Novel Modalities for Bimanual Scrolling on Tablet Devices

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Abstract. This paper presents two studies investigating the use of novel modalities for bimanual vertical scrolling on tablet devices. Several bimanual interaction techniques are presented, using a combination of physical dial, touch and pressure input, which split the control of scrolling speed and scrolling direction across two hands. The new interaction techniques are compared to equivalent unimanual techniques in a controlled linear targeting task. The results suggest that participants can select targets significantly faster and with a lower subjective workload using the bimanual techniques.

Keywords: Bimanual interaction, scrolling, tablets.

1 Introduction

Touchscreen tablet devices present an interesting challenge to interaction design: they are not quite handheld like their smartphone cousins, though their form factor affords usage away from the desktop and other surfaces. This means that users will often have to dedicate one hand to holding the device, constraining their ability to use two hands on the touchscreen. This work explores the possibility of using novel input modalities mounted on the tablet (such as pressure sensors and physical dials) to enable simultaneous two-handed input while the user is holding the device.

The form factor of tablet devices requires a user to support a larger weight and navigate more screen space than a phone. Thus, while the tasks being performed may be similar, the form factor of tablet devices dictates that either two hands or a supporting surface are required for interaction. Users may interact with the device while it is perched on a desk, worktop or even while the device rests on their lap. In these cases, it is possible to interact on the screen directly with both hands, which is not easy on a small phone screen as it could create 'fat finger' problems with screen occlusion [1], [2].

In other instances, users may need to interact with the tablet while holding it in their hands. To do this, users will need to dedicate one hand to holding the device, while interacting with the other [3]. Thus, the repertoire of touch gestures is reduced. From this, it is not clear how to design interaction techniques for tablet devices that work in all of the usage scenarios afforded by their form factor.

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Previous studies suggest there are bimanual interaction techniques that offer benefits over equivalent unimanual ones [4], though these studies have assumed static interactions in a desktop environment or have been limited to using only the touchscreen on a tablet device [3]. The challenge of designing bimanual interaction techniques for tablet devices is to allow simultaneous two-handed input while still allowing the user to hold the device comfortably. This paper presents two studies that aim to provide insight towards the design and future research of techniques that could allow such bimanual input.

1.1 Why Bimanual?

As human beings, we have natural bimanual motor skills that we have been using and perfecting our entire lives. This is not to say, however, that all two-handed action is equivalent and certainly not all tasks are performed best using two hands [5]. It cannot be said, for instance, that writing with a pen in each hand improves the efficiency of writing. Human beings have natural bimanual motor skills, but only when each hand adopts an appropriate role. Depending on the task being carried out, the two hands can cooperate symmetrically or asymmetrically. A useful and well tested characterisation of asymmetric bimanual action is Guiard's Kinematic Chain (KC) model [6]. Central to the KC Model is the cooperative and asymmetrical nature of bimanual action, meaning that when human beings perform tasks with both of their hands, they adopt different and complementary roles in order to do so. Guiard argues that the relationship between the dominant hand (DH) and non-dominant hand (NDH) is analogous to the relationship between proximal and distal elements in a kinematic chain (a series of abstract motors, a common example of which is an arm). The implication of this is that the dominant hand will act in relation to the non-dominant hand.

Tablet interaction, as it currently exists, conforms to the KC Model insofar as the user's NDH sets the frame of reference for the action of the DH by holding the device. Though, in much the same way as writing on paper - where the NDH holds the page (sets the frame of reference) for the DH to write on (the primary action of the task) - the NDH in tablet interactions primarily takes a passive role. Designing tablet interactions that offer the user's NDH a more active role in the interaction, while still properly supporting the device, has the potential to enable the user to use both hands to complete tasks in a richer way in a wider range of circumstances.

Previous work has suggested that interactions designed using the KC model can out-perform equivalent unimanual ones in a desktop environment [7]. There has also been early evidence suggesting that multitouch screen gestures that are based on human body movements that are not well documented or studied, can increase the risk of musculoskeletal disorders [4]. From this, the designers of tablet interactions could benefit from a better understanding of the ways in which human beings have evolved to use both of their hands to complete tasks. In doing so, interaction designers can take advantage of the natural abilities of human beings in order to create more effective ways to use devices.

Fig. 1. Bang & Olufsen BeoSound 5. The side-mounted dial is used to scroll the on-screen content.

