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RESEARCH ARTICLE



Image orientation and contents influence pointing movements on touch sensitive screens: a kinematic analysis

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ABSTRACT

Given the increasing use of touch-screens, the impact of *images* of objects upon cursor positioning were examined. As objects may present compatible and conflicting cues for movement, we examined the influence of relevant and irrelevant cues on responses when pointing to images on touch-screens. An experiment (N=24) examined leftwards or rightwards pointing movements to *images* of large or small cups with handles that could be compatible or incompatible for grasping and were depicted as full or empty. Handle compatibility only benefited response latencies for empty cups, and this effect was reversed for small cups. Kinematic analyses suggested movements were less efficient to images of cups with compatible handles. Aiming points varied with cup size and contents suggesting that handles influenced performance when they presented lower Indices of Difficulty (as per Fitts' law). Object characteristics can influence screen hot-spots, and this primarily occurs whilst the cursor is in motion.

Practitioner Summary: Although the success of computer interfaces depends upon the user's appropriate selection of menu options, the use of larger images on touch sensitive screens may confound symbolic information with depicted object properties that could then influence finger-tip placement. The present paper demonstrates image orientation influences response initiation, but depicted object properties can influence finger-tip and thus cursor placement 'in-flight'. Using asymmetrical images as targets should be avoided as they can increase the likelihood of target under/overshoot and menu mis-selections.

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Touch sensitive screens; object properties; Fitts' law; kinematic; hot spots

Introduction

Although Fitts' law (1954) is generally used to inform cursor control and screen design (MacKenzie 1992), performance also alters with variations in display (Bohan et al. 2010), controllers (Douglas and Mithal 1997; MacKenzie 2015), cursor shapes (Murata, Uetsugi, and Hayami 2013; Suzuki, Yousuke, and Ren 2005), cursor sizes (Grossman and Balakrishnan 2005; Kabbash and Buxton 1995) and orientation (Finch, Phillips, and Meehan 2008; Phillips, Triggs, and Meehan 2001). With the use of larger active screen areas, other factors are now becoming an issue.

Within computer interfaces users are now using fingers (Hoffmann and Sheikh 1991) to point to images on touch sensitive screens (Baber 1997; MacKenzie 2015) to signify their preferences (Billinghurst and Vu 2015; Kim and Lee 2023). A range of touch screen technologies are now available (Mundada, Ninave, and

Oberoi 2021). These touch screen technologies vary in size, capabilities and susceptibility to contaminants (Nam et al. 2021). As touch screens vary in size, there are concerns as to the applicability of Fitts' law (Chakraborty and Yadav 2023). Proportional scaling of target icons may pose different issues for smaller devices (Ljubic, Glavinic, and Kukec 2015; Okada, Akiba, and Fujioka 2009; Okada and Akiba 2010; Parhi, Karlson, and Bederson 2006) such as visibility and occlusion. Whereas, different effectors may now be involved when operating larger touch sensitive screens (List and Kipp 2019; Hoffman and Hui 2010; Takeda et al. 2019).

Unfortunately, some companies are deliberately seeking to nudge or confuse user choice (Brignull et al. 2023). For instance, by monitoring screen hotspots (e.g. <https://www.hotjar.com/heatmaps/click-maps/>) exploiting errors, introducing distracting elements, reducing

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required controls, shifting or providing oversized but irrelevant ‘hot’ regions (Conti and Sobiesk 2010). To understand the impact of larger images upon cursor control, the present paper systematically varied depicted objects on touch sensitive screens.

Response conflict

The nature of the relationship between a stimulus and required response can influence human performance (Alluisi and Warm 1990). Some relationships between a stimulus and the desired response are simple, straightforward and compatible, whereas other relationships between stimulus and desired response can be indirect, complex and incompatible (Reeve and Proctor 1990). Less obvious linkages between stimulus and response can contribute to slower, inaccurate and inappropriate responses (Fitts and Jones 1947; Kantowitz, Triggs, and Barnes 1990).

It seems response conflict can occur when an obvious, natural or highly practiced response competes with a *required* response that is novel, awkward, and/or less obvious (Kornblum 1992; Littman and Kalanthroff 2022). To understand such response conflict, the present paper seeks to decompose the response as it unfolds, conducting a detailed kinematic analysis of movements to *images* of an object that presents conflicting cues – namely variations in its compatibility for grasping. A kinematic analysis will allow us to document how any response conflict is resolved online during cursor placement (Dotan et al. 2019; Erb et al. 2016).

Objects and response conflict

Response conflict can occur when the available stimuli cue disparate responses. Objects have the potential to cause response conflict because objects have a variety of features (e.g. size, orientation, weight) and some of these features may not be relevant to task requirements (Kantowitz, Triggs, and Barnes 1990). Movement duration is typically influenced by factors such as required distance, accuracy (Fitts 1954), and impact (Teasdale and Schmidt 1991; Worringham 1991), however movements to objects can also be influenced by their shape (Sheikh and Hoffmann 1994), weight (Johansson and Westling 1984), handle orientation (Creem and Proffitt 2001), and intended use (Bub, Masson, and van Mook 2018; Rosenbaum et al. 2012). Users need to resolve any potential conflict to prevent clumsiness and apraxia (Worthington 2016).

Objects with handles provide a mechanism for probing such response conflicts (Creem and Proffitt 2001).

Cups do not just vary in size, but possess properties such as handle orientation and contents and such images online have been previously shown to affect overall performance within graphical user interfaces (Phillips, Van Gemmert, and Hughes 2024). However, as this study only reported ‘total time’ and hotspot locations, the precise causes of these effects are unclear.

