A Study of Tweetris - Eliciting Unconstrained Whole Body Interaction During an Art Event

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ABSTRACT

We present an in-depth analysis of player interaction with a whole-body videogame during an all-night art festival. *Tweetris* is a Kinect-based two-player game described as a combination of Tetris, yoga and Twitter. Both players are presented with a random tetromino from the game Tetris, and must race to match the shape of their body to the given tetromino. During the event, we collected over 6000 winning body shapes from more than 270 players in two locations. We study player behaviour using a new method we introduce, the *Low-Fidelity Elicitation Protocol*. We classify and analyze successful player strategies as design input for whole body interactive systems, and present results illustrating how small differences in physical environment can impact user behaviour.

ACM Classification Keywords

H.5.2. User Interfaces: Interaction styles

Author Keywords

Tetris; Kinect; Whole Body Interaction

INTRODUCTION

With the release of the relatively inexpensive Microsoft Kinect [13], whole-body interaction (WBI) may become increasingly mainstream. While it is relatively easy to treat a hand as analogous to a mouse cursor, this ignores that we can now use the *whole body as input*. There are some projects that explore using the whole body, but these are design instances and do not explore the space of possibilities in detail [12, 18]. If the whole body is to be taken as input, we must explore configurations beyond the user being attentively seated or standing in front of the interface. This freedom may mean that the user may be multi-tasking, either cognitively or physically. To this end, we must understand WBI in the context of a wide variety of body postures and real-world constraints. In some cases, hands might not be available, or possibly supporting the body's current position. Designers of WBI systems need to get a sense of how users can and will interact, given current posture and other properties of their physical environment.

Figure 1. Two players playing Tweetris in the back of a van.

This work examines the behaviour of the players of Tweetris, a WBI video game, during an all-night art event: *Nuit Blanche* [17]. The gameplay in Tweetris requires users to contort their bodies into unusual shapes to match the outline of tetrominos consisting of four squares, as found in the game Tetris (Figure 1). It is important to note that the position of individual body parts is *unconstrained* – players can create the shape with any body configuration they want, and we do not require individual body parts to be in a particular position. Our main contribution is our study of *how* players configured their bodies during the game. We conducted a brute-force analysis of player behaviour during the event, where over 270 players made over 6000 body configurations.

The experience of being at an art event, and being required to quickly go through a series of body configurations, is unlike any situation found in a "lab" or "home" setting. However, watching how players behave can help us understand how to design interaction for bodies that are in awkward or unusual configurations. In everyday life, excluding when we are seated in front of a computer, our body takes on many different configurations and postures. It is not surprising that interaction while in an unconventional body configuration has not been studied significantly – it has only recently become feasible to interact with digital systems this way outside of the research laboratory. If whole body or gestu-

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ral interaction becomes integrated into our work and living spaces, we will need to contend with a range of human and environmental factors in design. For example, imagine that your legs are sore from running, you need to reach out with a hand to stop your young child from going down the stairs, and a delivery requiring a signature arrives all at the same time. If you could engage with a gestural interaction system to open the door, how should this kind of interaction be designed? While this may sound like an extreme example, in our everyday lives we are often in postures that are sub-optimal for interaction with digital systems [15]. We cannot assume the convenience that potential users of WBI devices will always be standing in space cleared of obstacles, torso facing the camera, with both hands available.

With the goal of studying the range of expression of whole-body interaction, we have effectively invented a new interaction elicitation protocol during our study of Tweetris - the *Low-Fidelity Elicitation Protocol*. This is in comparison to previous study protocols such as Wizard of Oz or User-Defined Gestures [19]. In our protocol, participants are presented a series of low-fidelity "outlines" of body configurations, and are not given any constraints to complete the configuration. There is no metaphor or high-level goals given to the users, other than creating gestures as quickly as possibly. When the participant is quickly performing gestures without consideration or meaning, it allows them to experience the flow state [4]. When an expert is using an interface they are familiar with, they will also be in the flow state. By encouraging this behaviour in novice users, we are better able to observe expert-like behaviour without experts.

Unlike conventional forms of input, unconstrained WBI has an extremely high number of degrees-of-freedom. In Tweetris, some of the shapes players have to conform to are more awkward, while some are less so. There are also environmental factors that could affect player behaviour. We are curious to discover, first, under what conditions what behaviour is predictable, and second, when players are predictable, what do they do?

TWEETRIS

Tweetris was developed as an interactive art exhibit for the 2011 Nuit Blanche event in Toronto [17]. The design goal of Tweetris was to create an interactive experience bonding game players across a distance. We do not argue for the novelty of Tweetris in a research sense here; this paper is about analyzing what players *did* while playing Tweetris.

