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Gaze beats mouse: A case study on a gaze-controlled breakout

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ABSTRACT

We present an open-source, gaze-controlled adaptation of the well-known Breakout computer game. In a tournament where 20 subjects took turns playing this game against each other, one using gaze and one using a mouse, we demonstrate that gaze can be a superior input modality. In another experiment, we collected eye movement data from 9 subjects playing this game and find that expert and novice players differ in their employed eye movement strategies.

Keywords: *Gaming with gaze, human-computer interaction, alternative input devices*

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1. Introduction

Eye tracking has become cheaper and more robust over the last years because of the rapid progress in digital camera technology and the steady advance in computing power (Li & Parkhurst, 2006). With the advent of remote trackers and miniaturized eye cameras that can be integrated into comfortably worn glasses, it may soon become technologically feasible to deploy gaze-based systems in the mass market. However, there is still a lack of a "killer application" and existing, keyboard- or mouse-controlled applications often cannot easily be adapted to use gaze information (Jacob, 1993). One area in which an average consumer might benefit from eye tracking is in computer games, where gaze direction can add another dimension of input (Smith & Graham,

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2006; Isokoski & Martin, 2006; Dorr, Böhme, Martinetz, & Barth, 2007) Progress in this direction will also be highly relevant to disabled users who lack the dexterity to control the input modalities traditionally used in computer games. Not only could gaming with gaze be enjoyable in itself, but the virtual world of multi-player games might also be one arena where disabled users could meet non-disabled users on an equal footing (Istance, Bates, Hyrskykari, & Vicker, 2008).

However, for a satisfactory gaming experience, it does not suffice to simply replace the mouse with a gaze cursor; usually, changes to the game play will also have to be made. In this paper, we first present an open-source game adapted for control by either a mouse or gaze direction. We then show results from a small tournament that indicate that gaze is an equal if not superior input modality to a mouse for this game. Finally, we will analyze the eye movements made by players and investigate how eye movement strategies differ between novices and experienced players.

2. Modification of an Open-source Game

2.1 Breakout

Breakout was one of the first commercially available video games when it was released in 1976 (Kent, 2001). Its game play was based on Pong, where the player has to move a paddle horizontally to hit a ball that is reflected at the borders of the game area. Breakout now extended this concept by putting bricks in the upper part of the game area which dissolved upon contact with the ball; the goal of the game was no longer to keep the ball in the game as long as possible, but to destroy all bricks (see Figure 1 for a screen shot).

This simple, easy-to-understand game play makes Breakout still appealing today, more than 30 years after it was first sold. Countless clones have been published for various computer platforms (Wikipedia lists 56 “notable” clones alone), with better graphics and game-play-varying extra items, which are released upon the explosion of bricks and either need to be collected with the paddle (“good” extras, e.g. bonus points or an increase in paddle size) or should be avoided (“bad” extras, e.g. freezing the paddle for a short period or a speedup of the ball). The one-dimensional nature of paddle control in Breakout and Pong also makes these games suitable for input modalities that lack the degrees of freedom of keyboard, joystick, or mouse, or use noisier channels, e.g. brain-computer interfaces (Krepki, Blankertz, Curio, & Müller, 2007) or pitch of voice (the Sony SingStar console game). In the following, we will describe our version of Breakout, which was adapted for gaze control.

Figure 1. Screen shot of LBreakout2. The paddle at the bottom right can be moved horizontally to prevent the ball from hitting the bottom; the bricks in the upper part of the screen are destroyed on impact of the ball and might release extra items that modify the game.

2.2 Implementation

Our gaze-controlled version of Breakout is based on the open-source game LBreakout2 (Speck, n.d.). LBreakout2 is published under the GNU General Public License[1] (GPL), so that the game can be freely modified under the condition that the modifications will only be released under the GPL as well. This open-source approach is especially appropriate for such (currently) small markets as eye movement researchers and games geared towards those with severe motor impairments. Therefore, the source code of our modifications and a binary are available on our web site[2]; we would like to receive feedback and/or incorporate changes made by the community. LBreakout2 is written in C and uses the Simple Media Layer[3] for graphics, sound, and network functionality. We have modified it to work with SensoMotoric Instruments eye trackers, which use an ASCII network protocol sent over a UDP link, requiring no additional libraries. The major change to the source code was to implement a function that waits on a UDP socket for samples from the eye tracker and decodes them; instead of the paddle position being shifted by mouse movements, it is now set in absolute coordinates to the gaze position of the user. Because we do not have access to other eye-tracking equipment, we did not implement an interface to other trackers; however, this modification should be straightforward.

