuss some general observations about the intriguing patterns of practice in dyad interactions.

The initial period of exploration would see relatively even number of attempted manipulations. However, a change was noticeable at the point where one player gained a level of competence and fluency in dragging actions. Verbal explanations of game principles were frequently offered in these sessions when one participant gained an insight. There were also numerous examples of the more rapidly learning player miming gestures to explain a manipulation, before that player took over the performance of an action.

There were some initial examples of strategies from the analogue world being used inappropriately to specify exploratory action. These either took the form of inappropriate responses to display features, or more basic misinterpretations of system principles. One extreme example of this was a couple who used a cutting motion on jagged lines used to delineate a target area, cued by its resemblance to cut-out coupons in newspapers. On occasions (twice in all sessions) this misconception continued for a prolonged period of repeated attempts. However, it was more typically found that once the dragging principle was established, players were able to identify feature cues and operations without misapplying knowledge from the non-digital world.

In other examples for Game 1 a player would press a label expecting it to work as a push button, initiating a process. In several cases this strategy was then modified with the player using the other hand to specify the location. In two cases the other player verbally intervened having identified that the label appeared to move slightly when pressed, leading the players to work out the correct operational principle. This example demonstrated that exploratory learning through observation of a partner's actions can be effective, mitigating the fact that that a player may have less direct interaction time due to having to concede to the partner.

There were several examples where one member of a dyad took control of the game in the beginning. The dominant participant would interact with the touchscreen, while the other participant would initially only observe and comment. This suggests that during the first task, the gameplay condition allowed two players to work as if they were a single player. However, once a dyad acquired the requisite gestural skills, they would accelerate the completion of tasks at a pace faster than a single player, possibly due to peer pressure (or peer *pleasure* to show off the learned gesture). By the fifth tasks the performance attributes of the single players were even out with the dyads as the optimal level was achieved. The lack of significant difference between singles and dyads for the second game implied that after undertaking the six tasks of the first game, the players reached the optimal DRAG performance, and then further practice, be it solo or social, might only lead to negligible improvement.

The tendency for one player to become dominant in a session is exemplified by the following case. One player (P1) was rapid in finding the right motion and becoming competent. The other player (P2) was struggling with the initial tap and the amount of pressure in the drag as his attempts were too light and too quick. For a period after this, P1 decisively took over and began to dominate, performing all the manipulations while P2 observed, intermittently tried again and struggled. P1 became impatient on occasions and took over, finishing off the manipulations that P2 had been attempting. Only after several failures P2 managed to perform a successful DRAG after which his interactive behavior was distinguished by continually conceding to P1.

In some sessions there was evidence of an alpha/beta relationship between the participants. For example, in one of the sessions a protracted sequence of exploratory interactions performed by one player (P3) was spontaneously mimicked by the other player (P4). In this session P4 would not only mimic the action, but also focus on the same object. As P3 became more competent at the physical manipulation, P4 became more inclined to contribute just verbal suggestions and to make suggestions through 'mimed' gestures on the tabletop.

The implication in the above example is that players may in a sense 'negotiate' a delineation of roles in early play, based significantly on their relative ability to get the 'feel' of the manipulations rather than a gulf in their ability to understand the nature of the game or the tabletop's operational principles. The basic principle of operation is learnable from a playing partner through demonstration, verbal explanation, and brief explanatory gestures. However, some aspects of learning, especially the level of pressure and the pace of a drag action can only be acquired in the first person through direct physical interaction.

CONCLUSION

The findings of this study help us gain a deeper understanding of the naturalness and learnability of touch gestures for technology-naïve older adults. Specifically, we focused on evaluating the DRAG gesture among a representative sample with minimal digital experience which complies with the consolidated definition of learnability [15]. Our empirical results corroborate the argument that the naturalness of NUI is co-discovered in situ through different forms of social interaction such as guidance and imitation as observed in our dyadic gaming sessions. This also supports the social constructivist perspective [36] that learning is inherently social; this assumption is applicable not only for children, as originally addressed by Vygotsky's and Piaget's theories, but also for older adults. Nevertheless, we are aware of the limitations of this study, which was not lab-based with stringent experimental control. We avoided over-structuring the dyadic setting in order to facilitate the natural flow of interaction. We also avoided over-assessing the participants with a battery of tests for the purpose of mitigating the risk of arousing their resistance. Given these constraints, we are cautious about making strong claims about the generalizability of our findings. 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.

Players often had to go through some unsuccessful cycles of exploratory action to successfully blend general knowledge and principles from the analogue with the newly encountered digital world. This suggests that a short period of practice in a low-pressure environment such as gameplay can have a significant benefit in helping certain types of novice users, particularly older users, to overcome reluctance to use digital technology. The social dimension seems also to be beneficial both in providing an environment conducive to effective exploratory learning and providing participants with the confidence to apply themselves. It can be argued that one of the key differences between much of the analogue world and the digital world is the extent of learning through exploration that is demanded in order to become genuinely competent. Using games appears to have the advantage of motivating and supporting exploration, hypothesis generation and reactive planning in response to system feedback, which in themselves can be viewed as key skills.

Limitations and future work

This study is not without its limitations. On one hand, the study shows encouraging signs that touch gestures can be learned rapidly. However, it remains unclear whether the learned gestures are retainable and would be easily replicated when participants interact with a device after a prolonged period. More longitudinal studies are necessary in order to ascertain the solidification of learning and evaluate the possible decay effects. Furthermore, we did not specifically address the effect of perceptual and motor impairments, as most of the selected participants reported little or no physical and cognitive impairments. Older adults with more pronounced visual or hyperkinetic limitations may have significantly different needs to those used in the study. Finally, the selected metrics we chose for quantifying 'correct' and 'incorrect' gestures could not differentiate between high and very high performance. As we lacked a benchmark for high performance levels, we couldn't address the potential ceiling effect occurring due to the substantial decrease of incorrect gestures over tasks.

In future work we would like to investigate the utility of games as a conduit to digital competence and technology acceptance for older citizens. Games have an obvious potential as a gentle introduction to digital interaction both on an instrumental and an affective level. Nevertheless, it cannot be assumed that skills acquired in initial gameplay will be easily transferred and applied to non-game applications such as form-filling or social computing. Therefore, it will be necessary to study how the advantages of learning through games can optimally segue to wider learning of digital concepts in more longitudinal studies. As there is evidence that familiar metaphors such as card games and maps have a beneficial effect both in engaging users and in accelerating exploratory learning, another aspect to further investigate would be the actual design of games to support the teaching and learning of digital concepts through gameplay. Additionally, this study showed glimpses of patterns of collaborative learning. These patterns emerge mostly through quantitative analysis; hence we plan to extend the experiment protocol in order to better capture different patterns of learning. Further work will also consider ways in which learning can be enhanced through digital mentors, where potentially the mentor/learner roles are defined less by traditional notions of 'knowledge transfer' and more by presence and co-action.

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