The core part of Tweetris is the shape-matching game, where two players race to match the shape of their body to a *tetromino*, i.e. a shape composed out of four squares taken from the game Tetris: , , , , , , and . Whoever makes the correct shape fastest has their picture taken and uploaded to the @TweetrisTO account on Twitter. During the Nuit Blanche event (and at the time of publishing), anyone can go to a website and play a custom game of Tetris, where the pieces are overlaid with images of winners from the shape-matching game [1].

[1] anonymized for review

Figure 2 shows the experience of Tweetris from the shape-matcher's perspective. The interface presents the players with a real-time video as if they were looking at a mirror. The video is overlaid with a 6×4 grid of squares where each square is transluscent colour-coded depending on its state: red (right player) and blue (left player) indicate a square belonging to the current shape to be matched, using a darker colour when the square is successfuly occupied. A square that is not part of the goal shape, yet occupied, turns purple (not shown in Figure 2) to prompt a mismatch. Players must occupy all of the four grid squares for the given shape and no more, and hold that position for 1.5s while a white progress bar goes across the screen on top. If neither of the players is able to make the goal shape before a 10s countdown, shown by the decreasing length of the yellow bar at the top of the screen, a new random shape is selected and displayed.

Tweetris uses a Microsoft Kinect [13] as its input method. When Kinect sends the depth frame, each pixel is tagged with an id indicating the presence of a user. For a player to "occupy" a grid square in Tweetris, 30% of the pixels in that grid square must be tagged with a non-zero id. Tweetris uses the colour frame of the Kinect as feedback to the players.

BACKGROUND AND MOTIVATION

We aimed to learn about the nature of WBI by eliciting unconstrained interaction through Tweetris. This builds on previous work on eliciting gestures, the role of schema and metaphor in interaction design, and the nature of phsyical and environmental constraints on WBI. Tweetris can be viewed within Fogtmann et. al's *kinesthetic means* theme, and we make observations later in the paper about several of its design parameters: sociality and kinesthetic empathy, explicit and implicit motivation, and movability [6].

Whole-Body Interactive Experiences

The notion of bringing WBI into games has captured research interest for some time. VIDEOPLACE [12] provided early engaging examples of WBI as a mechanism to interact with virtual entities. In the 1990s several commercial WBI systems emerged, including the Mandala GX system targeted at installations, and the consumer-focussed RealityFusion GameCam and Intel Me2Cam. Arguably however, before the recent arrival of consumer devices like the Microsoft Kinect and Sony EyeToy, WBI found the most success in video arcade games including skiing simulators that require bending and twisting, and shooting games that require dodging [7]. Explorations such as the work of Warren [18] have demonstrated fascinating interaction techniques using the whole body that would not be possible before.

Elicitation Protocols

There are two major existing protocols for eliciting interaction signs from a user; the Wizard of Oz (WoOz) protocol and the User-Defined Gestures (UDG) [19] protocol. The role of interaction signs (in our case, whole-body configurations), how they are associated with referents, and the overall procedures differ under each protocol. A protocol's utility will depend on the application domain and the signs' medium of interaction.

