Tangible Awareness: How Tangibles on Tabletops Influence Awareness of Each Other's Actions

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ABSTRACT

Tangibles on multitouch tabletops increase speed, accuracy, and eyes-free operability for individual users, and verbal and behavioral social interaction among multiple users around smaller tables with a shared focus of attention. Modern multitouch tables, however, provide sizes and resolutions that let groups work alongside each other in separate workspaces. But how aware do these users remain of each other's actions, and what impact can tangibles have on their awareness? In our study, groups of 2–4 users around the table played an individual game grabbing their attention as primary task, while they also had to occasionally become aware of other players' actions and react as secondary task. We found that players were significantly more aware of other players' actions using tangibles than those using pure multitouch interaction, indicated by faster reaction times. This effect was especially strong with more players. We close with qualitative user feedback and design recommendations.

ACM Classification Keywords

H.5.2 Information Interfaces and Presentation (e.g. HCI): User Interfaces

Author Keywords

Tangibles; awareness; tangible interaction vs. touch interaction; large tabletops; collocated group work; information processing; secondary task awareness

INTRODUCTION

Tangibles are physical objects that can represent and manipulate digital content on a multitouch tabletop. On multitouch tabletops, tangibles have been shown to increase users' eyes-free performance [21], and their precision when manipulating digital objects [7, 20]. These results, however, consider only the scenario of a single user at the table. Since a table can be approached from different sides, a natural scenario is its use by several users collocated around the table [11, 22]. Recent advances in physical screen size, display resolution, and sensing technology have made this multi-user scenario technically feasible. For example, at a size of 220×117 centimeters,

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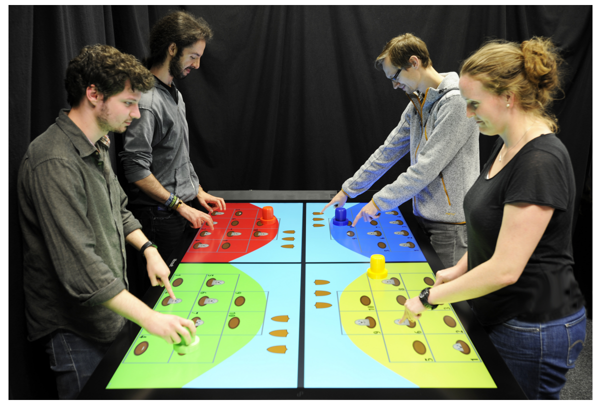

Figure 1. Four users playing the tangible version of our tabletop game. While playing Whac-A-Mole, each player also has to become aware of and defend attacks that other players trigger using their tangible, 3D-printed barrels.

Microsoft's largest Surface Hub 84", which we used in our studies, easily accommodates four people around it, with its display resolution of around 45 dpi allowing users to stand close to the tabletop and still be able to read text efficiently [23].

This raises the question to what extent tangibles provide additional benefits in such scenarios beyond their known single-user effects. Would users on such a table, for example, notice the actions of others more quickly if tangibles were used, and if so, how strong is this effect? This "understanding of the activity of others, which provides a context for your own activity" is defined as *awareness* in the CSCW literature [4, 8]. We thus decided to measure the effect of using tangibles on large tabletops on the collocated users' awareness.

In the remainder of this paper, after discussing related work, we first present the game we designed for our study. It supports 2 to 4 players at the table, with or without using tangibles. It creates a primary task that continuously captures each player's attention, while certain "attack" actions by the other players trigger a secondary "defense" task that the player has to switch to momentarily. We then describe our study that measured each player's awareness of these attacks by comparing how fast she would react to them when other players triggered them by moving a tangible vs. an on-screen virtual object. We report on the quantitative findings from our study and the qualitative results from post-game interviews. We close with a set of resulting design recommendations for creating tangible tabletop games and other applications for multiple users. These recommendations should help decide when and how to use tangibles in such a setting, and what side effects the designer may need to be aware of.

The main contributions of this paper therefore are:

- An analysis of the effects of tangibles on user awareness when using large multitouch tabletops together, combining findings from a quantitative lab study and user interviews;
- Design recommendations for games and other applications on such systems.