The present study

There is concern that some websites seek to confuse and misdirect users, placing nuisance apps in high traffic areas of a webpage. For instance, placing a green ‘Go’ arrow (linking to an online casino) next to the Search icon thus capitalising on cursor overshoot or screen refresh. With such misleading practices, marketing has been taking precedence over ‘web usability’ (Nielsen 2000). Unfortunately, some web designers continue attempts to confuse, nudge and influence users (Brignull et al. 2023; Conti and Sobiesk 2010; Phillips, Chow, et al. 2024).

Hence our previous interest in the impact of flanking objects (Carr, Phillips, and Meehan 2008) upon cursor positioning and a consideration of the benefits of multi-layer displays (Carr, Meehan, and Phillips 2006). Research has studied the impact of asymmetric cursors (Finch, Phillips, and Meehan 2008; Phillips, Meehan, et al. 2003; Phillips, Triggs, et al. 2003), and targets (Phillips, Triggs, and Meehan 2004; Sheikh and Hoffmann 1994). Our unpublished work examined images of glasses of beer on a larger touch sensitive screen, indicating that points of aim varied with glass contents. The use of a coffee cup allows us to further consider the impact of flankers (e.g. handles) or asymmetrical targets (and their ‘contents’) upon positioning movements within Graphical User Interfaces.

There are specific properties of cups that may influence movement trajectories and precision. Any effects could be attributable to variations in precision requirements (Fitts 1954; MacKenzie 1992). Images of larger objects enhance responses involving power grips and images of smaller objects benefit precision grips (Guerineau et al. 2022; Heurley et al. 2020). Movements to larger targets should be faster. In addition, the handle could serve as a target, or as a flanking object to be avoided (Hoffmann and Sheikh 2012; Tipper, Howard, and Jackson 1997; Welsh, Elliott, and Weeks 1999), influencing an actor’s required reach.

However, the intended uses of objects (Bub, Masson, and Cree 2008; Bub, Masson, and van Mook 2018; Rosenbaum et al. 2012) can also influence the point of aim and the nature of the grasp (Wagman, Caputo, and

Stoffregen 2016). As the contents of cups can vary (Bub, Masson, and van Mook 2018), this can pose additional constraints upon movement that may need to be resolved (Cavallo et al. 2016). In particular, cups do not just have handles that afford grasp, they also have properties (Neupärtl, Tatai, and Rothkopf 2021) such as contents that can alter rotational inertia (Kunde, Müsselar, and Heuer 2007; Wagman and Carello 2003) and influence premovement planning (Schneider, Buckingham, and Hermsdörfer 2019) and ongoing movement kinematics as a function of intended use (Cavallo et al. 2016). Hence a full cup may influence movement: affording 'drinking' (Cavallo et al. 2016) or alternatively 'spilling' if hit (Teasdale and Schmidt 1991).

The present study extended Philips, Van Gemmert and Hughes (2024) probing the effects of cup size, handle orientation, and cup contents. As far as the computer is concerned, the S-R contingencies of the task require that a participant drags a cross-hair cursor to a 5 cm or 10 cm square. However, participants are instructed to 'point to the cup'. The cup is an image possessing features that are irrelevant to S-R contingencies of the task as required by the computer (see Table 1), but those features may still influence responding.

Indeed, this is analogous to the underlying paradigm during Human Computer Interaction. People point to icons or images on the screen. These icons and images actually signify a (x1y1, x2y2) area used to identify application selection, but the actual features of these icons and images are irrelevant except as signifiers of specific menu options (see Table 1).

In the present study, these images have handles that point left or right. During leftwards movements, a handle that points right is compatible for 'grasping'. During rightwards movements, a handle that points left is compatible for 'grasping'. Such image compatibility effects have been demonstrated previously.

However Phillips, Van Gemmert, et al. (2024) used Qualtrics to collect their data and only considered total time and accuracy. This measure of total time was recorded over the internet and conflated preparation and execution. Therefore, the study required replication and extension. A comparison of response latencies with subsequent movement kinematics could be informative (Knol et al. 2017; Langridge and Marotta 2022), indicating whether such effects influence preparatory processes or the hand in flight (Till et al. 2014).

A dragging and pointing response to an image on a screen (Chaston, Thomas, and Niechwiej-Szwedo 2024), does not require manipulation of an object, but an image of an object may nevertheless elicit meaningful effects (Azaad, Laham, and Shields 2019;

Schwartz and Plass 2014) such as compatibility (Littman and Kalanthroff 2022). We hypothesised that task irrelevant cues such as handle orientation would influence response latencies. In addition, if images of objects automatically prime motor responses, it was expected that cup handles compatible for grasping would elicit more direct and more efficient movements (i.e. having fewer cycles of acceleration and deceleration) (Flash and Hogan 1985; Jagacinski et al. 1980). Even though other features of a cup such as contents and handle orientation were irrelevant when pointing to an image, compatibility effects were expected to influence movement endpoints.

The present study systematically investigated the impact of task-irrelevant features such as handle orientation and contents upon a task requiring left or right movements pointing to an image of a cup. Although the task involves a simple drag and finger positioning movement, it was predicted that task irrelevant information in the image such as handle orientation and cup contents would create response conflict influencing response preparation, movement duration, efficiency and accuracy. A detailed kinematic analysis of pointing movements could indicate the degree to which such movements are simple and 'automatic' or involve more complex trajectories during execution (Gallivan et al. 2018; Johansson and Westling 1984; Tipper, Howard, and Jackson 1997; Welsh, Elliott, and Weeks 1999).

Method

Participants

There were 24 right-handed participants (10 males and 14 females), with a mean age of 26.71 years (SD = 10.44) and normal or corrected to normal vision. The experiment was conducted in accordance with the Declaration of Helsinki and ethical guidelines approved by Auckland University of Technology's ethics

Table 1. Stimulus-response contingencies during the present experimental task, and during human-computer interaction (HCI).

