THE RELATIONSHIP OF PHYSICALITY AND ITS UNDERLYING MAPPING

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ABSTRACT

We understand how physical things work from our experience interacting with them. The cause-effect mapping instills our knowledge of interaction. We extend our knowledge of physical interactions when interacting with computing devices, especially when we do not have prior experience with those devices. But, the mapping of interaction in the digital world is not as straightforward as in the physical world. It is unclear how far the rules of physicality hold in the computing realm when the level and kind of feedback is not necessarily the same with physical effort? How do we cope when the underlying mapping is incoherent in relation to the physical control? In this paper, we report a study on Cruel Design. Its objectives are: i) to investigate the role of physicality in the physical-logical interaction, and ii) to observe the behaviors of users as incoherent mappings occur. Four conditions to illustrate the different design of mappings were presented to users. From the findings, the physical condition plays a more dominant role than having to remember the correct mapping of the logical states, and, inverting an action on the same controller (regardless the type of mapping) is the natural reaction to overshoot.

Keywords: Natural mapping, intuitive interaction, physicality, physical-logical relationship.

INTRODUCTION

In today's physical interaction with technology, controls are more pleasurable to use if there is coherence in the mapping between the physical action and its logical effect, as this leads to an understanding of the concept of mappings between the physical and the logical states. We learn so much from our everyday interaction with non-computing things, so we expect our interaction with computing devices to some extent, to be the same. The physical-logical relationship is what Dourish refers to as referential coupling between a system's internal representations and the context of use, and should be dictated by the users, and not the designers (Dourish, 2004).

It would be frustrating to use a control that had an incoherent coupling/physical-logical relationship, i.e. the effects are not what as we expected, where we have no clue as to how physical action actually couples with the logical effect. And it would be even worst when a single physical control is actually mapped to numerous features of a system, without us knowing it! Recent work by Sitenstra, Overbeeke & Wensveen (2011), however, took a challenge by providing mapping of one single touch to more discrete states or functionalities, where depending on the pressure of pointing to a device, a number of relevant information or application(s) will be displayed to a user.

The importance of having a coherent mapping in the physical world is discussed in Norman (2002), which argues that designers should pay, amongst other things, attention to the relationship between the physical controller and its effect (function), its distances, and its placement; this is so that the user can understand the physical-logical mapping. For instance, in a room with three switches, with two lights and a fan in the centre of the room, a person would be able to know that the middle switch is for the fan, right and left switch should control the right and the left lights, and their effects can be seen instantaneously. Recent work made an attempt to improve the situation by introducing a Previewable Switch (Park, Lee, Kim & Lee, 2014). The second type of coherent mapping is between the effort and its effect. If a person turns a knob of a shower clockwise, an increased amount of water is expected to take place (Norman, 2002; Ghazali, 2007).

Controls with a coherent mapping provide a pleasurable experience for users. When incoherent mappings occur, i.e. when the logical effect is not what the user anticipates, or, when the effect or feedback is not translated equally to the effort being put in, users can become frustrated.

This paper reports findings from a user study, where its focus was to investigate how users react or behave when presented with deliberately incoherent physical-logical mappings. We called this study, Cruel Design. The task of the study is simple, but when the mappings of the physical controller and its logical state are tampered with, it gets a little challenging. By doing so, we hope to discover how users cope with incoherent underlying mapping, and why. This is similar in intent to Garkinkel's (1966) breaching experiments, where social rules were deliberately broken in order to better understand social processes and expectations.

This paper is divided into several sections. The following section describes the background and related work, which provides a broader perspective of input devices. The type of experimental device and how we come to a set of design decision are presented in the subsequent section. The following section consists of details with regard to the experiment, such as procedures, subjects and data measurements. We then discuss the quantitative results, before concluding the paper with a concluding remark.

BACKGROUND & RELATED WORK

A natural mapping is of utmost important in any kind of interaction, but natural mapping interaction is particularly widely discussed in the domain of games in the specific topic of natural mapped control interfaces (NMCI). Works such as Abeele, Vanded, Schutter, De Gajadhar, Johnson & Geurts (2013), McEwan, Blackler, Johnson & Wyeth (2014), McEwan, Johnson, Wyeth & Blackler (2012), and Skalski, Tamborini, Shelton, Buncher & Lindmark (2011), found and stated that games with naturally mapped interfaces lead to a positive response to play experience.

The idea behind the Cruel Design study is to seek the properties that make things work well by making them difficult and annoying to use (Dix, Gilleade, Ghazali, Holt, Sheridan & Lock, 2005). As far as we are concerned, there is hardly any user study or experiment available for reference, which is purposely designed to be hard, difficult, or annoying to users. Nonetheless, if this particular study were to be treated like any other experiments, which its ultimate aim is to achieve robustness and effectiveness of a system of two-handed input, Leganchuk, Zhai & Buxton (1999) would be the most suitable reference. The study reveals the bimanual techniques resulted in significantly faster performance than the one-handed technique. In addition, this study also shows bimanual performance is far better and faster as cognitive difficulty of the task increases. In other studies by Buxton and Myers (1986) and Kabbash, Buxton and Sellen (1994), found that due to inefficiency of hand motion, the two-handed technique outperformed the one-handed technique, and two-handed technique with asymmetric bimanual technique, or Toolglass technique, gave rise to the best overall performance. The task was to perform a compound drawing or colour selection.