RELATED WORK

Underkoffler et al. [18] introduced Urp, one of the first tools using tangibles, to display shadows in a urban planning tool. The benefits of adding tangibles to touch-based interaction are well-established. Fitzmaurice et al. [7] showed that bimanual, graspable controllers allow the user to be more accurate than single-handed devices like a mouse. Tuddenham et al. [17] confirmed these findings for tangibles vs. multitouch input. Tangibles also increase users' ability to work eyes-free [20, 21], e.g., as indirect controllers [10]. However, these studies focused on the basic perception and motor performance of single users.

Tables naturally afford multiple actors to stand around them and work simultaneously. Fan et al. [5] evaluated Antle et al.'s *Youtopia* system [2], a tangible world building game for children on a 40" screen, and found children to communicate more with each other when using tangibles. Speelpenning et al. [16] presented a study comparing the user experience of tangible and digital interfaces in collaborative work. They observed that tangibles increased ownership and announcement of tool use, and deduced higher tool awareness from those findings. Olson et al. [15] found tangibles to help children resolve conflicts over limited on-screen controllers. Isenberg et al. [13] examined collaboration around a 56×53 cm Microsoft PixelSense table, and found that group tasks could be solved more efficiently when the group worked in closer proximity to each other. Inkpen et al. [12] evaluated user communication and awareness around a larger, 150×80 cm table. They observed higher interpersonal interaction and communication when using a stylus over a mouse. Morris et al. [14] developed *WeSearch* and studied it on a 180×120 cm interactive table, identifying the advantages and potential of large tabletops for collocated collaborative tasks using touch input.

In summary, these studies illustrate that large tabletops, tangibles, and spatial proximity benefit collocated groups in various ways.

Awareness on Tabletops

Larger tabletops allow users to create their own, personal workspaces, but this also means that the display no longer represents a single shared object of focus for all users. To continue to collaborate, users thus now need to recognize and become aware of each other's actions.

Hornecker et al. [11] showed that users had higher awareness for each other's actions when using multitouch than when using a mouse. However, at 65×50 cm, the system was too small to support working in parallel in personal workspaces. Chang et al. [3] developed an interactive timeline that helps users to understand a board game setting by making them aware of the automatic actions of the game. Their study on a 148×95 cm tabletop revealed increased situation awareness for players with individual timelines compared to users with shared controls. However, these timelines were purely virtual, on-screen objects. Gutwin et al. [9] argue that secondary task awareness can be improved if actions attract the user's peripheral perception: if the actions of another user are attention-grabbing enough, the user can recognize these actions while executing his own primary task on the multitouch surface.

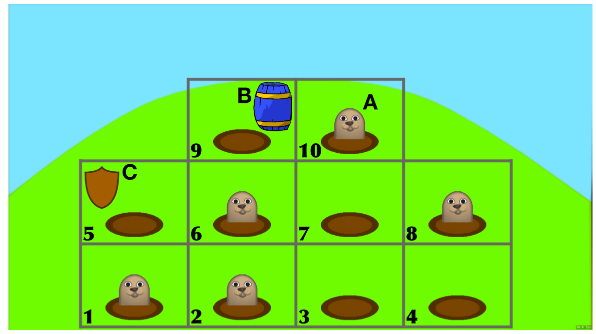

Figure 2. The game screen each player saw in our study, with moles (A) and one barrel (B) and shield (C). This is the green player's screen, as indicated by the "hill" color, in a two-player game.

Based on these results, the goal of our study was to determine if tangibles make it easier to become aware of other users' actions while completing an individual task.

STUDY DESIGN

To measure human awareness for another user's actions in a collocated tabletop environment, we created a game that is highly engaging and attention-grabbing in single-player mode, and added a secondary objective to it that required players to react to actions by other players. Since reacting to these events was necessary to win, we captured the percentage of successful reactions, as well as their reaction times, in order to determine a user's awareness for these events. This is reflected in our main research question:

Does the use of tangibles in a collocated touch-based game on a large tabletop improve a user's awareness of other users' actions, as indicated by the success and speed of his reactions to these actions while completing a primary task?