Unimanual and Bimanual Scrolling. On tablet devices, unimanual scrolling involves controlling speed and direction using flick and drag gestures on the touchscreen of a multitouch device or by performing similar rotational movements (flicking and dragging) on a physical dial (such as on the Bang & Olufsen BeoSound 5 (see Figure 1). The physical dial on the Bang & Olufsen BeoSound 5 is used to scroll through a music library displayed as a circular list on the screen. This kind of scrolling behaviour is also exhibited on scroll-wheels on mice and keyboards). While this technique is straightforward to learn, it only offers very coarse control over scrolling speed and scrolling long lists can be time consuming. There are several alternative strategies users can adopt to find items in long lists such as searching or filtering the list using text input, or by jumping directly to a letter in an alphabetically ordered list (such as on Apple iOS devices), or by employing a separate fast scrolling slider (as on Google Android devices), though these techniques often require the user to know what s/he is looking for in advance, which is not always the case. While the need for scrolling through large collections can be mitigated by finding better ways to provide good recommendations or by improving search, there is always a need to have an efficient and appealing way to access 'your stuff' in its entirety.

Scrolling is composed of two variables: the scrolling speed and the scrolling direction. The purpose of this paper is to establish whether there is a potential benefit in splitting the control of scrolling speed and scrolling direction over two hands. By allowing the user's NDH to set the scrolling speed while their DH controls direction, it may be possible to give the user more control over the interaction. In terms of the KC Model [6] we can say that the NDH is setting the frame of reference (the speed) for the action of the DH (the scrolling). In this paper, we describe a number of scrolling techniques whereby we augment existing scrolling methods (drag and flick gestures on a touchscreen and on a dial) with a speed control mechanism. Control of the scrolling speed is given to the user's NDH using either pressure input or an on screen slider, and the control of direction is given to the user's DH using on screen drag gestures or a rear mounted dial.

2 Background

2.1 Bimanual Interaction on Touchscreen Devices

Multitouch devices are, by definition, capable of accepting bimanual input. By being able to sense multiple points of contact on the screen, a user can use either multiple fingers from one or multiple hands to interact. Studies have shown that touchscreen bimanual interaction techniques can improve performance [7], [8] and selection accuracy [9]. However, these studies assume that both hands are free to interact. There is no evidence to suggest that they would be beneficial in contexts where one hand is constrained by holding the device.

Despite the fact that one hand is often required to hold the device, it can do so in a variety of ways. As the hand may be in contact with the bezel and back of the device, these areas could be augmented with additional hardware to enable interaction. For example, RearType [10] includes a physical keyboard on the back of a tablet PC. Users hold it with both hands while entering text, thus avoiding an on-screen keyboard and graphical occlusion by the fingers. Lucid Touch [11] is a proof-of-concept see-through tablet that supports simultaneous touch input on the front and on the back of the device. Users hold the device with both hands, with thumbs on the front and remaining fingers on the back. The device is small enough that users can reach the entire back allowing multitouch interaction with both hands while fully supporting the device. However, the arm-mounted camera currently makes this approach impractical. Gummi [12] is a prototype "bendable" tablet that allows bimanual interaction by deforming the device by gripping its edges.

Wagner *et al.* [3] designed BiPad, a user interface toolkit to introduce bimanual interaction on tablets. It is designed to work on existing touchscreen tablets, without any additional hardware. The users' NDH can execute commands on special regions of the screen that are accessible while they are holding the tablet. For example, users can activate contextual menus to control the zooming and rotation of maps by tapping, gesturing or making chords with their NDH, while their DH selects items from the menus, or controls the position of the zooming and rotation, simultaneously. They found that the bimanual techniques did improve performance over unimanual techniques. Their aim was to provide a general way to provide bimanual interaction on tablet devices and actual behaviour of the NDH would vary from application to application.

2.2 Models of Bimanual Action

Early work on bimanual HCI assumed that users would be sat at a desktop interacting through various peripheral devices placed on the desk. Leganchuk, Zhai and Buxton [4] give an overview and valuable insight into the early work. In surveying the literature on bimanual HCI, they observe that there are contrasting views on whether bimanual interaction techniques actually provide any benefit when applied to desktop interactions. By analysing the interaction techniques from the early experiments with

Fig. 2. Hardware setup for our study: Griffin Technologies PowerMate with extended radius (right), the dial affixed to the rear of the tablet (centre) and the pressure sensor affixed to the top-left of the bezel of the tablet (left)

respect to Guiard's KC model [6], they observed that bimanual techniques which conformed to the model showed advantage over unimanual equivalents, while those that did not showed little or no advantage over equivalent unimanual techniques. From this, they concluded that two hands are not always better than one, and that when designing bimanual interaction techniques, it is important to do so using the KC model.

While Guiard's KC model is a useful and well tested characterisation, it only models a particular class of bimanual action [6]: asymmetric bimanual action. The cooperative and asymmetrical nature of the KC model describes that when human beings perform tasks with both of their hands they adopt different and complementary roles in order to do so. Guiard argues that vast majority of real life human manual acts belong to the bimanual asymmetric class and that asymmetry in action is the rule and symmetry the exception. Meaning that not only are there a set of tasks, such as opening a bottle or slicing food, that are obviously bimanual and asymmetric, but that even supposed unimanual tasks, such as throwing a dart or brushing your teeth, are essentially bimanual actions (where the NDH plays a supportive, postural role) and tasks where both hands perform essentially the same role either in phase (such as rope skipping or lifting) or out of phase (such as typing or rope climbing) are the exception to the rule.