While there are varieties of controllers involved in gaming nowadays, from physical devices, such as the joystick or steering wheel, to tangible ones, such as Wii and body sensing, such as Kinect, we focus on the physical controller to study whether the natural inverse can help in unnatural mappings. By natural inverse, we mean the way that a movement forward is naturally felt to be the opposite of backwards and similarly up–down, left-right, or push-pull. This is closely related to what Blacker (2008) defines as intuitive interaction. Our previous work also observed how people recover from mistakes when interacting with daily appliances and other types of embedded systems (Ashraf & Ghazali, 2011; Ashraf & Ghazali, 2013).

This study is focused on physical controllers in order to investigate the relationship between physical movement and logical mappings; we therefore chose a joystick as the instrument in our study. A joystick provides 360 degree rotation and movement; with its precision and reliable performance it provides users with a sense of control in a simulated environment. A joystick is usually recommended when playing flight simulation games such as Namco's Ace Combat or Microsoft's Flight Simulator.

CRUEL DESIGN STUDY

Design & Task

The design of the Cruel Design program was motivated by our goal of discovering to what extent physicality is dominant over logical mapping. As there are four obvious prominent movements, or two obvious pairs of actions, users can do with the controller, i.e. left, right, up and down, we derived four sets of underlying mappings for these movements.

This study manipulates the coherency of physical-logical mappings of two joystick controllers of a simple program - as explained above. As coherency of mapping also affected by the proportion of physical effort, which does not translate equally logically, or digitally, this study considers this in the design. To fulfill the latter objective, we designed for overshoot to happen occasionally. We believe, in the situations where overshoots happen, natural inverse occurs in the same way as Visceral Interaction assisted users in the Cubicle study (Ghazali and Dix, 2005). That is, we believe that when there is an overshoot the instant physical reaction is to do the natural physical opposite; even if we know this is not the right thing to do to reverse the effect.

Before we came to arrive to the decision of the implementation of the Cruel Game, there were two design prototypes. The first one was aimed to destroy a target area by including a timer, where points were awarded based on accuracy and reaction action. But we felt the first prototype lacked the usage of joystick controller, i.e. lack of physical manipulation, so we thought about translating the same idea onto a grid. The second prototype, with the grid design, provides a variety of types of cursor movements, which make full use of the joystick controller. Nonetheless, we found it difficult to control the type (variation) of movement on the grid. Finally, we limited the 'grid' to appear as 6 boxes, hence made it easier in the development of the Cruel Design game. Figure-1 illustrates this.

In this study, the two joystick controllers are used to move a cursor across a screen. The cursor must follow a flashing blue arrow, which acts as a guide, out from the start box to the target box (see Figure-1, highlighted in yellow). Cursor movements include both horizontal and vertical movements. In order to encourage overshoots to occur, the velocity of the cursor is enhanced to a larger value depending on the speed of the joystick movement, which means, if the joystick is pushed forward quite rapidly, the cursor is likely to leap twice or thrice times greater to an unanticipated position.

In our study, we used two Microsoft SideWinder Joysticks, as they are easy and friendly to use, with no motorized feedback. Although there was an idea in the beginning to only use keyboard arrow keys, joystick

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seemed to be giving better physical control as it has stronger physicality characteristic. In our study, although the joystick can be rotated 360 degrees, we limited the logical mapping of both controllers to the Y-axis, which means, the user can only invoke actions in a virtual system by moving the physical controller up or down.

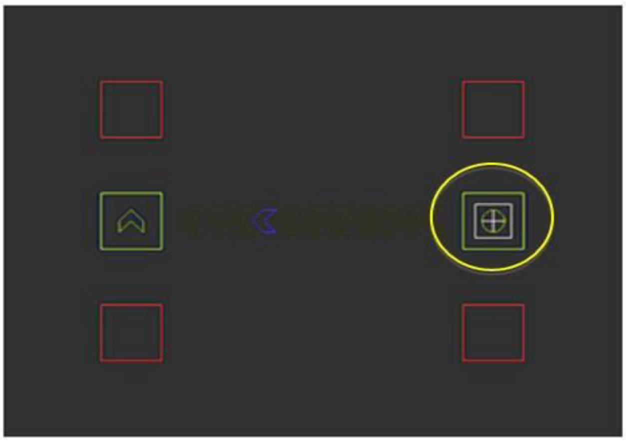

Figure-1. Cruel Design's grid design with a trace of blue arrows in the middle.