Experimental task		During HCI	
Computer requires	Movement to 5 or 10 cm square	Computer requires	Movement to an image/icon
Instructed	Point to the cup	User selects	Points to image/icon
Relevant cues	Movement amplitude Target width Direction	Relevant cues	Movement amplitude Target width Direction
Irrelevant cues	Handle orientation Cup contents Cup shape Cup colour	Irrelevant cues	Icon/image.... Contents Shape Colour

committee (AUTEC 21/40). Participants provided informed consent in writing, and were compensated with a NZ\$20 voucher for their time. Phillips, Van Gemmert, et al. (2024) reported the weakest interaction involving handle compatibility as having an η^2 of 0.11 which equates with a Cohen's f of .35. According to Gpower, we would need $N=10$ for an 80% chance at the .05 level of significance to detect a Cohen's f of .35.

Apparatus and task

Images used were identical to those of Phillips, Van Gemmert, et al. (2024). The task was conducted on an ACER 23.8" (60cm) all-in-one computer and touch sensitive screen. The screen refreshed at 60Hz and had a 1920×1080 resolution and images were 96DPI resolution, and were in RGB colour mode. Luminance was at 100%, but this was to enhance contrast, given that during data collection the screen background was black.

Stimulus presentation, data collection and analysis were conducted by the program WinPad. The computer screen was oriented vertically and presented a 6mm square white start target situated at the bottom centre of the screen (i.e. 20% from bottom). Participants were seated. Touching the screen controlled the movement of a green crosshair cursor. Images of coffee cups (see Figure 1) were presented as targets 35% to the left or right of screen centre. Images of coffee cups were created from photos in Microsoft Paint, but were basically the same image, simply being repositioned or rotated, with their size manipulated by a transform in MicroSoft Paint, or the 'coffee' edited out.

The images of small cups were 50x50mm and the large cups were 100x100mm. Cups were located as percentages of screen size and situated 70mm from screen bottom and 35% from screen centre, and corresponded to visual angles of about 9° or 18°. The centre of each image was in the shading at the bottom edge of the cup lip. Movements started in the middle of the computer screen (i.e. 50%) and travelled to 15% or 85% of the screen. These equate with horizontal movements of 18.5cm across a touch screen (approximately the median distance for cursor movements).

Touch sensitive screens require touch to register xy coordinates. Therefore, to enable us to perform kinematic analyses, a dragging motion was required. This is in keeping with ongoing human computer interaction where the computer mouse shifts the cursor, or users drag a cursor to a target icon. Dragging takes slightly longer than pointing (Whisenand and Emurian 1999).

Participants were required to use their fingertip on the touch sensitive screen to control the location of a crosshair cursor. Participants were instructed to drag their finger quickly and accurately to the picture of the cup. The task entailed moving their fingertip from a central start location to point to the image of the cup while keeping their finger on the touch screen. Speed and accuracy were emphasised by immediate knowledge of results and demonstration of kinematic analyses during practice.

A 2x2x2x2 factorial design varied Cup Size, Cup Contents, Direction of Movement, and Handle Orientation. To examine the compatibility of handle with direction of motion, the Direction of Movement and Handle Orientation were collapsed into handles that were Compatible or Incompatible for grasping (see Table 2).

Table 2. Types of trials in the experiment and the collapsing of direction of movement and handle orientation into handle compatibility.

	Cup size	Cup contents	Direction of movement	Handle orientation	Compatible for grasping
1	Big	Empty	Leftwards	Leftwards	Incompatible
2	Big	Empty	Leftwards	Rightwards	Compatible
3	Big	Empty	Rightwards	Leftwards	Compatible
4	Big	Empty	Rightwards	Rightwards	Incompatible
5	Big	Full	Leftwards	Leftwards	Incompatible
6	Big	Full	Leftwards	Rightwards	Compatible
7	Big	Full	Rightwards	Leftwards	Compatible
8	Big	Full	Rightwards	Rightwards	Incompatible
9	Small	Empty	Leftwards	Leftwards	Incompatible
10	Small	Empty	Leftwards	Rightwards	Compatible
11	Small	Empty	Rightwards	Leftwards	Compatible
12	Small	Empty	Rightwards	Rightwards	Incompatible
13	Small	Full	Leftwards	Leftwards	Incompatible
14	Small	Full	Leftwards	Rightwards	Compatible
15	Small	Full	Rightwards	Leftwards	Compatible
16	Small	Full	Rightwards	Rightwards	Incompatible

Procedure

Participants seated themselves at a comfortable distance (i.e. about forearm length) from the touch sensitive screen. Targets were 20cm above the desk. Each trial began when the computer sent a message asking participants to drag their finger to the centrally located start target. Once a participant's finger was within the start target, the experimenter triggered a trial. The computer then presented an auditory imperative signal, and an image of a cup to the left or right of the screen. Participants were required to point to the cup. Data recording ended 500ms after the cursor entered the image of the coffee cup.

Participants were given 16 practice trials to familiarise themselves with the task. They were then shown that the apparatus recorded speed and accuracy of performance. Participants then completed 6