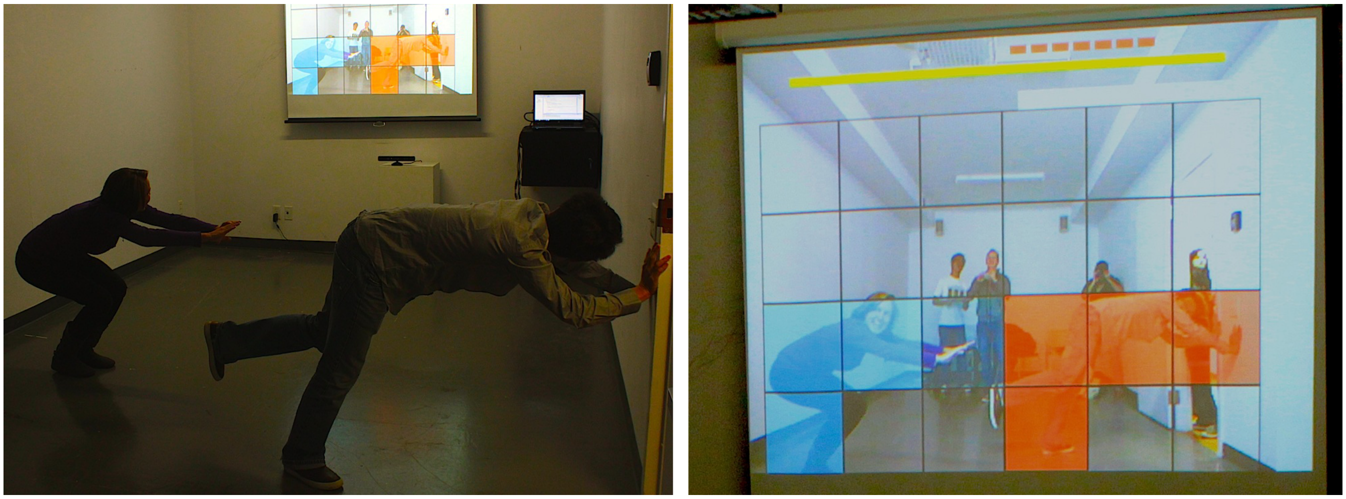

Figure 2. Two players attempting to match the same tetromino. On the left side, we see the view from behind the players. Note the Microsoft Kinect on the pedestal oriented at the players. On the right side, we see a close-up of the Tweetris shape-matching interface as the players would see it. The right (red) player's tetromino is fully occupied, and a progress bar (in white, difficult to see) is increasing across the top. The right player will win if they manage to hold their position until the progress bar finishes. The left (blue) player has filled 3 out of 4 of their squares; their rightmost square is not filled, and is thus a lighter colour of blue. Note that the right player is using the wall as support.

In the WoOz protocol, an application domain is selected, and participants are given a series of high-level goals to accomplish. Neither signs nor referents are known in advance by the participant or the researcher. The procedure is to have participants repeatedly attempt signs with the wizard attempting to interpret the signs. The interplay between signs from the participant and responses from the wizard will elicit knowledge and implications about the application domain and the expression medium.

In the UDG protocol, participants are shown a series of before-and-after states of a system, and asked to perform the corresponding sign. As opposed to the WoOz protocol, which gives high-level tasks, the set of referents is known in advance. In Wobbrock et. al.'s paper [19], there are no high-level tasks, and a sign is elicited for each referent only once. While this aids to constrain the results for easier analysis and application development, researchers are not able to observe a participant experiment with a few different signs and referents over the course of a high-level task. Researchers must determine a desired set of referents in advance. Wobbrock et al. derived their application-agnostic referent set came from observing a few other tabletop applications.

Hybrids of the WoOz and UDG protocols also exist. For example, Norton et al. [14] had participants play a commercial videogame with apparent WBI, while the game was actually controlled by the wizard. However, participants were told in advance what referents the game had (i.e. run, turn gaze, jump). Thus, as in the UDG protocol, the goal of the study is to match signs produced by participants to pre-determined referents.

However, both of these protocols introduce bias when eliciting interaction from users, which we will discuss in the following sections on metaphors and constraints.

Metaphors

Hurtienne et. al. [10] observed that an interaction sign is an instance of a cognitive image schema (e.g., up-down, big-small) associated through a primary metaphor with a particular target domain. An individual's set of image schemas are developed through interaction with the world during their lifetime. Users therefore can subconsciously apply these image schemas while signs are being elicited, especially where metaphor is clear.

Embodied cognition theory goes beyond cognitive image schemas to argue that complex abstract concepts (like justice, for example [1]) have their roots in our bodily and sensory engagement with our physical environment. Antle et al. [1] and Holland et al. [9] report on studies examining how to incorporate such conceptual metaphors into WBI systems, as a way to promote engagement and to guide complex interaction. Both studies identify the strong influence of other factors in their results (including physical effort and competing conceptual metaphors) which confound the predictive power of a specific conceptual metaphor.

Unsurprisingly, designers directly incorporate metaphor into any application, however this phenomenon may constrain what we can learn about the limits and potential of new mediums of interaction. Since the WoOz and UDG protocols offer high-level tasks and referents respectively, they bias the mind of the user towards particular metaphors when eliciting signs, limiting their ability to freely explore the whole space.

Constraints

In addition to metaphor, it is clear that physiological and environmental factors impose constraints on WBI. In Tweetris the decision of what body configuration to use to complete a shape is not influenced by explicit metaphor, but the ability to achieve a given body configuration is constrained by these other factors. Fogtmann defines movability as whether the body can move freely [6]. However, we argue that this definition is not subtle enough.

The work of Bardy et al. in human postural dynamics illustrates how multiple constraints combine to influence the selection postures when completing physical tasks. Bardy [2] identifies two broad classes of constraints: physical/behavioural (including foot size, athleticism, body stiffness), and environmental (including floor properties like hardness, and task stimulus). This research used object tracking as the physical stimulus driving posture selection, and as such provided little opportunity for metaphor connecting the stimulus and the postural act. Bardy et al. [3] further illustrate that transitions between postures exhibit characteristics typical of self-organized systems, including resilience of a held posture up to a threshold, after which a transition occurs to another more suitable posture.

Under the WoOZ and UDG protocols and in the embodied metaphor work a strong emphasis is placed on eliciting the application of image schemas or metaphors, either designed (as in UDG) or inferred (as in WoOZ). In our work, by not influencing how shapes are made we are able to focus on the impact of physiology and environment on WBI, and to identify the unsolicited emergence of patterns, of flow [4] (a feeling of optimal performance and mastery), and of the application of metaphor.