The four combinations of physical-logical mappings were designed to construct four different conditions in the program interaction, using bimanual technique. What we mean by, and how, we design every condition are described in the following sub-sections. The conditions are:

- better physical-logical mappings (condition A),
- good physical-logical mappings (condition B),
- bad physical-logical mappings (condition C),
- worse physical-logical mappings (condition D).

For condition A, a tutorial is given to participants to allow them to know, and learn, the (initial) mappings of the joysticks along the Y-axis. The revelation of the coherent mappings, which is visually displayed before the program begins and the provision of a laminated mapping diagram on the table, should assist participants by reducing cognitive load, while keeping each pair together along on one axis should give a good sense of physical-logical mapping (see Figure-2). The left joystick (Joystick A) is to control up/move right, down/move left, while the right joystick (Joystick B), which has good sense of direct manipulation (Shneiderman, 1983) is to control up/move up and down/move down.

A good sense of physical-logical (coherent) mappings is retained in condition B, but the mappings are now swapped by 180 degree from condition A. The mapping is actually an inversion of the logical effect of condition A and is common configuration in 3D video games, i.e. invert Y-axis. The left joystick (Joystick A) to control up/move left, down/move right, while the right joystick (Joystick B) to control up/move down, down/move up. Participants must explore and discover the new mappings themselves, as no diagram is provided. Figure-3 illustrates this.

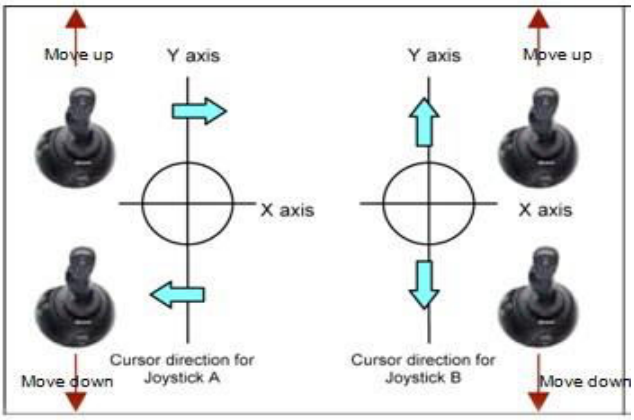

Figure-2. Condition A physical-logical mappings.

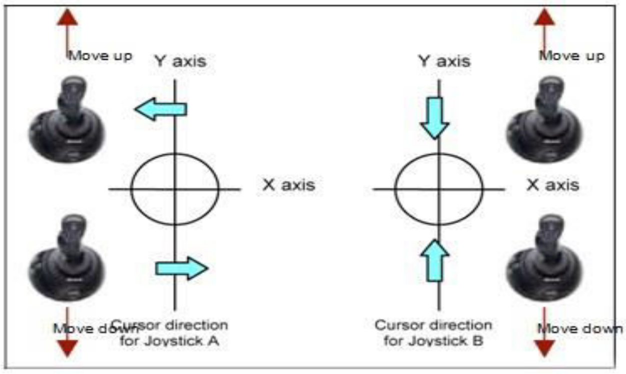

Figure-3. Condition B physical-logical mappings.

For condition C, we break the physicality rules, by swapping the directions across the two joystick controllers. The physical-logical mappings are now incoherent. The pairs, i.e. up, down and left, right, are no longer positioned on the same axis. A short tutorial is given on the screen for a few seconds just before the program of this respective condition begins. In addition, a tutorial sheet is provided on the table for reference. Figure-4 shows the mappings for Joystick A (left) and Joystick B (right) controllers.

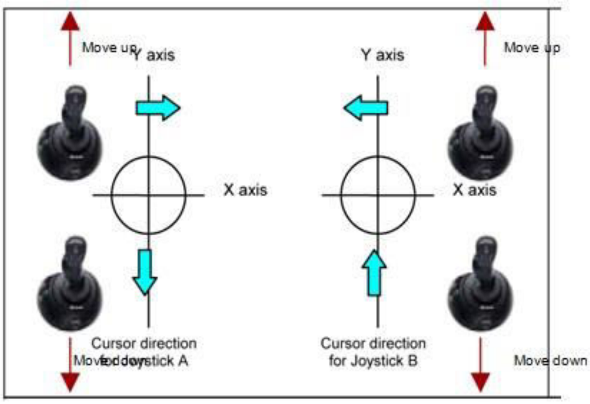

Figure-4. Condition C physical-logical mappings.

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Condition D, meanwhile, is designed to have the worse condition. Once again the physicality rules are broken, and participants are expected to explore the new mapping themselves. The incoherent physical-logical mappings are swapped from condition C, which is shown in Figure-5, with Joystick A (left) and Joystick B (right).