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[1] See http://www.fsf.org/licensing/licenses/gpl.html.

[2] See http://www.inb.uni-luebeck.de/tools-demos.

[3] See http://www.libsdl.org.

The part of the program that receives and parses gaze samples consists of a mere 120 lines of code and is quite simple. Implementing the calibration protocol, however, is slightly more complicated because data has to be sent back and forth between the client and the eye tracker. Therefore, a first version of the game used an external tool to calibrate the tracker to the screen before the game was started. Especially for demonstration purposes, where several players take turns, the constant need to shut down and restart the game rendered this external calibration impractical and led us to implement an in-game calibration procedure, initiated by key press from within the game. Furthermore, calibration procedures often use black markers on a light grey background; the background of the game, however, is of a very dark green. This reduction in screen brightness leads to an increase in pupil size compared to pupil size during calibration, which in turn reduces the accuracy of the eye tracking and for some subjects even makes tracking impossible (because their eyelids occlude a part of their pupils). Therefore, we calibrated on a screen of similar brightness as the game's background and increased ambient illumination in the room where experiments took place.

2.3 Adaptation of Game Play

To prevent the ball from going out of play, the paddle needs to be at the same horizontal position as the ball when the ball reaches the lower end of the screen. When the paddle is controlled by gaze, this means that, in principle, the player only needs to look at the position where the ball will meet the paddle. That this is very intuitive might be demonstrated by the following anecdote: During the CeBit trade fair show, we presented our game to a visitor who claimed to have had no experience with computer games at all. After calibration, she started playing and performed very well until, about 2 minutes into the game, she asked when “the whole thing would actually start”. Apparently, she had just constantly looked at the ball (and therefore always hit it with the paddle) without even realizing that the paddle followed her gaze!

Although playing with gaze is very intuitive, players naturally face other challenges in a gaze-controlled setting. A well-known problem for gaze-based user interfaces is how a user should confirm an action (the equivalent of a mouse click). In LBreakout2, a mouse click normally is needed to start the game and release the ball from the paddle. We solved this problem by releasing the ball automatically after 5 seconds when the game is played with gaze.

Another problem is that even the best eye trackers today cannot yet track gaze accurately when the subject makes abrupt head movements or blinks. There are also always calibration errors and, in video-based systems, some camera noise, so that the paddle position might be slightly shifted from the “true” gaze position. This can be highly irritating and must be consciously compensated for by the player, even though there are no fixation targets at the location that needs to be fixated.

Also, by carefully adjusting on which side of the paddle the ball is deflected, the player can control the direction in which the ball is sent off again, which is especially important when only a few isolated bricks remain on the screen and a failure to hit that one remaining target can be very frustrating. Due to tracking noise, this is much harder with gaze than with a mouse, but it seems that gaze players get better at this with some training (also see below).

In the Breakout version we have adapted, bricks that are destroyed sometimes release “extras” that fall towards the bottom of the screen. Once they are collected with the paddle, they alter the game by, for example, increasing the speed of the ball or making the ball explosive (so that several bricks can be destroyed at once). Some of these extras require a reaction by clicking the mouse (e.g. a “gun” that fires brick-destroying rounds), so we removed them from the game using the integrated level editor. Other extras should not be collected by the player because they have a negative impact; to carefully avoid looking at something in a dynamic environment requires a conscious effort and some training on the part of the player – that quick glance to check whether the bad extra has already disappeared could prove disastrous! One extra that is particularly enjoyable in gaze-playing mode, though, is the extra ball. Because of the much higher speed at which the eye can travel compared to the hand, it is possible to keep several balls in play simultaneously. Keeping track of a number of dynamic objects while still maintaining gaze on the ball that is going to reach the bottom of the screen next was a task that our subjects found highly entertaining.

3. Pitting Gaze against Mouse

LBreakout2 also offers a multi-player mode with one paddle at the bottom and one at the top of the screen. The goal is to play the balls in such a way that the opponent cannot return them. To make the game livelier, each player can fire up to 3 balls so that up to 6 balls are in the game simultaneously.