THE LOW-FIDELITY ELICITATION PROTOCOL

We propose a new protocol that aims to explore the range of expression in a new medium, while reducing the bias introduced by metaphors and constraints. The protocol does this by offering a series of low-fidelity signs and suggesting that the participant produce a sign to complete them. We give the following set of requirements:

Protocol Requirements

R1: The interface should offer as little opportunity as possible for metaphorical interpretations. There should be no explicit referents, or meaning attached to signs through kinaesthetic mimicry, the logical mapping from interface to real-world movements. [11].

R2: The procedure and low-fidelity signs must cover a broad set of possibilities in the expression medium, both simple and complex.

In terms of Fogtmann et al.'s parameters of explicit and implicit motivation [6], by giving a low-fidelity sign for participants to make, we are giving them a restriction on what to do, but also considerable freedom in how they accomplish it. The tension between explicit and implicit motivation is certainly worthwhile of further study.

To illustrate our protocol, imagine the medium of multi-touch tabletop interaction. A study using our protocol would show a series of touch contact traces across a tabletop to a participant, and then encourage them to attempt to mimic what they saw. If the traces were initially single points, we would expect to observe participants using mostly the index finger of their dominant hand. However, without running the actual study it is unclear what participants would do in the case of multiple simultaneous traces.

Tweetris as a Research Instrument

The primary goal when designing Tweetris was to create an experience that would be fun. By not constraining how shapes are made, such as by rewarding body presence in squares rather than exactly fitting into a human silhouette, we allow the player to make postural decisions based on physiological and contextual factors, permit the emergence of flow, and, as argued in [11], enhance the game's enjoyability. In contrast, too much precision in movement mechanics may reduce the opportunity to arrive at an "emotional end state" (e.g. the buoyancy of dance) [11].

Tweetris falls into the protocol described above:

R1: A tetromino, as it appears in Tweetris, is a *low-fidelity* version of a sign. There are many possible ways to form a sign that matches a given tetromino - it is *unconstrained*. The procedure is not to get the participant to accomplish a high-level task, nor to get them to produce a sign for a given referent, but instead to create an individual sign to match the given low-fidelity sign. There is also little opportunity for kinaesthetic mimicry [11], as the act of shape making does not directly map to any specific real world activity. Because Tweetris doesn't suggest or influence shape making strategy in these ways, the game allows us to focus on the influence of human physiology and environment on interaction.

R2: The set of tetrominos in Tetris under all non-unique 90-degree rotations (i.e. , , , , , , , , , , , , , , , , and —we omitted from our study as we were not interested in lying-down interaction) covers all reasonably well-connected arrangements of four squares, so we can be confident that we have a broad coverage of coarse body configurations possible in whole-body interaction. Completing some shapes will obviously be much simpler than others (for instance is less challenging than or). The result of a study of this form of protocol will be observations about ease of production of types of signs in the study's expressive medium.

EXPERIMENT

We exhibited Tweetris in two separate locations at the 2011 *Nuit Blanche* festival in Toronto.

The Nuit Blanche Event and Participants

Nuit Blanche[2] aims to bring contemporary art to free, public spaces over a 12-hour sunset-to-sunrise period. Nuit Blanche was originally conceived in Paris in 2002, with the Toronto chapter starting in 2005. From the Toronto website:

> *"From sunset to sunrise city spaces and neighbourhoods are transformed into temporary exhibitions. Unusual or forbidden spaces become sites of contemporary art open for all-night discovery and rediscovery...The everyday is suspended as the city's landscape is changed to welcome a variety of artistic experiences."* [17]

[2] All-Nighter, literally White Night, in French

Nuit Blanche attendees typically cover a wide range of the population; individual adults, families and groups of friends especially out for the event. Event goers usually wander around—with or without specific planned path—looking for opportunities to step in and engage in the various installations that happen to be close-by.

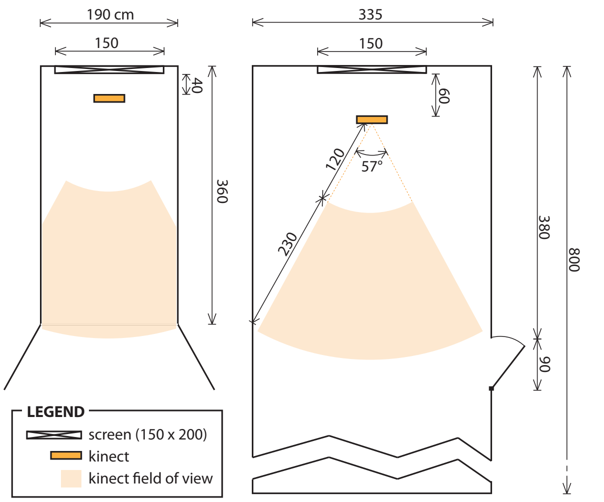

Figure 3. The two Tweetris installations: Van (left) and Gallery (right).