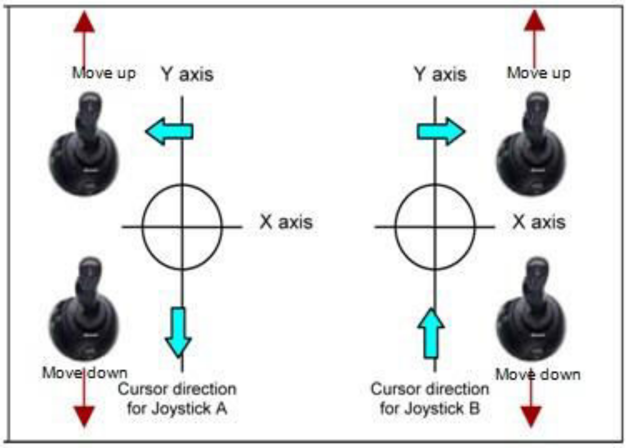

Figure-5. Condition D physical-logical mappings.

The sequence order for these four conditions in the user study is the same for all participants, i.e. not randomized. It is ordered in such a way to create a sense of moving from a better condition to good, then bad and lastly to the worse condition. The first condition with coherent physical and logical mappings should act like a benchmark for the rest of the conditions. We save the worst condition to last, to observe how participants cope with incoherent mapping and to see whether any of the previous mappings are any help to them.

A within-subject design was chosen for this study as it could reduce overall variability where each participant was required to perform all four conditions. The four conditions are ordered to be in a consecutive manner, but to minimize the order effect, the order of the nine attempts in each block are set to random.

Participants

We solicited volunteers from within Lancaster University's Computing Department and posted a call for participation on a university-wide mailing list. Our participants were a mixture of undergraduate and postgraduate students that makes up the total of 19 participants, with 6 male and 13 female. 16 out of 19 participants have never, and have limited use of joystick, but all of them are exposed to other input devices such as mouse and wireless mouse. Out of 19 participants, 4 participants play simulation games that use joysticks and steering wheel regularly, while few others play PC games that require inputs from keyboard and mouse. Only 1 participant involved in the pilot study before the actual test took place. Volunteers were informed prior to (and after) the test that they were participating in a user study that will assist in understanding cognitive and physical performance with different input mappings. 2 participants are left-handed.

Manipulation

Participants were first briefed on how the program works. We informed them about what they need to do: to move a cursor from the start box to the target box by using the joysticks. Once they reached the target box, a trigger must be performed for confirmation, before proceeding to the next task. A flashing blue arrow will guide them on which path to follow.

Participants underwent four sets of tests, which were displayed as Block1/4, Block 2/4, Block 3/4 and Block 4/4 consecutively. The order line for these four conditions in the user study is the same for all participants. Each set represents condition A, B, C and D respectively. The descriptions of the conditions, however, are not disclosed to the participants.

Participants were informed about the different mappings for each block. We provide participants with a 2-set of one-page guide, which illustrate a simple set of diagrams of mappings of Block 1/4 and Block 3/4 for their references. The same set of diagram is also being displayed for a few seconds just before Block 1/4 and Block 3/4 programs begin.

Each set, or block, consists of 15 attempts, in which each attempt comprises horizontal movement alone, or horizontal and followed by a vertical movement. The order and type of attempt is random. Below are the nine types of attempts we have in this program: (1) Horizontal, left to right of bottom boxes, (2) Horizontal, right to left of middle boxes, (3) Horizontal, left to right of top boxes (4) Horizontal, left to right of middle boxes, then vertical, 1 box down, (5) Horizontal, right to left of top boxes, then vertical, 1 box down, (6) Horizontal, left to right of top boxes, then vertical, 2 boxes down, (7) Horizontal, right to left of middle boxes, then vertical, 1 box up, (8) Horizontal, left to right of bottom boxes, then vertical, 1 box up, and, (9) Horizontal, right to left of bottom boxes, then vertical, 2 boxes up. There would be a repeating type of attempt(s) to make up a total of 15 attempts per set.

Measures

To record our data, we used a combination of video recording to allow post-test qualitative and quantitative analysis, and also collected qualitative data during the experiment including observations and questionnaires. All tests were recorded by using two video cameras, and log files were used to record the data about the joysticks' movement. The results of the log files, which presented accurate data of movements of the joysticks, were first analysed before taking them into synchronization with the two recorded videos, which recorded participants' physical movements and on-screen presentation. Volunteers were asked to fill out a background questionnaire prior to the study and they were informed before beginning the test that they were going to be videotaped. Investigators recorded participants' non-verbal manipulation, via pen and papers. Using multiple forms of observation and data collection from log files allowed for detailed evaluation and analysis of user behavior.

Procedures

Our study took place within two days in our department. Each participant interacted with two investigators before and after the test. The primary investigator was responsible for greeting and debriefing the volunteers and collecting background questionnaires. A second investigator was responsible for videotaping. Both investigators were responsible for note taking during the study and for analysis.

The study was evaluated in three separate stages. First, participants filled out a background questionnaire individually, which allowed us to gather background data about each participant. Prior to each test, we briefed the participant of the simple instructions. We then observed participant's performance as each of them manipulating the joysticks in the four mapping conditions (see Figure-6). Investigators directly observed participants and collected data concerning these observed activities. As well as investigators directly observing participants, investigators used video camera I to record user activity (audio and visual), video camera II to record on-screen presentation, whilst the log data recorded the joystick movements. Lastly, the collected data were analysed.