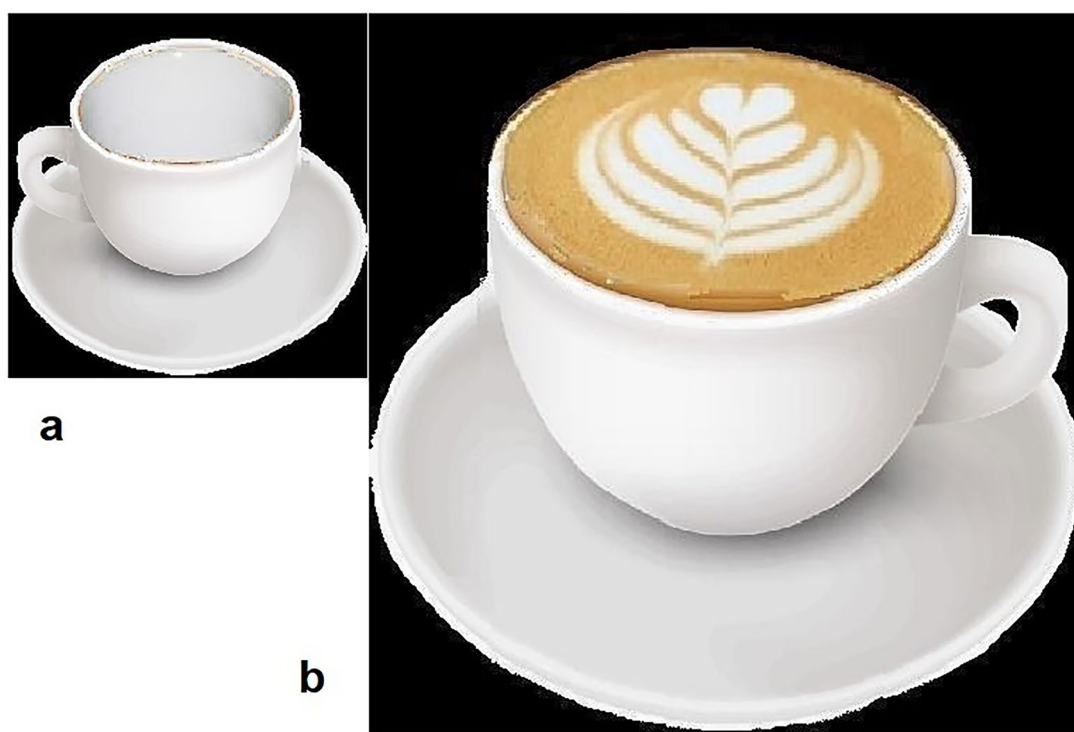


Figure 1. (a) Small, empty cup with handle compatible for grasping when moving from the left. (b) Large, full cup with handle incompatible for grasping when moving from the left.

blocks of 16 experimental trials. A block of experimental trials quasi-randomly presented every combination of cup size (Big, Small), contents (Empty, Full), handle orientation (Left, Right), and direction of motion (Left, Right). For analysis, handle orientation and direction of motion were collapsed into Compatible and Incompatible for grasping: when moving the cursor right, a leftwards pointing handle would be compatible for grasping; and when moving the cursor left, a leftwards pointing handle is incompatible for grasping. Thus, each condition of the 2x2x2 design was based upon 12 trials (see Table 2).

Analysis

Fingertip location (X, Y coordinates) from the touch sensitive screen was oversampled at 200 Hz (Weitkunat 1991) and low-pass filtered (8 Hz cutoff) using a recursive, dual pass, second order Butterworth filter. To produce velocity and acceleration profiles, coordinates were then double differentiated using 9-point central finite differences (Teulings and Maarse 1984). These procedures remove high frequency artefacts such as finger tremor and electric jitter (see Teulings and Maarse 1984; Weitkunat 1991) which was confirmed through visual inspection. Then after checking each trial, features of interest were determined using automatic algorithms that had previously been calibrated

against human measurements during interactive computer graphical analysis.

Response latency – served as an index of preparatory processes. Response latency measured the period of time between imperative signal and movement onset as indicated by a change in XY coordinates.

Movement duration – provided an index of movement execution. Movement duration was the period between movement onset and movement cessation within the target as indicated by an absence of changes in XY coordinates.

Movement Accuracy – to determine aiming points, the distance of the movement endpoint in X and Y coordinates was recorded from the centre of the image at movement cessation.

Movement Inefficiency – the number of submovements and cycles of acceleration and deceleration were determined by counting zero crossings in the X velocity and X acceleration functions. Analyses focussed upon the X dimension, because the participant was required to point either to the left or right of screen centre. Movement Inefficiency was estimated by dividing the number of cycles of acceleration and deceleration by the number of zero crossings in the X velocity function. The Movement Inefficiency metric indicates the number of cycles of acceleration and deceleration per submovement. Crossman and Goodeve (1983) considered such measures to indicate feedback guided

amendments to movement trajectories. Higher values of the Movement Inefficiency index indicate more hesitation and trajectory amendments, whereas lower values indicate a more ballistic movement.

This was a Cup Size (Big, Small) by Handle Compatibility (Compatible, Incompatible) by Cup Contents (Empty, Full) design. The underlying assumptions of ANOVA were tested. Data were then analysed by separate 2x2x2 repeated measures Analyses of Variance (ANOVA). Data is available from the corresponding author upon reasonable request.

Results

Response latency

ANOVA considered response latencies. The main effects of Handle Compatibility ($F(1,23) = 0.117, p = .736, \eta^2 = .01$), and Cup Contents ($F(1,23) = 0.591, p = .450, \eta^2 = .03$) were not significant. However, there was a significant main effect of Cup Size ($F(1,23) = 23.462, p < .001, \eta^2 = .51$). Even though the large cup should be the easier target, people were slower initiating responses to the large ($M = 632.35 \text{ ms}, SE = 14.58$) than the small ($M = 614.35 \text{ ms}, SE = 15.28$) cup. The interaction between Cup Size, Cup Contents and Handle Compatibility was significant ($F(1,23) = 6.017, p = .022, \eta^2 = .21$) (see Figure 2). This three-way interaction was decomposed into its component two-way Size by Compatibility interactions. The simple Size by Compatibility interaction was significant when the cups were Empty ($F(1,23) = 6.063, p = .022, \eta^2 = .21$), but was not significant when the cups were Full ($F(1,23) = 1.013, p = .978, \eta^2 = .02$). This indicates a potential compatibility effect for Big Empty cups.