Physical Set-Up
Our Nuit Blanche shape-making set-up consisted of two simultaneous installations: one in a parked van on a city street, another in a dedicated room, at a University gallery space. The physical setting is depicted in Figure 3.

Collected Data
Before they participated in the game, we ensured visitors understood and agreed that snapshots of their full body were being taken when playing and posted on Twitter. We did not want participants' behaviour to be affected by the knowledge that they were in a researcher study. Thus, we only mentioned our research purposes after participants played the game, and invited them to fill in a post-participation questionnaire if they wanted. Participants who filled out a questionnaire also signed a consent form allowing their data to be used.

The data we collected is as follows [3]:

Snapshots: a snapshot of the winning participant was taken via the Kinect, each time a shape was correctly held for 1.5s. We collected 3424 shapes in the van and 2954 at the gallery, from over 270 participants.

Questionnaire: after they played the game, attendees were invited to fill in a questionnaire if they wanted to. The questionnaire asked for demographics, and qualitative feedback on the player's experience with the game. We collected the answer of 34 participants on the van site, and 31 participants at the gallery.

[3]We only detail here the data that is relevant to this paper.

For each snapshot of a successfully made shape, we recorded: the location (van or gallery), participant id, participant location (left or right), the timestamp and the tetromino and its rotation.

Manual Coding
Four of the authors performed data coding on image snapshots of the successfully made shapes at the van location:

Body rotation: the player's body rotation towards the game display (left, right, forward)

Body posture: We captured the basic posture used by players when forming shapes, by categorizing each successful shape according to whether the player was sitting, lying down, standing, squatting, kneeling, or "crouching" (kneeling on one leg).

Limbs location: the body limbs (left and right hand, left and right elbow, left and right knee, left and right foot, head, hips) that were contained within each square of the tetromino.

Hand availability: for each hand, whether it was considered as available or unavailable (e.g. a hand on the ground, used for balance would be considered as unavailable)

Hand behaviour: for both hands, whether they were both clenched, both relaxed, both extended, or different.

There was substantial agreement between the coders on a ten snapshot test set, after which each author encoded about 360 snapshots, for a total of 1438 encoded images (outlier snapshots being discarded because of poor lightning conditions or other issues).

To compare the differences between location, we also coded *Body Rotation* and *Body Posture* at the gallery location, for a further 1812 shapes. We did not do the full coding at this location as it was extremely time-consuming.

OBSERVATIONS
Here, we report on qualitative observations about how our participants engaged with Tweetris. While there were a small number of individuals who looked to be seriously concentrating while playing, the vast majority smiled and laughed, corresponding with the questionnaire responses about enjoyment and play experience. 15/65 respondents indicated that they ignored scoring to make a fun shape, which is reflected in the creativity and variety of approaches we observed.

After having demonstrated Tweetris in a number of other locations since this study, we attribute the positive response to a combination of gameplay *and* social context. While enthusiastically embraced at the all-night art event, play was less dynamic and creative at an educational event, for example, where players may have been more self-conscious and seemed to be enjoying themselves less. Tweetris has a visual interactive interface with no textual instructions; audience members at the art event (especially those who had recently played) would often call out instructions to players, adding further to the social context of the game.

Players could move forward or backward as well as side to side in order to make shapes, however we saw very little forward-backward movement. Instead, players adjusted their body posture to fit each new shape. Some participants would begin too close or too far from the sensor; while some of these players adjusted their distance, often due to instructions from the audience, others tried to make their body footprint smaller by lying face-down. This non-optimal behaviour may be due to most participants' experience with a live image of themselves: a mirror. One's apparent size varies much more with towards-and-away motion in a camera than in a mirror, and participants may not have realized that they could take advantage of this feature.

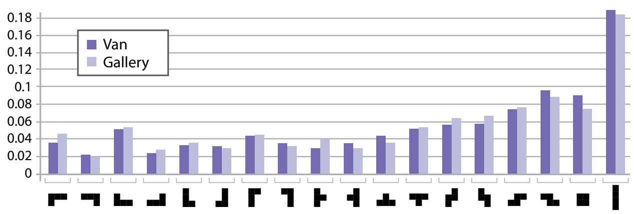

Figure 4. Proportion of successful shapes made, for each tetromino, in the van and gallery settings.

RESULTS

Figure 4 shows the proportion of successful shapes for each tetromino, in both the van and gallery settings. The figure illustrates that the overall level of difficulty in making the various shapes remained consistent across locations.

Body Rotation

More than twice as many shapes (351 to 145) were successfully made turned away from the wall than turned toward it. A binomial test for one proportion shows that this difference is significant ($z = 9.25, p < 0.0001$).