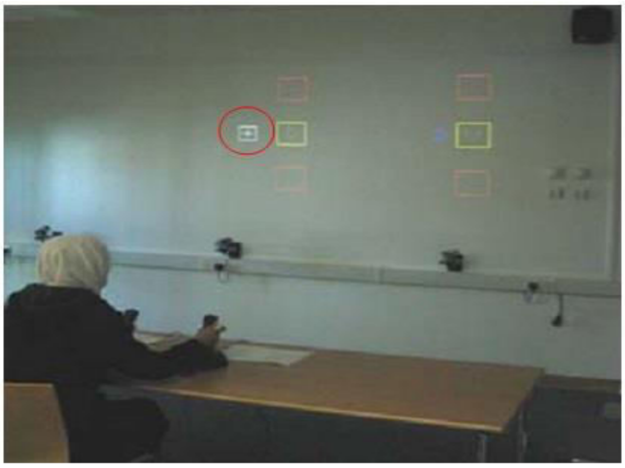

Figure-6. The white cursor must follow the flashing blue arrow (highlighted in the red circle).

RESULTS ANALYSIS

What follows is an analysis of the results from our study. We grouped the results into three categories, but only report the quantitative results in this paper, i.e. the (1) and (2) as described next. The categories are: (1) Learning effect - here, we will be able to find out whether there is any learning effect picked up by participants as they go along from first (01) attempt to fifteenth (15) attempt, (2) Statistical analysis - we will see whether the different conditions have effects on the performance from the statistical perspective, and (3) Observations – we observe participants' usage of joysticks under the different conditions and their reactions toward overshoots.

Despite the fact that both horizontal and vertical performances data were being logged, we only consider the horizontal performance results in our analysis. As the vertical movements are of many kinds, the results were proved to be inconsistent throughout the 15 tests for each block. The only consistent movement that occurred throughout all 15 tests was the horizontal movements, as for each vertical movement was preceded by a horizontal movement.

Learning Effects

Each condition consists of fifteen attempts. We use the log data to tell us whether there is any effect on learning as participants went through all fifteen attempts for every condition. The learning effect that we are looking for is to see whether the performance of each user improves throughout the fifteen attempts. We will be looking at both horizontals' reaction time (RT) and movement time (MT) to find out whether there is any learning effect taking place.

Reaction Time (RT)

Reaction time (RT) is the number of milliseconds (ms) elapsed between the start of attempt and when the joystick controller is moved out of its deadzone. RT can also be considered to be as thinking time, as it is a phase before participants proceed with a decisive movement. By calculating the average, or mean time in milliseconds spent in every attempt of each condition, we generated a graph, which illustrates the overall performance of RT for horizontal movements for every condition (see Figure-7).

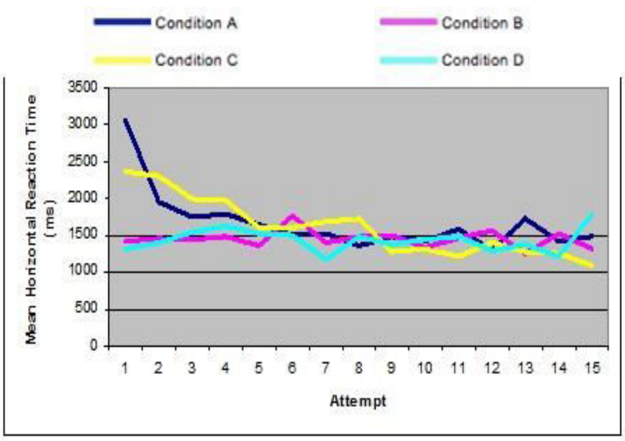

Figure-7. Mean horizontal reaction time (RT) for all conditions.

Reaction times are well above 200ms (Dix, Finlay, Abowd & Beale, 2004, pp27), which corresponds to the reaction time in other studies (Card, English & Burr, 1978). The conditions with less cognitive load seem to begin with a short pause, with about 3,000ms for condition A: attempt 01, and about 2,400ms for condition C: attempt 01. It is suspected that this is due to introductory to the new sets of reference mapping tutorial sheets, which are provided on the table. Having provided the sheets for these two conditions, this tempted the participants to spend a longer time on this first trial to familiarise themselves with the new mapping before proceeding with a movement. Without any mapping tutorial sheets, both conditions B and D had a shorter (in the context of ms) horizontal reactions mean time, of about 1,400ms. Throughout all fifteen attempts for every condition, the horizontal reaction mean time drops quite significantly from their first few attempts to the remaining of the attempts in conditions A and C, whilst conditions C and D tend to have a consistent reaction mean time, which is about on the same level throughout all the fifteen attempts.