Game Description

The game we implemented for our study is based on the arcade game classic Whac-A-Mole [1]. Traditionally a single-player game, it challenges the player to hit or touch moles that appear randomly in holes in front of her.

Following the definition of *awareness* [4, 8] introduced earlier, we added a secondary task to the game that required users to be aware of other players' actions. The game mechanics are described below; we refer to our video figure for a better sense of the game in action.

Primary Task: Catch the Moles

Each player has their own, individual game screen displayed in front of them (Fig. 2). It contains 10 bordered holes (Fig. 2-A).

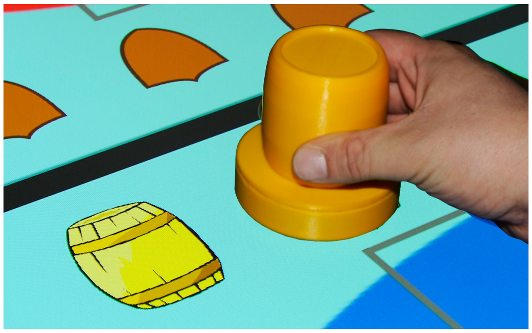

Figure 3. Virtual and tangible version of the barrel. To place an attack, the barrel must be moved next to a hole in the player's own area. This is the action that the defending player needs to notice and react to, which was used to study players' awareness of each other's actions.

For every player, we generate 10 moles every 2.5 seconds, pseudo-randomly distributed over the ten holes. The primary goal is to catch each mole by tapping on it within the 1.5 seconds before it disappears again, for 1 point per mole caught. This primary task thus represents a straight multitouch adaptation of the original Whac-A-Mole. Each player's hill has a different color: red, blue, green, or yellow.

Secondary Task: Defending "Attacks"

Our secondary task allows players to steal points from each other. For this, each player has a barrel in his own hill color (Fig. 2-B). To steal points from another player, the attacker moves her barrel near a hole on her own playing field, inside the box around it. As soon as the barrel is placed, all opponents start losing 1 point per second each, which the attacker gains. In the digital condition, the attacker drags an on-screen barrel icon with her finger; in the tangible condition, she grabs and moves a 3D-printed plastic barrel of similar size. (Fig. 3).

To stop losing points from an attack, a defending player needs to place one of his virtual shield icons (Fig. 2-C) next to the corresponding hole on his own field. This stops and prevents any further attacks on a hole while the shield remains near it. Although players were not aware of this, noticing the attack was the secondary task and key activity we were interested in during our study. We informed players that, since attacks continue to steal points over time, reacting to incoming attacks as soon as possible is crucial to win the game. This was to ensure that players would try to react immediately to an attack. Players had no other hint than the barrels to recognize incoming attacks. Only at the end of a game we revealed the score, i.e., the total amount of points collected and stolen. We balanced the scoring mechanics until attending to both the primary task of catching moles and the secondary task of defending attacks was necessary to win. Note that it was not necessary for the shields to be tangibles, since we were just interested in the "peripheral" awareness of the barrel actions of others.

Figure 4 shows the timeline of a successful attack-defense event. These were the events that we looked for and analyzed to determine awareness. The time to react to an attack is defined by the time between an attacker starting to move a barrel and the defender starting to move a shield.

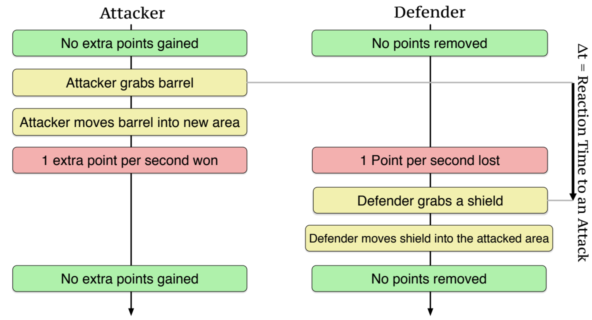

Figure 4. Timeline of a successful attack-defend combination. The reaction time is measured between the attacker beginning to move a barrel and the corresponding defender beginning to move a shield.