Simple main effects were used to interpret the Size by Compatibility interaction for the Empty cups. The simple effect of Compatibility was significant for Big Empty cups ($F(1,23) = 7.571, p = .011, \eta^2 = .25$), but was not significant for Small Empty cups ($F(1,23) = 3.380, p = .079, \eta^2 = .13$). It seems handle compatibility is important for planning purposes, but only when dealing with big empty cups. As will become apparent in other analyses, participants appear to be less careful or ignore the incompatible handle and aim instead for the body of the small cup.

Movement duration

As expected there was a significant main effect of Cup Size upon movement duration ($F(1,23) = 33.425, p < .001, \eta^2 = .59$). Participants were faster moving to a big cup ($M = 1050.11 \text{ ms}, SE = 29.98$) than a Small cup

($M = 1086.75 \text{ ms}, SE = 30.26$). However there was also a significant Cup Size by Cup Contents interaction ($F(1,23) = 5.987, p = .022, \eta^2 = .21$) that may be seen in Figure 3. For Empty cups, movement durations varied significantly as a function of cup size ($F(1,23) = 13.122, p = .001, \eta^2 = .36$), but not for Full cups ($F(1,23) = 1.382, p = .252, \eta^2 = .06$). The full cups imposed additional constraints upon movement, such that movement times were comparable for big and small cups.

Inefficiency

Inefficiency of movement trajectories was determined from the ratio of the number of accelerative/decelerative impulses per movement, which served as an index of the hesitancy of movement (Phillips, Stelmach, and Teasdale 1991). The impact of spillability can be seen in the significant effect of Cup Contents upon the Inefficiency of movements ($F(1,23) = 7.178, p = .013, \eta^2 = .24$). Movements seemed more efficient to Full cups ($M = 4.96, SE = 0.18$) than Empty cups ($M = 5.17, SE = 0.21$).

However, the efficiency of movement trajectories varied within the significant three way interaction between Cup Size, Cup Contents, and Handle Compatibility ($F(1,23) = 13.643, p < .001, \eta^2 = .37$) (see Figure 2). To interpret this interaction, tests of the simple two-way interactions were performed separately for Big and Small cups. For Big cups the interaction of Cup Contents and Handle Compatibility was not significant ($F(1,23) = 1.328, p = .261, \eta^2 = .06$), while the Content by Compatibility interaction was significant for Small cups ($F(1,23) = 8.459, p = .008, \eta^2 = .27$). For Empty cups, the simple main effect of handle compatibility was significant ($F(1,23) = 6.854, p = .015, \eta^2 = .23$), but not for Full cups ($F(1,23) = 1.137, p = .297, \eta^2 = .05$). This indicates handle compatibility was less important for the trajectories of movements to small empty cups.

Higher values of the inefficiency index imply more amendments to movement trajectories. Movements required more amendments to cups with compatible handles (viz., small empty or big full cups). Lower values of the inefficiency index suggest fewer amendments of movement trajectories and more ballistic movements. The more efficient movements occurred to small, empty cups with incompatible handles and to big full cups with incompatible handles. As movements are more efficient for cups with incompatible handles, this implies that people sometimes ignore the incompatible handles (see Figure 2).

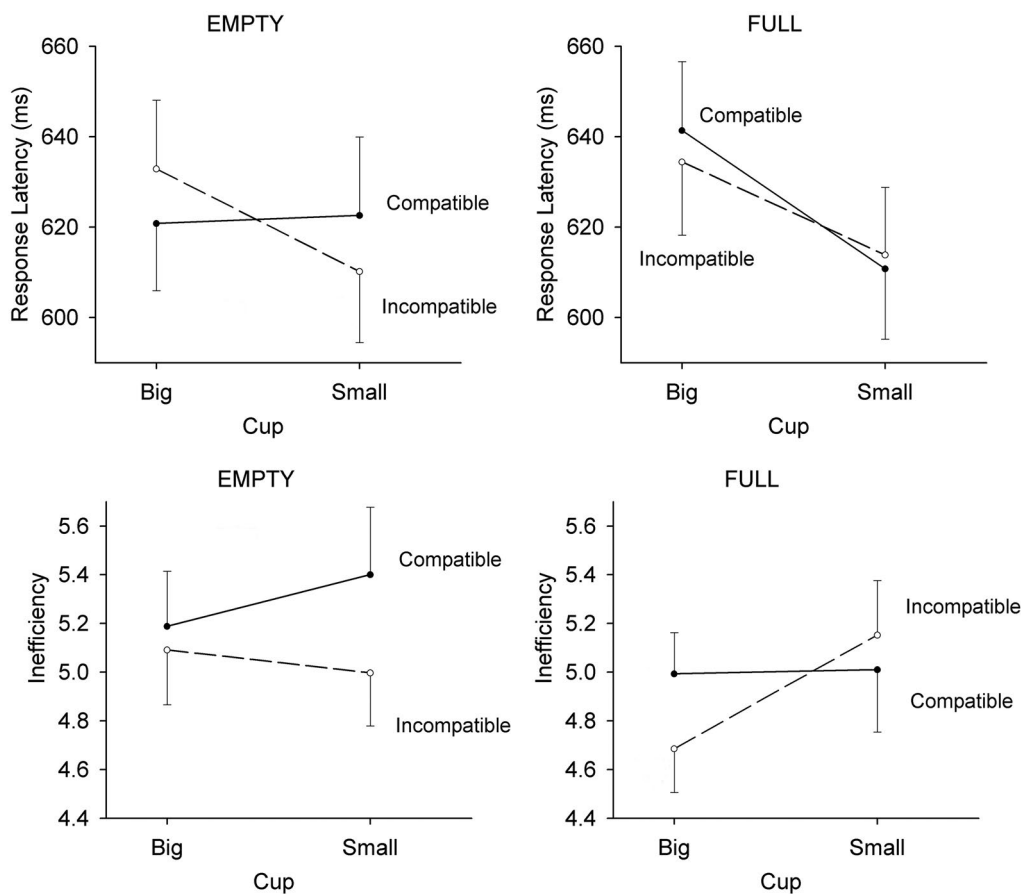


Figure 2. The significant 3-way interactive effects of Cup Size, Cup Contents, and Handle Compatibility upon Response Latency and Inefficiency (cycles of acceleration/deceleration per submovement) (error bars represent one Standard Error).