We treat the first 7 attempts as ‘learning’ – as from observation, the participants were trying to familiarize themselves with the mappings and movements. They performed quite well in the remaining attempts. Henceforth, we refer to the first 7 attempts as 'learning sessions', and the remaining 8 attempts as 'actual sessions'. We use the division to enable us to see whether there is any learning effect in the reaction phase itself (see Figure-8).

Learning effects seem to take place from conditions A to B and from conditions C to D (as shown by the curve lines). Looking closely at conditions A and C, the learning sessions are about 420ms and 615ms, respectively, higher than their actual sessions. This may cause by the provision of the tutorial sheets. Ruling this reason out, there is no substantial learning effect as shown by both B and D conditions.

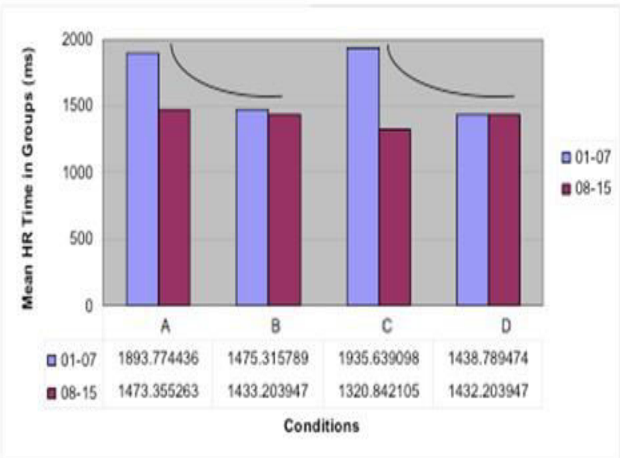

Figure-8. Mean horizontal reaction time (RT) for learning and actual sessions.

Movement Time (MT)

Movement time is the number of milliseconds (ms) elapsed from the time the controller is moved out of its deadzone to when the user correctly acquires the target and fires. The time spent for each movement may be affected by the speed of the controller.

Our approach in manipulating the movement time log data is similar to our approach in RT. By finding the average (mean) horizontal movement time (MT) for each attempt in every condition, we are able to see the generic overall performance, as per shown in Figure-9.

Both conditions A and C have high mean horizontal movement time, with condition A recorded high mean MT from its first to fourth attempts, and only in the first attempt for condition C. The significance difference of about 17,000ms for these two conditions before they both leveled at the range of 6,000-9,000ms is suspected due to the way the participants attempted to refer to and tried to follow what is presented on the tutorial sheets provided and to steer the controller at the same time.

The fluctuation we see for all conditions is due to the unexpected augmentation effects caused by the speed participants performed on the joystick controller, which at most times created confusion especially when participants were introduced to a new mapping condition. For example, when the cursor was supposed to go up, it bounced against the top of the screen and resulted in the opposite direction. But due to the high speed, this confused the participants especially when they had already understood the current mapping. Out of all four conditions, condition B’s mean horizontal MT ranges the lowest. Conditions with high cognitive load seem to keep the horizontal MT lower than when the conditions are said to be cognitively good (low cognitive load).

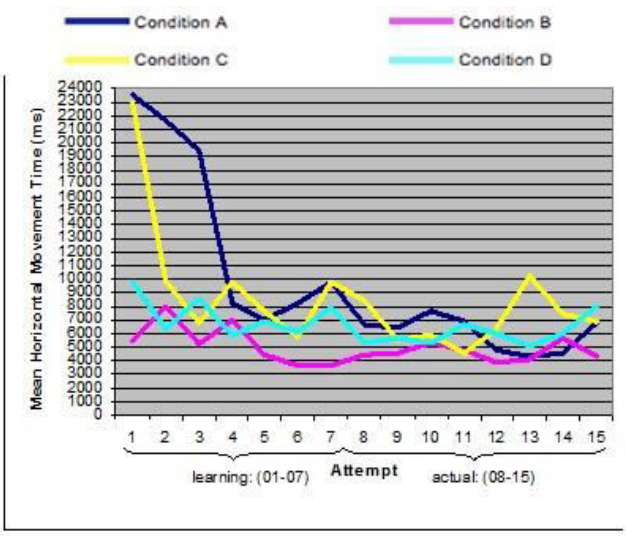

Figure-9. Mean horizontal movement time (MT) for all conditions.

As we did the analysis of reaction times, we grouped the attempts into two groups: 01-07 as training session, 08-15 as actual session, we are able to identify for any learning effects between the transitions. Figure-10 shows comparison between these two groups in all conditions.