Positioning Players Around the Table

All actions of an individual player on the table take place in his personal workspace of about 100×80 cm. Participants were asked to stand around the table at four different positions along its long sides, as shown in Fig. 1. We labeled these player positions as Bottom Left (BL), Bottom Right (BR), Top Left (TL), and Top Right (TR).

To understand whether awareness of tangible or virtual actions changes with the position of players around the table, we used five different combinations of player positions. We included the four-player condition to study how tangibles influence awareness with more users around the table.

1. Bottom Left vs. Top Left (opposite of each other)
2. Bottom Left vs. Top Right (diagonally right across)
3. Top Left vs. Bottom Right (diagonally left across)
4. Top Left vs. Top Right (next to each other)
5. Everybody (4 players at the same time)

Hardware Setup

Players were asked to stand around an 84" Microsoft Surface Hub. This multitouch display detects up to 100 touch points on a 220×117 cm display with 3840×2160 pixels. We placed the display on a frame with wheels, bringing the tabletop surface to a height of 87 cm for use while standing. Fig. 1 shows our setup with four players playing our version of "Whac-A-Mole" with tangible barrels. Horizontal use of this display is not officially supported by the manufacturer. However, we added additional fans with 3D-printed mounts below the table along its long edges that recreate the convection air flow to cool the display, and did not encounter any issues running the system continuously for several hours at a time. Our 3D design files are available online in the Supplementary Materials for this publication.

Our barrel tangibles needed to be detected by the capacitive touchscreen even when players were not touching them, and the table needed to be able to tell the different barrels apart. To achieve this, we built our tangibles following our design of PERCs [19], which provide these capabilities. Figure 5 shows the internals of a tangible barrel.

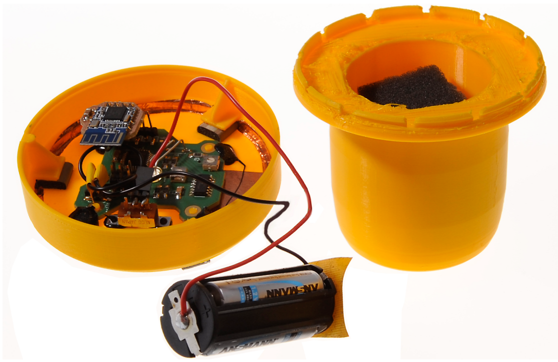

Figure 5. Our tangible barrels are based on PERCS tangibles. Using sensing circuitry, a microcontroller, and a Bluetooth module, they are tracked persistently on the capacitive touchscreen of our display, even when players are not touching them.

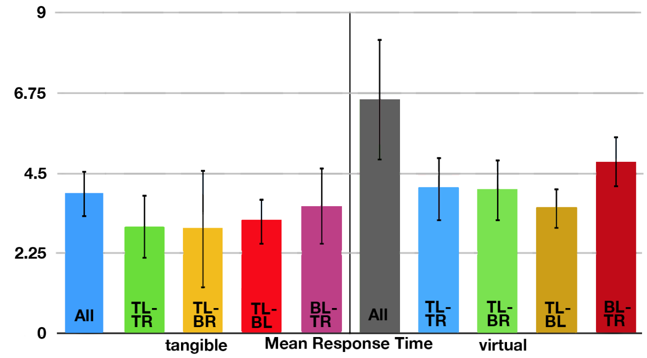

Figure 6. Mean response times for tangible and virtual games, with 95% confidence intervals. Players reacted significantly faster in the tangible than in the virtual conditions.

Measures
We logged timestamps for every barrel and shield movement, and used these to compute the reaction times of successful defenses as explained in "Defending Attacks" above, to determine players' awareness of each other's actions.

We also videotaped every game to enable us to identify and review player strategies later, and to get a rough sense of the players' current locus of attention (we discuss using eye tracking for this under Future Work).

After the experiment, participants filled out a questionnaire, rating the effort of the different tasks for each version of the game. We also asked them to briefly describe their strategy, to understand whether they balanced or prioritized their primary and secondary tasks.

Experiment Procedure
To avoid learning effects between the tangible and virtual conditions, we used a between-subjects design. To avoid influencing participant behaviour, we did not share beforehand that our primary goal was to measure their awareness of other players' actions.