Guiard argues that the relationship between the dominant and non-dominant hand is analogous to the relationship between a proximal and distal element in a kinematic chain. The implication of which is that the DH will act in relation to the action of the NDH, the granularity of action of the NDH is much coarser than the DH hand (i.e. the movement of the NDH is macrometic while the movement of the DH is micrometric) and the sequence of motion is NDH followed by DH. However, Latulipe and others [13–15] have demonstrated that there is a class of common HCI tasks that can be modelled as symmetric bimanual actions. Particularly, geometric translations are more effectively performed symmetrically than asymmetrically. Latulipe [15] describes a model of symmetric bimanual interaction in which tasks can be thought of and broken down into symmetric components that can be distributed over two hands.

However, one of the caveats of the model is that in order to perform symmetric interaction effectively, a user requires device symmetry. Therefore, using both hands on the touchscreen, symmetric bimanual input is possible (as is demonstrated in the 'pinch-to-zoom' and 'rotate' touch gestures on many touchscreen devices).

Since the goal of this paper is to explore ways to enable simultaneous two-handed input while the user is comfortably holding the device, we must conclude that in delegating one hand to holding the device, both will not be able to gain full access to the touchscreen and so asymmetric bimanual input should be used.

3 Bimanual Scrolling – Experiment 1

This study was based on the premise that the control of scrolling speed and vertical scrolling direction can be thought of as separate tasks and that the current *status quo* of combining both into a single unimanual gesture on a touchscreen or on physical dial can be improved upon. The experiment sought to determine whether splitting the control of scrolling speed and scrolling direction over two hands, in accordance with the KC Model [6], could improve user performance in a one-dimensional scrolling task on a touchscreen tablet device.

In this paper we control both the way the user holds the tablet and the amount they have to support it in order to determine whether these techniques have any value in and of themselves without having to deal with the numerous different ways people choose to hold tablets [3], which we saw as a confounding factor.

3.1 Input Methods

For direction control, we chose to use two existing scrolling methods for our input modalities: drag gestures on a touchscreen and a free rotating physical dial. Therefore, our direction control modalities were Touch and Dial.

A pressure sensor was chosen for one of the speed control modalities, since pressure has been demonstrated to be a useful modality for the control of speed (for rate based cursor control) [16]. A pressure sensor can be mapped well to the control of speed using an accelerator metaphor, where increasing the force will increase the speed and *vice versa*. Furthermore, isometric force input is useful as an input modality on mobile devices [16–18] and as an augmentation of finger/stylus input on touchscreens [19] (although not tested in the NDH). It can be detected using force sensing resistors (FSRs) that are flat and can be added to different locations on a device without changing its form factor.

Since we have a combination of physical and touch interactions in the direction control, we included a touch-based slider control for speed control as well. It did not require the NDH to perform a precise task (just one dimensional movement) and that it could be mapped well to speed control: up to increase the speed, down to decrease.

Fig. 3. Experimental Setup – Participant sat at a desk with the tablet supported on a stand

3.2 Interaction Techniques

There were six interaction techniques used in the study: two unimanual and four bimanual.

Unimanual Techniques. The two unimanual techniques were Unimanual Touch and Unimanual Dial, in which scrolling direction and speed were combined. The Unimanual Touch technique was the same as that found on current tablets and was used as a control condition for the experiment. To scroll through the list used in the study, participants would either drag on the screen or to perform a flick gesture on the screen that would cause the menu to scroll quickly in the direction of the flick. Flicking faster increased the velocity of the scrolling. The Unimanual Dial technique was similar insofar as participants could drag the dial to scroll through the list, or 'flick' the dial to scroll quickly in the direction of the flick in a way similar to that on the BeoSound 5 (See Figure 1).

Bimanual Techniques. The bimanual techniques used the same scrolling direction devices as the unimanual techniques, but two additional methods were used to control speed. The speed could be controlled dynamically using either a force sensing resistor (FSR) mounted on the top left front of the device's bezel or a software slider bar that appeared on the top left of the screen. Participants controlled speed by applying force to the FSR using the thumb of their NDH on the sensor and their other fingers behind the device, in a pinching gesture. Increasing the pressure dynamically increased the speed at which the direction control methods would scroll the menu. Releasing the pressure from the sensor would decrease the speed. A pressure space (amount of pressure that has to be applied to reach the maximum speed) of 9N was used for speed control. This was chosen because pilot tests revealed that with smaller pressure spaces, the speed control became binary, with the pinch pushing right through the pressure space.

The software slider bar was also controlled by the participants' NDH. Pushing the slider bar upwards increased the speed of scrolling and *vice versa*.