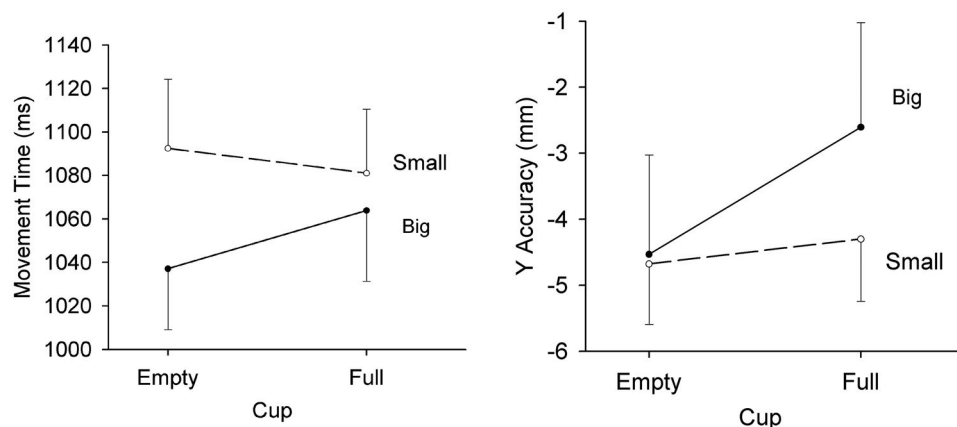


Figure 3. Cup Size has a significantly greater effect upon Movement Time for Empty Cups, but a significantly greater effect upon accuracy along the Y axis for Full Cups (error bars represent one Standard Error).

X accuracy

Accuracy of finger placement was analysed along the X dimension. There was a significant main effect of Cup Size ($F(1,23) = 34.461$, $p < .001$, $\eta^2 = .60$). People undershot and were less accurate when positioning their finger on Big ($M = -4.30$ mm, $SE = 2.05$) than Small

($M = 2.55$ mm, $SE = 1.74$) cups. There was also a significant effect of Handle Compatibility ($F(1,23) = 9.200$, $p = .006$, $\eta^2 = .29$). People undershot their positioning movements more when handles were compatible ($M = -1.97$ mm, $SE = 1.79$) than when incompatible ($M = 0.22$ mm, $SE = 1.91$). However, the Cup Contents by

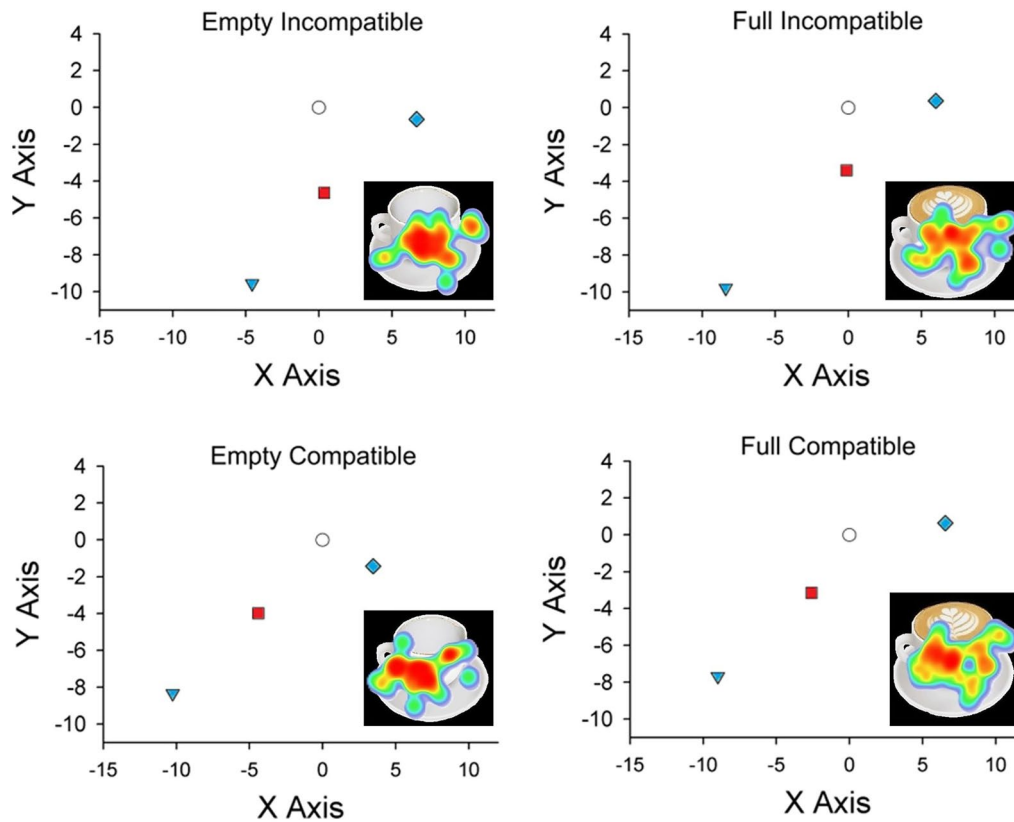


Figure 4. Heatmaps and associated interquartile ranges of movement endpoints in mm (blue triangle 25%, red square 50%, and blue diamond 75%) around the cup centre (denoted by open circle). A cup handle that is compatible for grasping encourages undershooting of movements (leftwards shift). A full cup alters the point of aim (upwards shift).