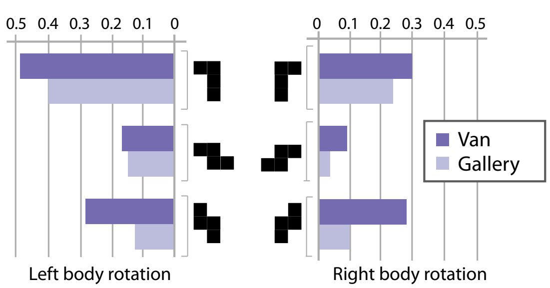

Figure 5. Percentage difference in successful shapes made for body rotation. The differences are significant for shapes 1,2,4,5,6 in the van setting, and in 1,2,4,6 in the gallery setting.

We also examined whether the presence of the wall would impact which tetrominoes were more successfully made on one side of the van versus the other. There was no significant difference between the left and right side in the number of shapes successfully made overall, however the relative frequencies of specific tetrominoes were different on each side. Figure 5 shows the shapes with the most pronounced differences. All of these shapes require the player to move their upper body to the left or right relative to the screen, and the differences in proportions between the sides correlate with moving away from the wall rather than toward it.

Because the gallery space was larger (1.45m wider, giving more room between each player and the wall), we hypothesized that the impact of the wall found in the van data would be less pronounced in the gallery data. As Figure 5 illustrates, the differences in proportions remain, but are less pronounced than in the van setting.

Effect of the Gallery Door

In the gallery, we surprisingly saw a mild preference to rotate to the left on both the right (181/325 rotations, z=2.052, p=0.02) and left (168/282 rotations, z=3.216, p=0.001) player sides. The entrance to the gallery space was at the right side of the room (see Figure 3), meaning that rotating to the right would put players face to face with the crowds peering inside to watch the game. We suspect that there may have been a desire by some players to turn the other way to avoid awkward eye contact.

Body posture across shapes

In terms of posture, while standing, squatting and crouching, the legs could remain active, permitting rapid changes in body posture. Sitting, lying or kneeling require more effort to engage the legs and feet to move into a new posture, and so we expected that these postures would be held for longer periods of time, while players might more rapidly cycle between the other postures. In our own experience playing the game, we noticed that kneeling was an effective strategy, as it could be held comfortably and allowed all shapes to be made (including if one was willing to stretch). For these reasons we expected to see a high degree of consistency in the use of kneeling as a strategy, versus the other postures.

We analyzed the number of times each player used each basic posture. In the van, 35% of all shapes players were kneeling, with the remaining split between standing (25%), squatting (20%), crouching(15%), sitting (4%) and lying down (1%). This makes a large contrast to the gallery, where only 7% of shapes had the player kneeling. Most were standing (40%), with the remainder crouching (31%), squatting (18%) and sitting or lying down (4%). We observed that the body movements overall seemed more subdued in the gallery. A lot of shapes were completed standing or almost standing. The cause of this could stem from factors in the physical environment, such as a harder floor enabling less configuration, or the social environment, such as the audience being much closer to the players in the gallery than in the van.

Hands Behaviour

Manual coding. For every image, we classified the behaviour of both hands into one of the categories *clenched, relaxed, extended, different*. Clenched hands looked like fists. Extended hands were where the fingers were extended straight, parallel to the palm; we did not differentiate on whether the fingers were together or not. In 27% of the total number of images, we could not accurately classify both hands.

Results. Extended was the most common behaviour (59%), followed by Relaxed (24%) and Clenched (14%). Both hands tended to have the same shape, even if they were not in the same grid square; hands were only different 12% of the time. Interestingly, hands were often Extended when it was not necessary to complete the shape. While an extended hand does take up more pixels than a fist, it does not make significant difference unless the palm of the hand is turned to face the camera; players rarely did this.

The proportion of clenched, relaxed and extended hands varied significantly from shape to shape in interesting ways. Extended hands were the most common in every shape except , where they accounted for 7% of shapes, with the remainder clenched (49%), relaxed(43%) or different (%1).

Different hands were much less common in symmetrical shapes: (%1), (3%) and (1%). The exception is , which had 21% different hands, but this mostly occurred when the player was turned left or right, with one hand extended and the other relaxed or clenched near his or her crotch. This posture was the pattern of most of the hands coded as different in the asymmetrical shapes. This was most common with and , with 29% of hands coded as different.

Clenching was interesting to observe, as it should be a sub-optimal strategy as it takes up less pixel space. As we noted, the most common occurrence of clenching was with (49%). The second most common occurrence was with , at 41%. After that, the most common occurrence is in and at 15%. The rate of occurrence drops off quickly after that. In many cases, participants would clench hands near their face when having them relaxed by their side would be suitable.