In the bimanual techniques, the speed control was completely separated from the direction control and so it was no longer possible to perform 'flick' gestures on either the dial or the touchscreen to increase scrolling speed. All permutations of these bimanual techniques were used: Bimanual Touch and Pressure, Bimanual Touch and Slider, Bimanual Dial and Pressure, and Bimanual Dial and Slider.

3.3 Participants

Eighteen participants (4 female, 14 male) ranging from 19-55 years of age (M=23) took part in the study, all of whom were right handed. They were paid £6 for participating.

3.4 Hypothesis

H1: Bimanual techniques designed with the KC Model will outperform equivalent unimanual techniques, measured by faster movement times, fewer target overshoots and lower subjective workload.

H2: The bimanual techniques will provide more benefits as the distance to the target increases, measured by faster movement times, fewer target overshoots and lower subjective workload.

H3: Within the bimanual techniques, pressure will outperform the touch slider as a speed control method, measured by faster movement times, fewer target overshoots and lower subjective workload.

H4: Within the bimanual techniques, the dial will outperform touch drag as a direction control method, measured by faster movement times, fewer target overshoots and lower subjective workload.

3.5 Experimental Design and Procedure

The study aimed to answer two research questions. Firstly, whether the bimanual techniques were better than the unimanual ones and secondly which combination of bimanual modalities were most effective. For the former, we simply compared each of the techniques, resulting in the variable *Interaction Technique* with six levels: Unimanual Touch, Unimanual Dial, Bimanual Touch + Pressure, Bimanual Touch + Slider, Bimanual Dial + Pressure, Bimanual Dial + Slider. These variables were used to test H1 and H2.

However, in doing this we cannot say anything about the different speed and direction control techniques that are being used. Since it is not possible to compare the bimanual speed and direction controls with the unimanual techniques (the control of speed or direction cannot be isolated in the unimanual techniques), an additional set of independent variables was required. Therefore, the variables *Scroll Method* and *Speed Method* were used to compare the bimanual techniques to one another, excluding the unimanual techniques. Each of these had two levels: Scroll Method (Touch or Dial) and Speed Method (Pressure or Slider). These variables were used to test H3 and H4.

Across both the research questions, we considered the effect of target distance on performance. Target distance was a useful measure as it allowed us to assess whether having a greater control of scrolling speed was useful when moving different distances. Therefore, the independent variables in the study were *Interaction Technique* and *Target Distance*, or *Scroll Method, Speed Method* and *Target Distance*. The dependent variables were *Movement Time* and Number of *Target Overshoots.* After each condition participants completed a NASA TLX [20], a six item questionnaire that assesses subjective workload. Movement Time was a measure of how long it took to complete a selection, from the first scrolling movement to the last scrolling movement before selection. Movement Time encapsulated the entire time to scroll though did not include any additional time taken to select an item (when, for instance, a participant had to move his or her hand from the dial to the touchscreen). Number of Target Overshoots was defined as the number of times a target disappeared from view after being visible. This meant we could measure how many times a participant overshot a target before selecting it, which served as a measure of control; fewer overshoots meant that the technique allowed greater control. Finally, Subjective Workload was measured using the NASA TLX [20], which gave a measure of how hard a participant though s/he had to work using each technique.

Procedure. The interaction techniques were implemented on a Viewsonic Viewpad 10” touchscreen tablet running custom software on Windows 7. A Griffin Technologies PowerMate Dial, with an extended radius (using the lid from a jar of fruit so that it could be easily reached at the side of the tablet), was used for the dial conditions and a single Force Sensing Resistor connected through a SAMH Engineering SK7-ExtGPI01 input/output module (which handled A-D conversion and sensor linerisation [21]) was used for pressure sensing (See Figure 2). Users applied pressure by performing a pinch gesture with the thumb and forefinger of their NDH on the left-hand bezel of the device.

The experimental task involved participants scrolling to and selecting an item from an alphabetically ordered list of 312 musical artists, which is similar to the task of selecting an artist to listen to from a long list within a music library on a tablet. In each condition, participants performed 19 tasks in total (the first 6 being training tasks). Target names would appear automatically on screen and after a selection had been made (whether correct or incorrect) the next task would begin automatically with the user being returned to the top of the list. This continued until all tasks had been completed. There were 6 unique data sets used in the study to avoid learning effects, and each participant used a different data set in each condition. Each set contained 312 alphabetically ordered musical artists.

The tasks were defined in terms of how far the participant would have to scroll from the very top of the list to the target. There were 13 experimental tasks (excluding the 6 training tasks) and the target to be selected in each task was different in each condition since there was a different data set for each condition. The distances associated with the tasks were 10, 35, 60, 85, 110, 135, 160, 185, 210, 235, 260, 285 and 310 items from the top. By defining the tasks in this way, and using a different dataset in each condition, we could compare the performance of each interaction technique over distance while mitigating any learning effect that might have occurred if participants were asked to select the same items in every condition. Conditions were counterbalanced using a Latin Square to mitigate any order effects.