Handle Compatibility interaction was not significant ($F(1,23) = 3.838$, $p = .06$, $\eta^2 = .14$). Although movement endpoints tended to undershoot when the handle was compatible, the tendency to undershoot was greater when the cup was empty (see Figure 4).

Y accuracy

Accuracy of finger placement was examined along the Y dimension. There was a significant effect of Cup Contents ($F(1,23) = 11.194$, $p = .003$, $\eta^2 = .33$). People pointed closer to the top of a full cup ($M = -3.45$ mm, $SE = 1.22$) than an empty cup ($M = -4.61$ mm, $SE = 1.15$). The effect of Handle Compatibility was also significant ($F(1,23) = 6.850$, $p = .015$, $\eta^2 = .23$). People pointed closer to the top of a compatible ($M = -3.58$ mm, $SE = 1.18$) than an incompatible ($M = -4.48$ mm, $SE = 1.20$) handle.

There was also a significant interaction between Cup Size and Cup Contents ($F(1,23) = 5.330$, $p = .03$, $\eta^2 = .19$) that may be seen in Figure 3. To interpret the interaction, simple main effects considered the effect of Cup Size. There effect of Cup Size was not significant when cups were empty ($F(1,23) = 0.047$, $p = .829$, $\eta^2 = .00$), but there was a significant effect of

Cup Size when cups were full ($F(1,23) = 6.382$, $p = .019$, $\eta^2 = .22$), aiming closer to the top of a big full cup (see Figure 4).

Discussion

The present study examined problems posed by the use of screen images providing conflicting object cues to action, and examined their resolution as actions unfold. Asymmetric targets such as cups can influence points of aim. There were handle compatibility effects for large, empty coffee cups, but these effects could be subsumed by other factors such as object size and contents. As cups and handles became smaller, the handle became less important, trajectories became more ballistic, and the body of the cup seemed to emerge as the preferred aiming point. When the cup was full, the point of aim was higher, possibly to adjust for apparent torque or spillability, and handle compatibility became less important and trajectories were more ballistic.

Compatibility

In the present experiment, a handle that was compatible for grasping influenced response latencies, but only for empty cups. This finding replicates Phillips, Van Gemmert, et al. (2024). They performed a cursor placement task over the internet using mouse or touch sensitive screen. Recording total time, they found cup handles and contents influenced cursor placement. Compatibility effects were observed for empty cups, but these effects reversed for full cups and seemed to depend upon Index of Difficulty (Fitts 1954). Our more sensitive kinematic analysis replicates and extends those of Phillips, Van Gemmert, et al. (2024): – indicating effects upon preparatory processes when cups are empty, and changes in movement execution when cups are full. Conceivably, movement trajectories have been influenced by cup contents (Hoffmann and Sheikh 1994; MacKenzie and Buxton 1992) or object properties (Yamamoto, Incera, and McLennan 2016), with the handle sometimes serving as a distractor.

Fitts' law

Using an information theoretic analogy, Fitts' law considers the geometric relationship between movement amplitude (A) and target width (W) (Fitts 1954). It has been shown that there is a linear relationship between movement duration and an index of movement difficulty. The index of difficulty (ID) is expressed as a logarithm of the ratio of the required movement amplitude to the width of the target, such that $ID = \log_2(2A/W)$.

As a target, the body of the large empty cup presents an Index of Difficulty (ID) (Fitts 1954) of 2.5. According to Gan and Hoffmann (1988) movements cease being 'ballistic' somewhere between the ID of 3 and 4. As the present study required movements of around 18.5 cm, the likely transition occurs around $ID = 3.8$ (see Gan and Hoffmann 1988, Figure 1). Movements to the body of the large cup pose an ID of 2.5 and would lay within the ballistic range (see Table 3), whereas the handle of the large cup presents an ID alternating between 4.3 and 4.87 depending upon its orientation. By contrast, the body of the small cup poses an ID of 3.6, which is within the ballistic range (Gan and Hoffmann 1988), however a compatible handle presents with an ID of 5.46, and an incompatible handle has an ID of 5.73. The body of the smaller cup is thus a more convenient target than its handles (Kroemer 1986). Our Inefficiency measures indicate that the big full incompatible cup, and the small incompatible cup had more efficient movements,

implying for these conditions that the point of aim was changing from the cup handle to the cup body.

Movement accuracy

As compatible handles present the most convenient option for grasping, it might be expected they would automatically afford the fastest and most ballistic movements (Tucker and Ellis 1998). Instead, a reverse pattern has been observed, with the shortest response latencies and most efficient movements occurring for the small empty cups with handles that are incompatible for grasping. This probably occurs because people are envisaging a different grasp (Kroemer 1986) and taking less care with the small target.

While Fitts' index of difficulty considers the geometric relationship between movement amplitude and target width, in practice people's movement accuracy and endpoints vary. Therefore the effective movement width (Welford 1968, p. 147) can apply a realistic correction that reflects observed performance. Assuming that movement endpoints are normally distributed, and allowing for 4% movements to lay outside the target, then the effective target width is $4.133 \times SDx$.

Calculating the effective ID indicates the large cup has an effective ID of 2.67 that is comparable to the theoretical ID of 2.5 (see Table 3). However, while the small cup has an effective ID of 2.78, its theoretical ID is 3.6 (see Table 3). The greater mismatch between effective and theoretical ID for the small cup indicates that people were taking appreciably less care when moving to the small cup.