The experiment was carried out in groups of four players. All participants played twice against one opponent (2-player version) and once against all three opponents (4-player version), for a total of five games per group. Participants were assigned randomly to a position and opponent. The order of the 2-player games was counterbalanced with a Latin square to avoid learning effects.

At the beginning of the experiment, we introduced the game and allowed players to ask any rule-related questions. Players who were not currently playing were asked to wait in a separate room to relax, to avoid distracting the active players, and to avoid learning effects from watching. The four-player game was played last, thus all players had the same amount of experience with the game at this point. After finishing all games, participants were asked to fill out the questionnaire.

Participants
64 participants (28 female), with a mean age of 28 (SD = 10.1), took part in the study. Through our between-groups design, 32 participants each played the virtual and tangible version of the game. All participants played in groups of four. Most users stated that they had not used a multitouch device of the size used in our study before. However, all were familiar with portable multitouch devices like smartphones or tablets.

RESULTS
Since the primary Whac-A-Mole task was quite demanding, some players did not always react correctly to an attack. To remove potential false-positives, we focused our analysis on successful attack–defense events, and thus only considered the reaction time if a new area had been attacked, and the defending player reacted with a correct defense. If an attack was not correctly defended, i.e., the shield was moved into the wrong area, we considered the defense to be unsuccessful.

Using our videos and questionnaires, we identified two players who chose not to react to incoming attacks at all. We excluded their timing results from our analysis. We found 1149 successful attack–defense combinations, 785 in the virtual and 364 in the tangible condition. The amount of evaluated tangible attacks is smaller since we only evaluated attacks with complete touch traces; if the tangible was lifted or the touch trace was lost, we did not evaluate this attack. The success rate to evaluated incoming attacks was similar in both conditions, 58% in the tangible and 54% in the virtual condition.

Since the reaction times were not normally distributed (Shapiro-Wilk test, $p < .0001$), we log-transformed them before performing a one-way ANOVA to check for significance. Although the amount of evaluated attacks is not the same, an ANOVA is valid, since the variances of both conditions are equal [6]. It revealed that players were significantly faster in the two-player tangible condition ($F(1,883) = 7.97, p = .0049$). Participants in the tangible condition needed 3.1 seconds on average to react to an incoming attack ($SD = 3.56$). Participants in the virtual condition needed 4.2 seconds ($SD = 6.12$). We also found a significant difference in the four-player version ($F(1,261) = 15.99 p < 0.0001$). Players needed 3.9 seconds on average to react ($SD = 4.26$) in the tangible vs. 6.5 seconds ($SD = 8.08$) in the virtual condition. Fig. 6 shows the different game versions with mean response times and 95% confidence intervals. This shows that tangible attacks were recognized significantly more quickly than virtual attacks.

We also investigated how reaction times changed when moving from two to four players. In the virtual condition, reaction times went up significantly ($F(4,832) = 23.73, p < .0001$). In the tangible condition, however, this was not the case ($F(4,359) = 1.93, ns$). A pairwise comparison revealed that the 4-player version was significantly slower than all other conditions ($p < .0001$ each). We also found one of the diagonal conditions (BL–TR) to have significantly slower reaction times compared to the opposing and side-by-side conditions ($p = .0012$ and $p = .0112$). Other pairwise comparisons were not significantly different.

Questionnaire Results

Most users reported that the 4-player version was more difficult and more demanding than the corresponding two player versions. On a 5-point Likert-scale, participants agreed an average of 4.3 in the virtual version ($SD = 1.37$) and 3.9 in the tangible version ($SD = 1.26$). The tangibles were rated easier to notice than their virtual counterparts both in the two-player games ($M = 3.9, SD = 1.24$ vs. $M = 3.4, SD = 1.27$) and in the four-player games ($M = 1.7, SD = .79$ vs. $M = 2.4, SD = 1.02$). However, these differences are small, and again, for both versions the 4-player version was rated more difficult. However, the free-form answers revealed interesting strategies performed by the participants. 11 participants in the virtual version reported that they had to look for incoming attacks since they were not able to react using only their peripheral vision. This shows that the workspaces on the screen are actually big enough to put content beyond them out of peripheral attention. However, 10 participants stated that they were able to react to incoming attacks in the tangible version of the game. This shows that users also perceive tangible actions to be more noticeable. 8 players tried to react to the sound the tangibles made when they were moved, an especially interesting effect we had not considered beforehand. When being asked, players noted the diagonal condition to be the hardest to react. The quantitative results, however, did not support this, as we could not find significant differences in reaction times between the different game versions. Only one player mentioned the tangible barrel to be “in the way” when trying to hit moles.