4 Results

4.1 Overall Results – Interaction Technique and Distance

This section presents an overall analysis of the bimanual and unimanual conditions in which we compare each of the techniques to each other whole. In doing so, we can compare the performance of each technique to one another and test H1.

Movement Time. A two-way, repeated measures ANOVA showed a main effect for Interaction Technique, F (5, 85) = 23.555, p < .001, a main effect for Distance, F (12, 204) = 47.653, p < .001. The Interaction Technique x Distance interaction was not significant, F (60, 1020) = 1.638, p = .099.

Post hoc pairwise comparisons with Bonferroni corrections revealed that the combination of Dial and Slider was significantly faster than all other interaction techniques (p < .001). Touch and Slider was significantly faster than both the Unimanual Touch and Touch and Pressure techniques (p <.001). Unimanual Dial was significantly faster than the Unimanual Touch (p < .001) and the Dial and Pressure technique was significantly faster than the Touch and Pressure Technique (p < .001) and the Unimanual Touch Technique (p<.001).

Number of Target Overshoots. A two-way, repeated measures ANOVA showed no main effect for Interaction Type, F(5,85) = 2.245,p = .057. There was a main effect for Distance, F (12, 204) = 1.516, p < .001. There was no interaction between the two.

Subjective Workload. A one-way repeated measures ANOVA on the overall workload scores for each condition showed a significant main effect for Interaction Technique, F(5, 85), p <.001. *Post hoc* pairwise comparisons with Bonferroni corrections revealed that the combination of Dial and Pressure had a significantly lower workload score than Dial and Slider (p<.05), Unimanual Touch (p<.001) and Touch and Pressure (p<.05).

Discussion. With this analysis we were interested in trying to ascertain whether there were any benefits of bimanual techniques over some equivalent unimanual techniques. The hypothesis that bimanual techniques designed to conform to the KC model will outperform equivalent unimanual techniques (H1) was generally borne out. The Dial and Slider technique was superior to the others in terms of Movement Time (see Figure 4a) with the Dial and Pressure technique superior in terms of Subjective Workload (See Figure 4b). These results suggest that the bimanual techniques do have advantages over unimanual equivalents.

In general, it took participants longer to select targets that were further away, which explains the main effect for Distance, but since there was no interaction effect for Interaction Technique x Distance there is no evidence to suggest that any of the bimanual techniques provide additional benefit as the distance from the target increases, and thus there is no evidence to support H2.

A more detailed analysis of the bimanual techniques in the following section will attempt to explain why participants performed better with the Dial and Slider combination, though had a lower subjective workload with the Dial and Pressure combination. A fully balanced experiment was not possible with these six interaction techniques (we could not isolate speed control for the unimanual conditions), we cannot make any concrete inferences about whether the Dial is a superior modality to Touch for controlling scroll direction either unimanually or bimanually.

4.2 Detailed Results – Scroll Method/Speed Method and Distance

A second analysis was carried out to test H3 and H4 which are concerned with the particular modalities used in the bimanual techniques and aim to test which, if any, resulted in better performance. The Independent Variables in this analysis were Scroll Method (Dial or Touch), Speed Method (Pressure or Slider) as well as Target Distance. The dependent variables were the same as the previous analysis: Movement Time, Number of Target Overshoots and Subjective Workload.

Movement Time. A three-way, repeated measures ANOVA on the movement times showed a main effect for Scroll Method, F (1, 17) = 44.262, p < .001, a main effect for Speed Method, F(1,17) = 35.747, p < .001 and a main effect for Distance F (12, 204) = 27.898, p < .001. There were no significant interactions between these three.

In general, it took longer to select items that were further away in the list. In addition, the movement times for the techniques that used the slider as a Speed Method

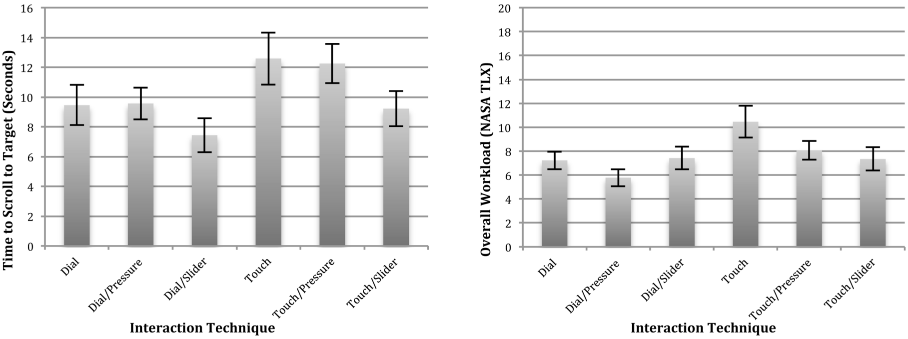

Fig. 4. (a) Average Movement Times for each Interaction Technique (b) Overall Subjective Workload for each Interaction Technique

were faster (M=8330ms, SD=5005ms) than the techniques that used the pressure as a speed control method (M=10911ms, SD=5290ms).