The high amount (41%) of clenching in was an anomaly. had 0% clenching – in the 54 coded shapes for , no one was clenching at all! While we cannot be sure why clenching is so common in , we do note that the players' arms typically need to reach farther to form the shape. As repeated players experience these two shapes over and over, they conform their hand behaviour to give themselves the sensation of significantly longer or shorter arms.

STRATEGIES

Going through the manual coding of the players' poses helped us gain knowledge about how shapes were successfully performed. We did a secondary coding to better understand players' strategies, classifying, for each tetromino, the winning shapes into categories of poses alike. This was to better understand if, and in which proportion a pose strategy is likely to be a winning one.

Pose strategies

Manual coding. Based on our observations during the first manual coding of the data, we identified typical behaviour (e.g. hands are stretched out to fill in extremal square) while performing successful shapes. In most cases, we can relate a pose to a intended strategy that guides where to place the limbs. We empirically determined different pose strategies for each tetromino and used them to classify the images.

Results. Figures 6 and 7 show an overview of the pose strategies for each tetromino (note that we consider horizontal reflections of tetrominos to be of the same category). We only report here on the winning strategies that were adopted in more than 20% of the overall winning images for the tetromino classes. With such a threshold, we end with exactly one or two main pose strategies for each tetromino.

Overall, we found that winning strategies tended to be poses where members are stretched out to reach the extremal squares, rather than contorting the torso to match the shape. Participants tend to choose the strategy that requires the easiest movements. Moving the arms, even for reaching far extremals, seems to be a preferred and successful strategy overall (see for example Figure 7K2-4).

Surprisingly, the most successful strategy for and with a single bottom square (see Figure 7C-D) involved a challenging pose, demanding flexibility (see 1), or balance (see 2), whereas the second most common strategy appears more stable and comfortable, and thus less physically challenging. Such awkward poses are due to the fact that participants decide to use both hands in the far side extremal.

We also found a number of interesting isolated strategies, usually corresponding to a very awkward pose, but still successful. Good examples are Figure 7F5, H5 and J6.

DISCUSSION AND CONCLUSION

Environmental Impacts

While previous work has shown that even desktop interfaces are subject to the influence of the environment [16], whole body interaction (WBI) is by its nature inextricably connected to physical environment [1, 9]. Designers of WBI systems must therefore be cognizant of the impacts of physical environment on WBI, however, surprisingly little research has been done in this area.

Our results show that even in spaces cleared of furniture, etc., environmental layout can significantly impact whole body interaction. Proximity to a wall influenced how our players rotated to complete shapes, and also which shapes were completed successfully. Modest changes in layout can reduce or eliminate these effects. Further research is needed to better understand the relationship between proximity to a inert or living objects and personal space during whole body interaction. As Harrison and Dourish (among others) have noted [8], environments are more than just physical layouts, and need to be understood within larger social contexts. In our gallery setting, the location of a door (and of inquisitive onlookers beyond it) in the play space impacted how some players chose to orient their bodies when making shapes.

Patterns of Shape Making

Our analysis of player strategies reveals many nuances in shape making behaviour. While we attempted to reduce the opportunity for embodied metaphor in the design of Tweetris, we see indications that players expressed an internalization of the shape. Hands were often engaged in as part of a whole body "expression" of the shape being made. Typical examples are in Figure 7G5-7, where the right hand overlaps the head from the camera's perspective, and is therefore not necessary. Other are in Figure 6A4-7, where participants tended to form a shape by bringing hands together on top of the head. In "stretched" shapes, such as or , the hands tended to be more extended; in "squished" shapes, such as , the hands tended to be more clenched. This supports both the notion of interaction as a connection to an image schema via a primary metaphor (in this case stretched-squished) [10], as well as the the whole-body engagement hypothesis [5]. The explicit or implicit engagement of the hands in shape-making calls into question designs that presume hands will be free to perform operations that are independent of a gesture expressed by the body, although this requires further research (we did not require such an interaction in Tweetris). We also observed that some players wanted to explore interesting/fun configurations (examples in Figure 6-7), demonstrating *engagement* and *implicit motivation* [6]). This sort of flexibility of expression in interaction may still have value in everyday interfaces.

Low-Fidelity Elicitation Protocol

Inventing a new protocol was a by-product resulting from our evaluation of Tweetris. It allows for a broader exploration of an expression medium than if researchers were to come up with gestures or referents, or participants are given time to think and come up with a gesture. The set of tetrominos in Tetris covers all reasonably well-connected arrangements of four squares, so we can be confident that we have a broad coverage of body configurations. Had we not used this protocol, we would not have been able to make the observations about how presence of walls or onlookers influences behaviour, or the expressive behaviour of participants' hands. We hope to see others use this protocol in other expressive mediums.