To test how well our gaze-based interface fared against the mouse, we set up a little tournament in which pairs of players took turns playing against each other. First, one player controlled the game with gaze and the other with the mouse, subsequently the roles were reversed.

Twenty undergraduate and graduate students from our department volunteered. Four had been previously involved in writing or presenting the game; the other 16 had had little or no eye-tracking experience and had not played the game before. To ensure a fair game, we also matched pairs by their general computer game experience.

Eye movements were recorded with a SensoMotoric Instruments iViewX Hi-Speed tracker running at 240 Hz. After a 5-point calibration, the gaze player was able to try out gaze control for about 15 to 30 seconds (which also served to validate the accuracy of the calibration). Then, the match started. Each match lasted 5 rounds. For every ball that the opponent could not return with their paddle, a player scored 1 point; a round was won by the first player to win 10 points. Each round was set on a different background, i.e. the layout of ball-deflecting bricks in between the players changed. Such bricks close to the player's baseline are a slight disadvantage for the gaze player because it is easier to aim shots exactly with the mouse (see above).

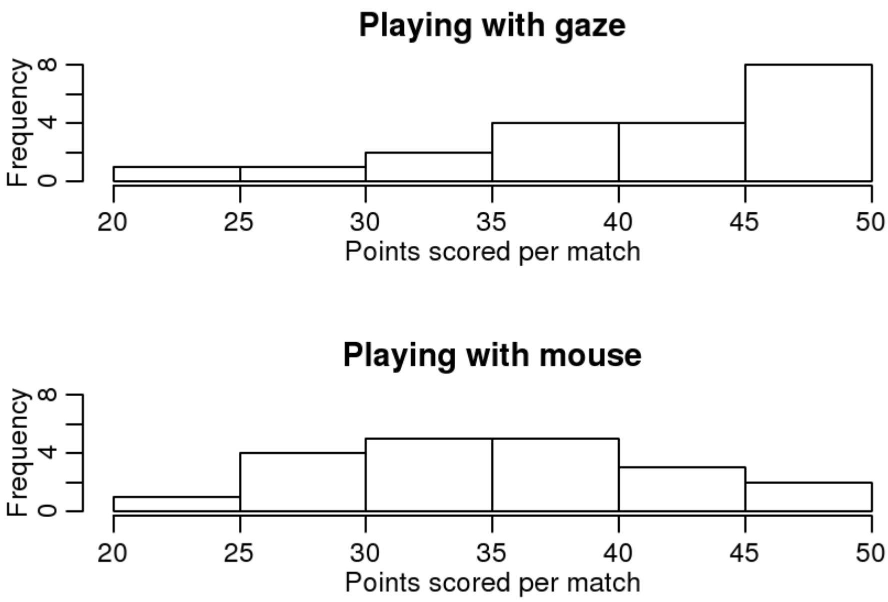

Figure 2. Results for the tournament where players using the gaze-controlled game competed against players with the mouse. Gaze outperformed the mouse as an input modality.

The results are shown in Figures 2 and 3. Clearly, playing with gaze yielded a higher score on average (41.95 vs. 36.25). Almost two thirds of all rounds (65 out of 99; one data set had to be discarded because the tracker had lost the pupil temporarily) were won by the gaze player. Gaze control was thus a statistically significant advantage ($p<0.0015$).