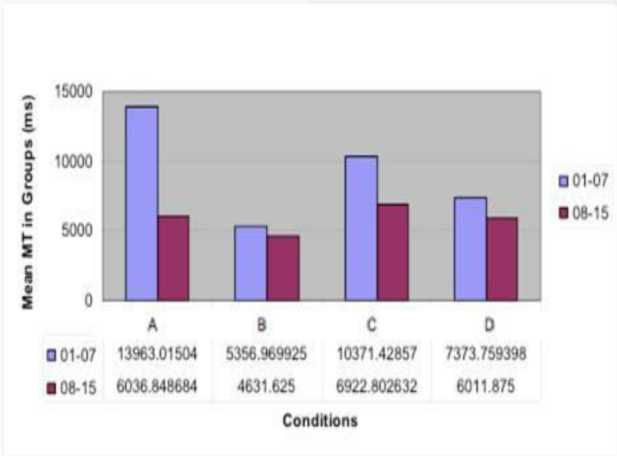

Figure-10. Mean horizontal movements time (MT) between learning and actual sessions.

Figures-11 to 14 shows that for all four conditions, the mean for every attempt in the actual phase is lower than the mean for every attempt in the training phase, with about 7,900ms, 700ms, 3,400ms and 1,300ms difference respectively. From this evidence, there are learning effects that take place during the transitions between the two phases. The obvious difference seen in condition A is due, we suspect, to the fact that condition A was the first condition participants encountered (see also Figure-11). They had to learn the usage of joystick, become familiarised with the environment and the program, and in addition, to overcome the surprise caused by the augmentation effects due to the speed of the joystick movement. Furthermore, in the first few attempts, participants still tend to look and refer to the tutorial sheet. And this is the similar factor that contributed to the significant difference of mean 3,400ms showed in the condition C (see Figure-13).

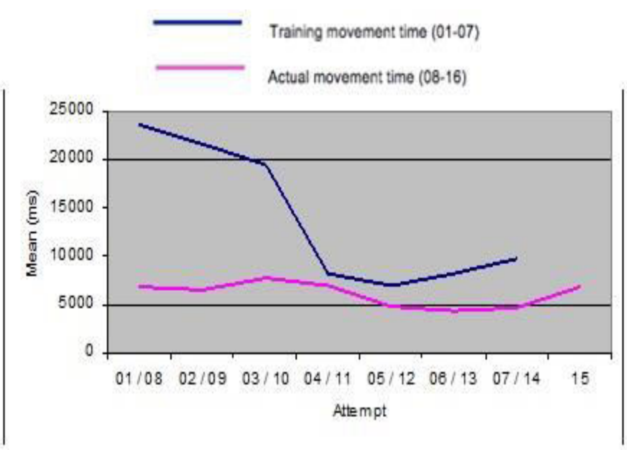

Figure-11. Condition A training vs. actual performances.

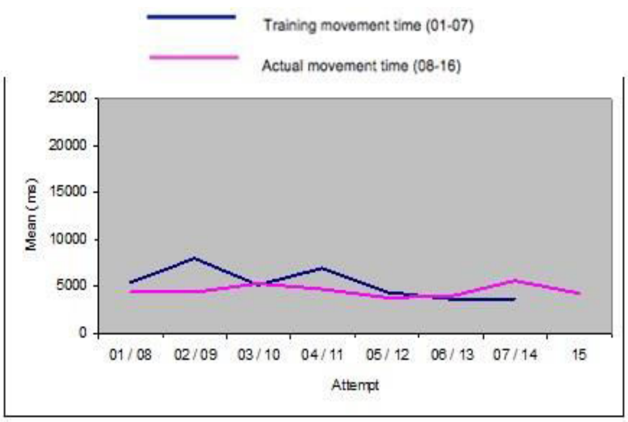

Figure-12. Condition B training vs. actual performances.

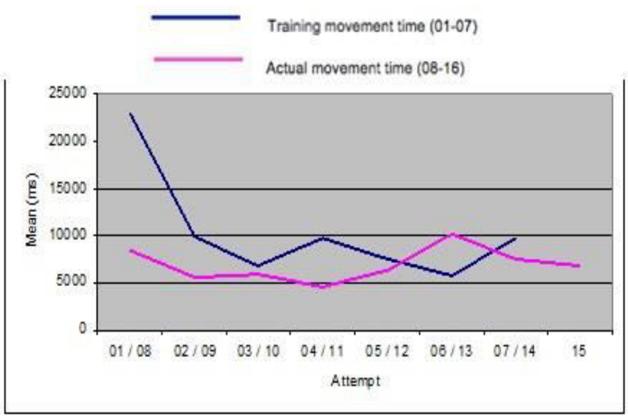

Figure-13. Condition C training vs. actual performances.

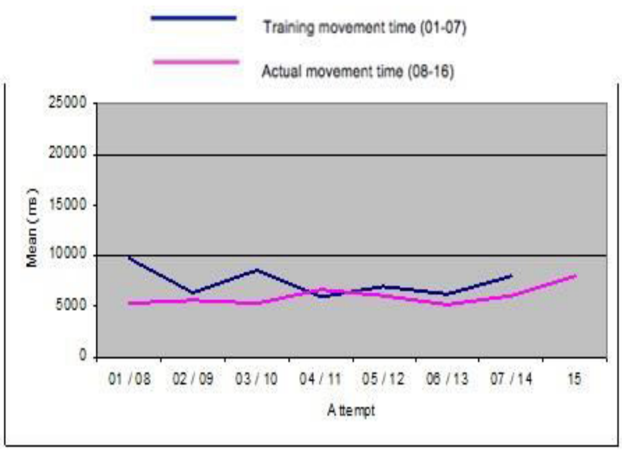

Figure-14. Condition D training vs. actual performances.