Number of Target Overshoots. A three-way, repeated measures ANOVA on the number of target overshoots showed no significant main effect for Scroll Method, F(1,17) = .592,p= .452, nor for Speed Method, F (1, 17) = .426, p = .523. There was a the main effect for Distance F(12,204)= 3.381, p < .001. Only the Scroll Method x Speed Method x Distance interaction was significant F (12, 204)=2.778, p <.05.

Subjective Workload. A two-way repeated measure ANOVA on the overall workload scores for each condition showed no significant main effect for Scroll Method F(1,17) = 3.373, p = .084, no significant main effect for Speed Method F(1,17) = 1.255, p=.278 though there was a significant interaction between Speed Method and Scroll Method F(1,17)=10.111, p<.05. *Post hoc* pairwise comparisons with Bonferroni corrections revealed that the combination of Dial and Pressure had a significantly lower workload score than Dial and Slider (p<.05), and Touch and Pressure (p<.05).

Discussion. The results from the second analysis reveal that, as a direction control method, participants performed tasks faster using the dial than with on screen touch gestures, though there was no evidence to suggest that Scroll Method has any effect on number of target overshoots, lending some support to the hypothesis that participants would perform better using the dial than the touch gestures (H4). Repetitive flick and or drag gestures make it difficult to get anything but very coarse control over the scrolling speed and cause the interaction to become slow and staggered. We believe that the reason the dial turned out to be faster was because it provided more continuous control during scrolling.

As before, it took participants longer to select targets that were further away, which explains the main effect for Distance. However, since there was no interaction effect between Scroll Method, Speed Method or Distance there is no evidence to suggest that any of the bimanual techniques provide additional benefit over any of the other techniques as the distance from the target increases.

As a speed control method, the on screen slider was better than the pressure sensor. Participants performed tasks faster when using the on screen slider than when using the pressure sensor. However, the pressure sensor was favoured in the subjective workload metrics, implying that people found it easier to use. There was no evidence to suggest that either of the modalities had an effect on the number of target overshoots. The hypothesis that pressure will outperform the touch slider as a speed control method (H4), then, was not supported. If we examine the differences in the levels of speed achieved using each of the techniques we can begin to explain these differences. Figure 5 shows the variation in the speed values for each technique. It can be seen that the distribution of speed values was skewed toward to lower end of the scale for the techniques that used pressure for speed control and is distributed across the centre for techniques that used the on screen slider for speed control.

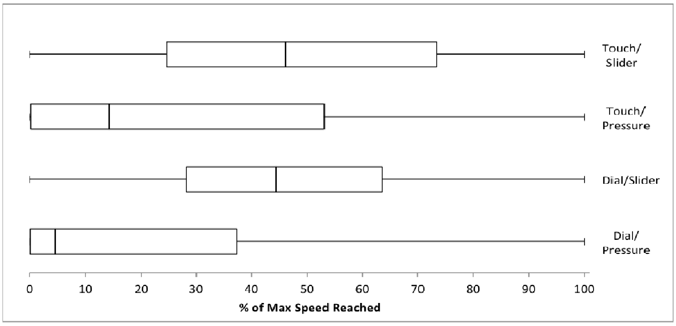

Fig. 5. Distribution of Speed Levels

During the experiment debrief, a number of participants commented that they found that they had to apply too much force in order to get to maximum speed; they therefore only applied a comfortable amount of force, and did not reach maximum speed. To scroll the list at the maximum speed, the participant would have to apply a force of 9N continuously on the pressure sensor. Whereas while with the touch slider it was possible to reach maximum speed by simply moving the slider knob to the top of the slider bar, participants rarely set is to the maximum value. Rather, participants commented that they only moved the slider in small increments or decrements because it was awkward to change. It was easier and more comfortable to travel at slower speeds with the pressure sensor, which could explain why participants took longer to complete the tasks with the pressure sensor. From this, we could hypothesise that by reducing the amount of force that is required to reach the maximum speed, we could reduce the amount of time needed to carry out the task while maintaining the subjective workload benefits of the pressure sensor.

5 Bimanual Scrolling – Experiment 2

The goal of the second study was to investigate further the use of pressure as a speed control method for bimanual scrolling interactions. In the previous study, the techniques that used pressure control did not out perform others, though participants perceived them to have a lower subjective workload. From this, it seems possible that the pressure space was too large. In this study, we tested whether decreasing the pressure space could improve objective performance while maintaining perceived workload. We were also interested in whether there is an optimal pressure space for bimanual scrolling.