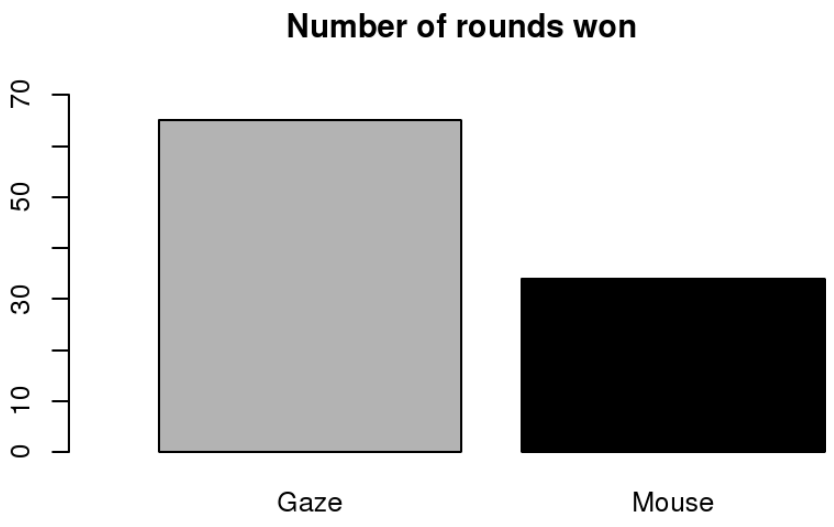

Figure 3. Results for the gaze vs. mouse tournament in terms of number of rounds won. 65 out of 99 rounds were won by the player using their gaze; gaze control thus was at a statistically significant advantage ($p<0.0015$).

4. Analysis of Eye Movement Strategies

4.1 Methods

Despite the game play's intuitiveness, an obvious question is whether different players might employ different strategies to control the paddle with their eyes and how such strategies might evolve with training. To answer this question, we collected data from 9 subjects; 5 were novices, i.e. had never played a gaze-controlled game before, the other 4 were experts and had at least several hours of gaming experience (two of them were authors, but one of them was naive with regard to the exact analyses to be conducted on the recorded data).

Eye movements were recorded from one eye with a SensoMotoric Instruments iViewX Hi-Speed tracker running at 500 Hz (the tracker is capable of sampling at 1250 Hz, but such high temporal precision was not required for the present study). This tracker requires the head to be fixed using a chinrest. We also have successfully played the game with a 50 Hz SMI RED-X remote tracker, which is obviously better suited for gaming and entertainment because it allows free head movement. However, the accuracy of the remote system is still considerably lower than that of the head-fixed tracker. This was particularly important for the gaze vs. mouse tournament, where no input modality should have an unfair advantage.

Subjects were seated 55 cm away from a screen of 40 cm width and 30 cm height, so that the game screen covered a visual angle of 40 by 30 degrees; at 640 pixels horizontal resolution, 16 pixels thus corresponded to 1 degree. After a short briefing on the game, subjects were seated at the tracker, the game was started, and an in-game 9-point calibration was performed. The subjects' task was to “Try to collect as many points as possible”'; if a subject had lost all their “lives”, the game nevertheless continued (but the score was reset to zero). The trial ended when all bricks were destroyed or there were only very few remaining bricks left; because of the difficulty in precisely placing the paddle with gaze, accurately aiming at isolated bricks can be tedious to impossible (note that this premature termination only took place in this experiment where eye movement strategies were investigated; in the gaze vs. mouse tournament, no such unfair advantage was granted to the gaze players). It took subjects between 5 and 7 minutes to finish the level.

The level used for this experiment consisted of 16 rows with 14 bricks each, out of which a randomly drawn 22 (10%) contained extra items. To avoid any bias in extra item selection, the type of extra contained in these bricks was chosen randomly at the beginning of each trial.

It is quite difficult to keep the head still for more than 5 minutes, especially for subjects unfamiliar with eye-tracking experiments; for this reason, our data contained a certain amount of impulse noise (where gaze position briefly changes greatly). We therefore computed the sample-to-sample velocities and discarded the 2% highest-velocity samples, which showed biologically implausible speeds of up to more than 1000 deg/s.

4.2 Number of Saccades

As can be seen in Figure 4, there is no clear difference in the number of saccadic eye movements made by experts and novices.

4.3 Focus of Fixations

We analysed how often experts and novices looked at the ball, which is the most relevant in-game item, and at good and bad extras. For each gaze sample, we determined the in-game item with the smallest Euclidean distance to gaze position on the screen; if the point of regard was more than 80 pixels (5 degrees) away from any ball or item, we classified this sample as “no identifiable focus”. The results are shown in Figure 5: clearly, experts spend more time looking at the ball than novices (71.8% vs. 61%); they also spend a lot more time looking at good extras (15.3% vs. 9.8%), but there is no big difference for the bad extras (7.6% vs. 8%). Note, however, that the latter percentages for the extra items are relative only to the time in which any good (or bad, respectively) items were shown on the screen (18.9% and 15.3% good extras, 10.2% and 9.2% bad extras), so that both experts and novices still spend considerable time “looking” at no item in particular (24.5% for experts, 36.7% for novices). The result for the good extras could be explained by the higher cognitive demands placed on novices compared to the experts; novices might employ a narrower attentional focus and therefore ignore good extras more often. This is at odds, however, with the result for ball-following, which seems to indicate that novices are also more easily distracted from the ball.