When we look closely at the individual conditions of B (Figure-12) and D (Figure-14), the learning and actual performance both have small range of mean difference between the two. Without the mapping tutorial sheet, the transition effect is reduced and closer to the range of difference between the learning and actual phases. Furthermore, conditions with low cognitive load seem to allow the participants to perform faster and rather well compared to other conditions.

Statistical Significance

Data were further analyzed to test the significance of differences of the four conditions using analysis of variance (ANOVA). The ANOVA fitted for participant effect, main effect of the condition and learning and actual sessions effect.

The initial by eye analysis of graphs seem to suggest effects caused by different type of conditions, which in fact is statistically significant at 5%, with $F(3, 54)=4.748$; $P<0.05$.

The type of condition does affect participants' performance. In addition to this, by referring to the above table and in the columns highlighted, the conclusion we can reach is that there is also a main effect for session ($P=0.011$, significant at 5%), and interaction effect between the two factors ($P=0.05$, significant at 10%). Thus, it did matter if one was in condition A, B, C and D, and it did matter if one was in the training or actual session. Furthermore, the type of condition does have an impact differentially on the type of session's performance. Having said this, for this particular analysis, we only selected horizontal movements log data and left out other type of vertical movements log data, which consist of moving upwards by one box and two boxes, and moving downwards by one box and two boxes, as all attempts began with horizontal movement. We are not certain if this in any way affected participants' performance and consequently draw different significance effects. Longer experiments, which consist of larger number of attempts, or, eliminating the vertical movement altogether might result in different performance, but we can be confident from these results that the type of conditions used had a substantial effect.

CONCLUDING REMARKS

The four conditions were designed to represent four different types of mappings. In conditions A and B, good physical-logical mapping have helped participants in getting the correct movement faster. Different types of conditions do affect the participants' performance. In addition, surprisingly, conditions with high cognitive load, as in condition B and D, lead to faster performance, despite the absence of references or tutorial. It has been shown from the results that inversing an action on the same controller (regardless the type of mapping) is the natural reaction to overshoots. The time taken for inverse actions, however, was not as quick as we initially thought. This could be due to the augmentation effects. These effects, which were perceived to be unexpected and difficult to control caused the participants to be conscious with their actions (Miyata & Norman, 1986). Nonetheless, the likelihood of inverse recovery is high when the opposite mapping is retained on the same controller.

Different backgrounds of participants showed variations in the performance style of joysticks usage. Expert gamers' are not afraid of exploring and always want to make sure they perform the best in each condition. During the overshoots, the pairing concept that exists in A and B conditions seemed to assist participants in their inverse action. In some occasions, the concept of good physicality is very hard to break, as shown by some persistent participants.

The graphs have shown us that the types of condition do give rise to different results in the participants' performance, but with the ANOVA statistical analysis, it has given us confidence in confirming this fact. Furthermore, the type of sessions one was in (first seven training attempts, or, the last eight actual attempts) also has a main effect on the performance. Whilst the interaction effect shows that type of condition does have an impact differentially on the type of session's performance. With these significance statements, we believe that participants performed best in conditions where participants had to rely only on the physical controller and not thinking much about the cognitive aspect, based on the previous graphs analysis.

This study, nonetheless, had to rely only on the horizontal movements and had to ignore all vertical movements. The reasoning behind this, as mentioned in the previous section, is the inconsistent data of vertical movements. As the vertical movements are of many kinds, the results were proved to be inconsistent throughout the 15 tests for each block. The only consistent movement that occurred throughout all 15 tests was the horizontal movements, as each vertical movement was preceded by a horizontal movement.

Eliminating the vertical movements altogether may seems to be a sensible thing to do to improve the results, due to their inconsistent data. But it would not be a wise decision, as the procedure would not have worked with just horizontal mappings on two joysticks. Thus, the program requires the vertical mappings to accompany the horizontal mappings in order to enable the swapping between conditions. We do not see the data from the vertical movements as wasted, because the logged vertical data can be explored in a future study. This study can be improved further by increasing the number of attempts per participant to show the transition effects between learning and actual attempts. Moreover, this would produce more confident results in terms of different conditions of physical and cognitive factors.

Above all, the study has shed light on the relevancy of physicality at a time where everything else has become digitalized. The relationship between physicality and its underlying mapping is still very important in order to retain any kind of relationship as natural, despite the existence of incoherent mappings, which is due to the ability to manipulate its logical effects in the digital world. This would definitely open up to many more possibilities of actions and interactions of the physical and the digital world.

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