5.1 Interaction Technique

There were eight interaction techniques used in the study, all of which were bimanual and all of which used pressure as a speed control method. They differed from the techniques used in the previous study in the following ways. Firstly, two different, and smaller 4N and 6N pressure spaces were used. These were smaller than the pressure space used in the last study (9N), which had been chosen because pilot testing had suggested that with too small a pressure space the control of speed became binary. Thus, while the aim of this study is to evaluate whether decreasing the pressure space improves performance, we do not expect that the smallest pressure space will necessarily be the best.

In addition to varying the pressure space, the way in which the pressure sensor controlled the speed was varied as well. In the first study, an accelerator metaphor was used, but we encountered the problem that participants struggled to reach maximum speed. While reducing the pressure space, as discussed above, could solve this it could also be solved by applying a "brake" metaphor instead. A brake metaphor could be useful because by default the scrolling speed would be set to maximum, and then could be decreased by applying pressure. In doing this it makes it easier to achieve higher speeds, though could also make it more difficult to scroll at slower speeds, reducing target selection accuracy. By including this variation here we hope to characterise this trade-off as well.

5.2 Participants

Sixteen new participants (9 female, 7 male) ranging from 19-31 years of age (M=21) took part in the study, all of whom were right handed. They were paid £6 for participating.

5.3 Hypothesis

H5: The larger (6N) pressure space will outperform the smaller (4N) pressure space, measured by faster movement times, fewer target overshoots and lower subjective workload.

H6: As a method of speed control, Brake will provide better performance over longer distances than Accelerator, measured by faster movement times, fewer target overshoots and lower subjective workload.

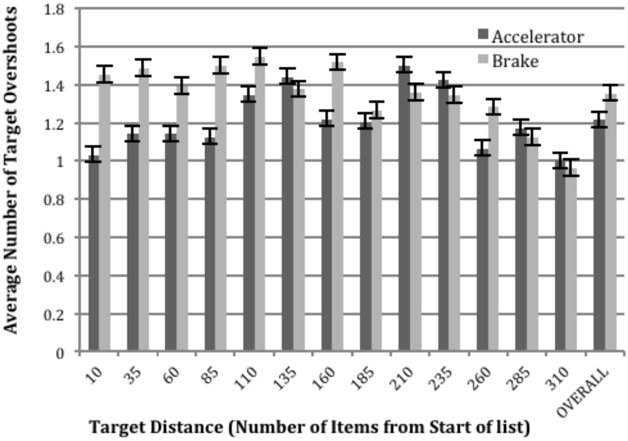

Fig. 6. Number of Target Overshoots

5.4 Experimental Design and Procedure

The experimental task was identical to the one in the previous study and involved participants scrolling to and selecting an item from an alphabetically ordered list of 312 musical artists. Conditions were counterbalanced using a Latin Square to mitigate any order effects.

The independent variables were: Scroll Method (Dial, Touch Drag), Pressure Space (4N, 6N), Pressure Mode (Accelerator, Brake) and Distance (10, 35, 60, 85, 110, 135, 160, 185, 210, 235, 260, 285 and 310). The dependent variables were Movement Time, Number of Target Overshoots and Subjective Workload.

5.5 Results

Movement Time. A four-way, repeated measures ANOVA showed a significant main effect for Scroll Method F (1, 14) = 5.426, p < .05 and for Distance F (12, 168) = 11.413, p < .001. There was no evidence that either Pressure Mode (Accelerator or Brake) or Pressure Space (4N or 6N) had any effect on Movement Time. There were no significant interactions. In general, participants took longer to scroll to targets that were further away from the start of the list and participants took longer to scroll to targets when using the Touch Scroll method (M=13708ms, SD=7135ms) than when using the Dial Scroll method (M=12429ms, SD=7922ms).

Number of Target Overshoots. A four-way, repeated measures ANOVA showed a significant main effect for Pressure Mode, F(1,14) = 7.583,p < .05, and a significant main effect for Distance F(12, 168) = 2.985, p < .001 as well as a significant interaction effect for Mode x Distance F (12, 168) = 1.973, p < .05 and for Scroll Method x Pressure Space x Pressure Mode x Distance F (12, 168) = 2.246, p < .05.

In general, there were significantly more target overshoots in the conditions in which the pressure sensor was used as a brake (M=1.35, SD=0.9) than in the conditions in which it was used as an accelerator (M=1.21, SD=0.58). *Post hoc* pairwise comparisons of the number of target overshoots across all 13 Distances revealed that when selecting the target at position 310 (the distance furthest away from the top, which was on the last page of targets and could not be overshot) participants had significantly fewer target overshoots than with any of the other distances (p < .001). As can be seen in Figure 6 the Pressure Mode x Distance interaction can be explained by the fact that for the targets closer to the start of the list, the Brake mode had a much larger number of target overshoots than the Accelerator mode, though as the target distance increases, the difference between the two modes decreases.