DISCUSSION

Our study showed significantly faster reaction times for the tangible version of the game, indicating that players were more aware of others’ actions that version. We expect this difference to become even more noticeable in a less competitive setting. As stated by Gutwin et al. [8], collaboration is increased by a higher awareness for each other’s actions. We discuss some possible explanations for the effect we observed below:

Shape: A tangible’s physical shape stands out from the 2D tabletop surface. It provides cues through different reflective surface properties, by throwing shadows, through our stereoscopic depth vision, and through motion parallax, all of which likely make it easier for our peripheral perception to notice it than on-screen icons. However, none of our players mentioned these cues as helping them scan for a tangible on the table or when reacting to incoming attacks. We also expected more players to mention the tangibles being in the way when catching moles. However, due to the between-groups setup, no player had the chance to play both versions of the game. These observations may become more pronounced in a within-groups study.

Sound: Our tangibles had soft pads to improve detection and to protect the screen from scratches. This created a sliding sound when moving a tangible that was very different from tapping or dragging with a finger. Eight participants stated that they listened to that specific sound to notice a tangible barrel attack. While we did not intentionally design this effect, it shows that tangibles can provide natural acoustic cues when handled, to improve awareness for others’ actions even in a somewhat noisy environment (our players were tapping frantically, and occasionally shouting at each other.) This highly localized acoustic effect would be difficult to reproduce on a fixed speaker system.

Player Movement: Picking up or moving a tangible requires a different arm and hand posture than multitouch, which other players may notice. Our players did not mention this to be a factor, but a within-groups study might reveal more about this potential effect.

Design Implications

Our study showed that tangibles increase users’ awareness for actions of collocated workers. This is especially useful when attention is captured by a demanding individual primary task. In these situations, the tangibles’ properties, like their physical shape or natural auditory feedback, help others to react more quickly to events that are outside their locus of attention.

We still need to study if these effects prevail when tangibles are used for most or all interactions on a group tabletop. Therefore, our current recommendations for researchers and designers intending to integrate tangibles into their applications are:

- Use tangibles for special actions that others need to notice, rather than for the primary task.
- Be aware that their shape, and the movements handling them, make them rather attention-grabbing.
- Design to make use of the natural auditory feedback of dragging and placing tangibles for subtle feedback to coworkers.

Conclusion and Future Work

We showed that users around a large multitouch tabletop react significantly faster to other users’ actions when those use tangibles instead of multitouch interactions. This indicates a higher awareness of others’ tangible actions. We found that this effect increased with more users, and provide some initial design guidelines for such systems from these and other qualitative findings.

A within-groups study with feedback from users after experiencing both tangible and virtual conditions could help better understand how tangibles improve awareness.

We chose to use tangibles only for the secondary task to isolate their effect on user awareness, and because we expect that also using them for a primary task will introduce new distractions and thus decrease their beneficial effects on awareness. A follow-up study could help verify and quantify this theory.

While commercial tangibles for multitouch surfaces have started to appear, users are not generally familiar with them yet, similarly to when smartphones introduced multitouch gestures. Learning effects may thus still play a significant role when studying users interacting with tangibles.

Since some participants stated that they tried to listen to the sound the tangible made when being moved, we suggest investigating further what types of subtle, inherent feedback tangibles may provide to both the user and collocated actors around a large multitouch table.

Finally, eye-tracking could reveal even more precise information about users' current locus of attention and reaction times. For example, it might show if a player who already recognized an incoming attack rather decided to catch another mole before performing his defense.

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