Implications for Whole-Body Interaction Design

We make two major observations. First, physical objects in the environment affect how users orient themselves, even if they are not in danger of colliding with them. Second, whole-body interaction uses the *whole body* – if unconstrained, the hands will expressively mimic the shape that the whole body is forming. We recommend that WBI systems should have an awareness of the constraints and tendencies of the current stable posture of the user, and adjust widgets and targets individually. As our results show, this can be determined by the low-fidelity elicitation protocol.

We have learned much about the nature of constraint. When given repeated low-fidelity signs to match without any imposed constraints, the players almost universally enjoyed themselves and experienced a state of flow. However, it is unclear how to interpret the relative variety of elicited signs from a single low-fidelity sign. Does a high level of variety suggest capacity for expression, or difficulty in achieving the low-fidelity sign consistently? We seem to suggest that, for a "real" interface, we should create and teach a gesture set to users, based on the knowledge of their unconstrained flexibility. Adding meaning to specific body positions, however, is a form of constraint. The tension between expression and constraint is certainly worthy of further study.

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Figure 6. Examples of shapes made by participants

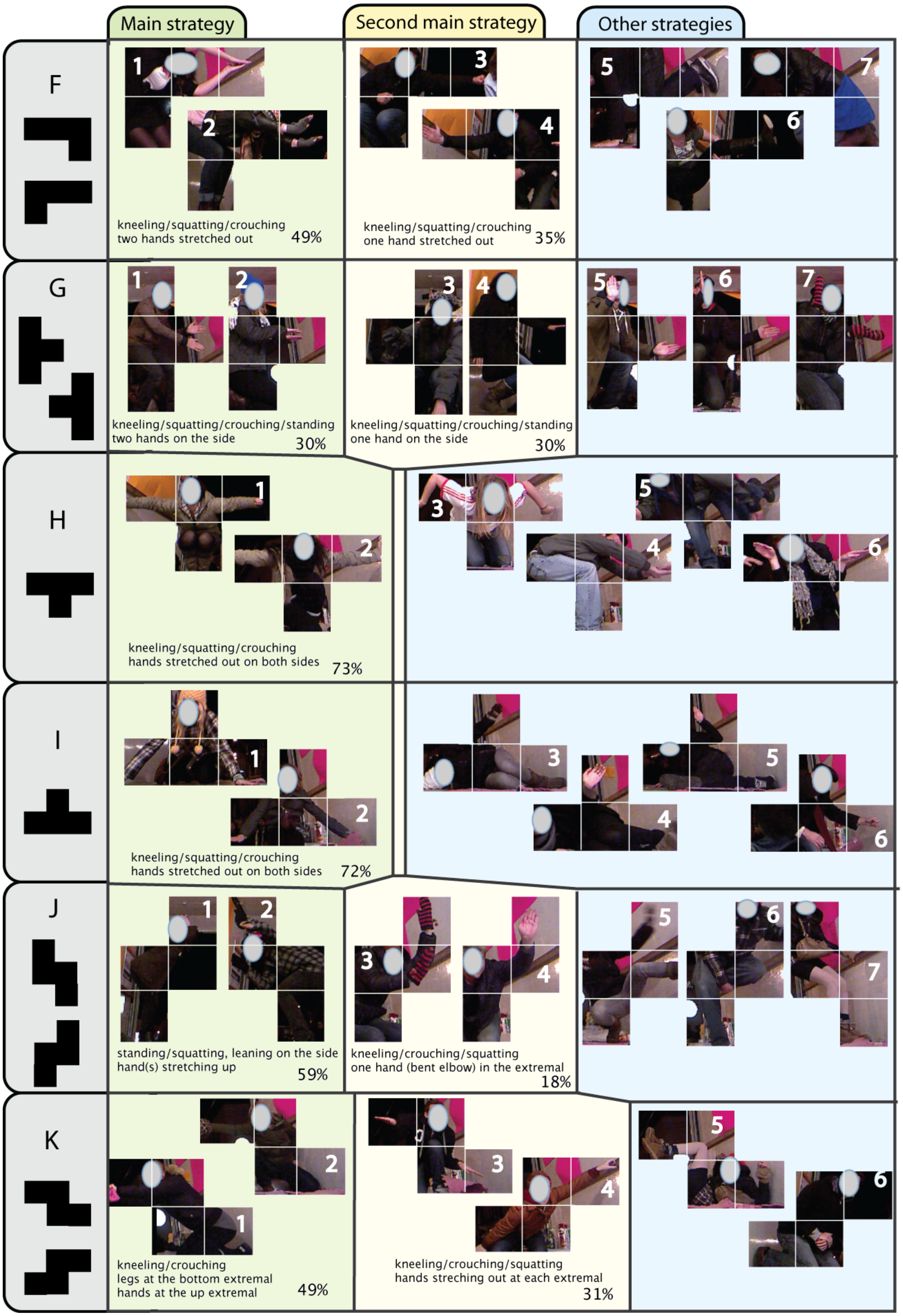

Figure 7. Examples of shapes made by participants