Subjective Workload. A four-way repeated measure ANOVA on the overall workload scores for each condition showed no significant main effect for Scroll Method F(1,15) = 2.475, p = .137, no significant main effect for Pressure Space F(1,15) = 2.524, p=.133 and no significant main effect for Pressure Mode F(1,15)=3.750,p=.072. There were no significant interactions.

5.6 Discussion

The results of the second experiment were not conclusive. There was no evidence to suggest that the differences in Pressure Space (4N or 6N) or Pressure mode (Accelerator or Brake) had any effect on Movement time. However, the data do suggest that participants could perform faster with the Dial over Touch as a method to control scrolling direction, supporting H4. This mirrors the results obtained in the first study and suggests that the dial is better suited as a direction control device for these interactions.

The data also suggests that the Brake mode resulted in less accurate performance for targets that were closer to the start position. Since, by definition, the Brake mode moves very quickly for small movements when no pressure is applied, and the starting state for the condition was to have no pressure applied, then it is conceivable that for targets that are a short distance away participants are more likely to overshoot. The potential advantage of the Brake mode lies in the fact that it requires less effort to achieve higher speeds, though it comes with the trade-off of more effort to reach lower speeds. Thus, it is not clear whether this potential advantage has any merit in realistic situations due to the extra effort involved in travelling short distances. In addition there was no evidence that the Brake mode actually improved performance or reduced subjective workload for larger distances, leading us to reject H6. When using the Accelerator mode, people can always navigate to a target, albeit slowly, without needing to apply a great deal of pressure, which for short distances seems to result in more accurate performance.

6 General Discussion

6.1 Dial vs. Touch for Direction Control

With the prevalence of touchscreens, physical dials are not particularly common on modern devices. However, the results in this paper suggest that, in terms of movement time and subjective workload, they are superior to flick and drag gestures on a touchscreen for the control of scrolling direction. Numerous keyboards and mice contain small dials that are used for scrolling through content on a desktop machine, and the first generation Apple iPod featured a front mounted touch sensitive dial that was the main source of input on the device.

A dial provides the opportunity for continuous control during a scrolling task, unlike the flick and drag gestures that are used on touchscreen devices, which may be part of an explanation as to why it performed better in the studies described in this paper. However, the dial used in this study was cumbersome when mounted on the device. Future work will consider less obtrusive ways to incorporate a dial into the form factor of a tablet, such as with a flat touch sensitive dial.

6.2 Pressure Space

There were three 'pressure spaces' used across the studies presented in this paper: 9N in the first study and 4N and 6N in the second. It was observed that the 9N pressure space might have been too large for participants to comfortably apply the force required to reach the maximum speed. In response to this, the second study contained two smaller pressure spaces (4N and 6N) as well as introducing a 'brake' metaphor for speed control (alongside the 'accelerator' metaphor that was used in the first study) in an attempt to make it more comfortable to control the scrolling at higher speeds. We hypothesised that the 6N pressure space would give rise to better performance than the 4N pressure space since it would reduce the amount of force participants had to apply, while still giving a wide enough range to allow expressive use of the speed control. However, there was no evidence to suggest that the differences in pressure space had any effect on performance. It is possible that the distances travelled during the experiment were too small to allow for truly expressive use of the speed control. For some target distances, it may not have been possible to achieve maximum speed before the target was reached (or overshot). If this were the case, the effect of pressure space would be masked because the task did not require it to be fully utilised. Future work will explore this issue by evaluating the interaction techniques using tasks that are longer and more involved than targeting tasks, such as a browsing task. This will mean that the use of the techniques can be studied when the user has to navigate the collection in more detail, thus giving more opportunity to make use of the input strategies available.

7 Conclusions and Future Work

The studies presented here suggest that the bimanual scrolling techniques are better than the status-quo unimanual techniques in terms of both performance and preference, lending support to the body of evidence in HCI that the KC Model [6] is a useful tool to inform the design of bimanual interactions that allow people to carry out tasks more effectively than with unimanual equivalents. The studies also suggest that, as a method of scrolling control, the physical dial is better than conventional touchscreen gestures in both the bimanual and unimanual techniques.

As for speed control methods, the evidence suggests that using touch slider resulted in faster performance than the pressure sensor, however participants favoured the pressure sensor in terms of subjective workload, implying they found it easier to use. There was no evidence to suggest that either had an effect on target overshoots. We proceeded by investigating how different configurations might improve performance with the pressure sensor with no clear results. No particular configuration came out as better than the rest, and the average movement time across all conditions was higher (M=13s, SD=7.5) than the first experiment (M=10s, SD=5.5s). However, since each study used different participants and the second had more conditions, we cannot compare the results of the two studies directly. In future work we will look more closely at the different pressure configurations and in such a way that allows us to compare them to the touch speed control method we used.

In conclusion, the studies presented in this paper suggest that splitting the control of scrolling speed and scrolling direction across two hands is a viable way to scroll on a tablet, which could support simultaneous two-handed input while the user is holding the device.

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