Context

The present experiment demonstrated that a compatible handle does not simply 'afford' or automatically prime reaching movements irrespective of context. Instead, as cup handles vary in size, they cease to be suitable targets for ballistic movements (Kroemer 1986). Similarly, as the (virtual) contents of a cup varies, the significance of the handle changes. A full cup imposes torque on the handle and points of aim vary accordingly. In another words, a large empty cup presents participants with a more symbolic task, but as the cup becomes smaller, or is full then additional

Table 3. Indices of difficulty according to Fitts' law.

Index of difficulty	Large	Small
Cup body	2.5	3.6
Compatible handle	4.3	5.46
Incompatible handle	4.87	5.73

constraints assume a greater importance (Rosenbaum et al. 2012; Wagman, Caputo, and Stoffregen 2016), such as the magnitude of impact forces on the target (Petrič et al. 2017; Teasdale and Schmidt 1991; Worringham 1991).

While drawing on their own experience of the natural world to select points of aim (Neupärtl, Tatai, and Rothkopf 2021), participants simplified the task, selecting more convenient aiming points, but the need for such choice influenced response latencies. It took longer to initiate movements to the larger cup where there was more 'choice' of aiming point. Indeed, handle compatibility imposed additional burdens upon pointing movements. *Cursor movements were actually less direct and ballistic when pointing to empty cups with compatible handles.*

The present study indicates that as behaviour transitions from traditional buttons and microswitches to targeting objects, there is a shift from purely symbolic effects to incorporate physically important aspects of a task. When the task was more 'symbolic' (empty cups), compatibility effects were observed, but when movement precision was more salient there were fewer differences in response latencies. An insensitivity of reaction times to differences in Index of Difficulty has been demonstrated previously (Fitts and Peterson 1964). Indeed, as object properties became more salient the points of aim were selected on the basis of intuitive physics (Neupärtl, Tatai, and Rothkopf 2021). This demonstrates the hierarchical nature of response selection as a function of task priorities (Rosenbaum et al. 2012; Wagman, Caputo, and Stoffregen 2016). Similar occurs during a sequence of cursor placements (Tang et al. 2018). It is likely that during such selections, determining an aiming point requires the resolution of the 'figure' part of an object (e.g. controller) from the 'ground' (e.g. surrounding control panel). (Kantowitz, Triggs, and Barnes 1990). Such decisions likely occur as a function of discriminability (Worringham and Kerr 2000) and economic considerations (Rosenbaum et al. 2012).

Limitations

Nevertheless, it is likely that there will also be differences in response speed as a function of direction of cursor movement, distance (Whisenand and Emurian 1999), screen orientation (Phillips, Triggs, and Meehan 2005) and cursor control device (MacKenzie 1992; Stevenson, Phillips, and Triggs 2004). Although Phillips, Van Gemmert, et al. (2024) demonstrated little difference between Mouse and Touch Screen, they found response latencies were longer with a Mouse, possibly due to problems mapping the coordinate system

generated by mouse (e.g. gain, orientation) to the coordinate system of the display (Phillips, Triggs, and Meehan 2005; Phillips and Triggs 2001).

Implications

As computer interfaces have evolved from command prompts and menus to icons and larger active screen areas (Baber 1997; Nielsen 2000), usage has changed from the more symbolic to increasingly natural forms of option selection. The present paper indicates that as icons develop into larger images, people will be selecting an aiming point on images from their previous natural experience. Images are not neutral rectangular screen areas, and are affected by task requirements (Gillan et al. 1992), hence there will be preferred points of aim and areas where hot-spots and under/overshooting are more common. As Phillips, Van Gemmert, et al. (2024) demonstrated, image characteristics such as handles or adjacent labels can bias cursor aiming points. However, the present study indicates such complex images are more likely to influence cursor motion 'in flight'. Hopefully designers will take note of these issues when creating websites for the purposes of *usability*, rather than impolitely (Whitworth 2005) seeking to capitalise on user error to increase click-throughs and forced sales (Brignull et al. 2023; Conti and Sobiesk 2010).

Conclusions

Phillips, Van Gemmert, et al. (2024) demonstrated images of coffee cups influenced cursor placement over the internet, but simply examined total times required. The present study used similar stimuli, but a kinematic analysis allowed a replication and separate estimates of the influence of images upon response preparation and execution.

Although the computer merely required the cursor to stop within an area of the screen, participants reacted to images of empty cups differently to full cups. Preparatory processes only took into account the compatibility of the handles of big empty cups, and movement execution only responded to the width of empty cups. Cursor trajectories suggested that people ignored incompatible handles, and movement endpoints indicated that people undershot their movements to compatible handles and aimed closer to the top of full cups.

Although it could be considered that people reacted to the 'affordances' offered by these images, a handle does not automatically afford grasping, as perceived cup contents also provide a context that influenced movement trajectories (Bohan 2003). Conceivably

experience with real objects is influencing people's movement trajectories and aiming points.

People responded to the empty cups in a more symbolic manner, but seemingly treated full cups with more care. At the very least, providing asymmetric images within graphical user interfaces encourages biases in responding and changes points of aim and likely areas of error. Asymmetric images should be avoided, or care should be taken when placing critical icons in the flanking surrounds. Designers may need to be aware of such tendencies (Nielsen 2000). Otherwise the user-perceived aiming points and task-simplification may have unexpected consequences for designers that generate common types of recurring errors that users will find annoying (Whitworth 2005).

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Authors' contributions

CRedit: **James G. Phillips:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing; **Arend W. A. Van Gemmert:** Conceptualization, Formal analysis, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing; **Barry Hughes:** Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Resources, Writing – original draft, Writing – review & editing; **Alison J. Phillips:** Data curation, Investigation, Methodology, Visualization.

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Data availability statement

Data are available from the corresponding author upon reasonable request. Data associated with this manuscript is available from <https://osf.io/rq6wt/>.

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