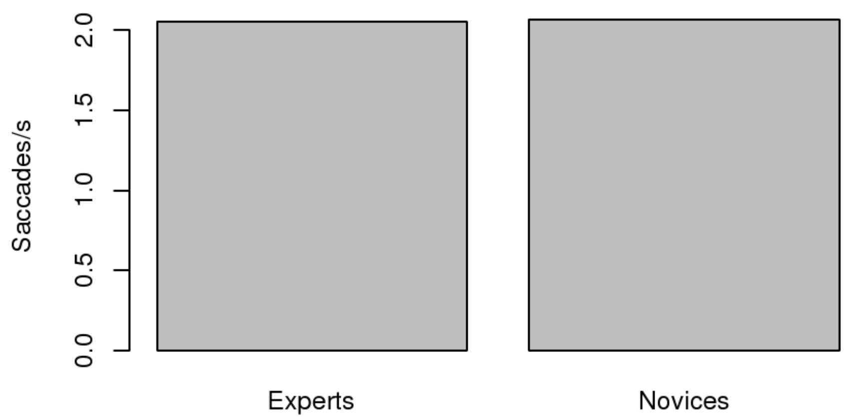

Figure 4. Saccade rates for experts and novices. There is no significant difference.

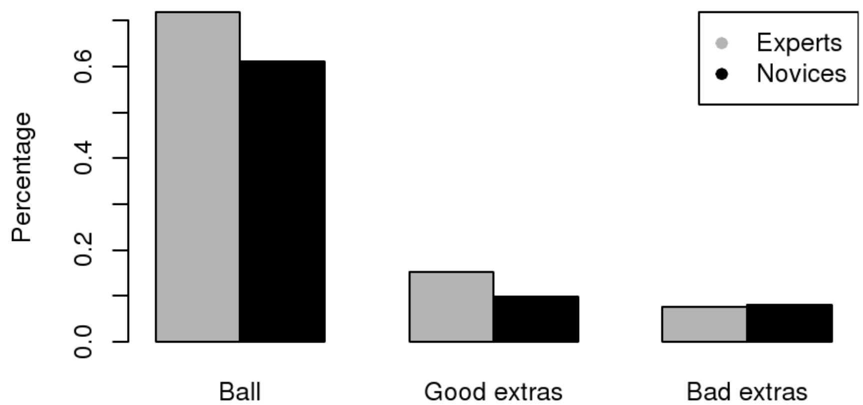

Figure 5. Distribution of time spent fixating different in-game items. Experts spend more time looking at the ball and at good extras than novices. Note that percentages for extras are relative to the time where any good (or bad, respectively) items were shown on the screen (between 9 and 19% of overall time). Values missing to 100% correspond to those fixations where no clear fixation target could be identified.

4.4 Distribution of Distance from Gaze to Ball

We now turn towards the question of how close gaze follows the ball. A distribution of distances for the experts can be seen in Figure 6: 50% of all gaze samples are closer to the ball than 2.76 degrees (experts; 3.45 degrees for novices) and 75% of samples are still closer than 5.24 degrees (6.46 degrees for novices). To visualise the difference between experts and novices more clearly, empirical cumulative distribution functions are plotted in Figure 7 and they show a clear difference between the two groups.

This difference is highly significant (p<<1e-10) using a corrected Kolmogorov-Smirnov test. The test statistic had to be corrected for the overestimation of sample size introduced by the high sampling rate of the eye tracker: because eye position is sampled at 500 Hz, but significant eye movements occur at a much lower rate, the distance measurements are highly correlated and therefore violate the assumption of independent samples for the statistical test (Weiss, 1989). To correct for this bias, we estimated the amount of statistical dependence by evaluating where the autocorrelation function of the distance measurements had dropped to 0.5; we then subsampled the distance distributions by that factor (averaged over all 9 subjects 118.9 samples, s.d. 28.1).

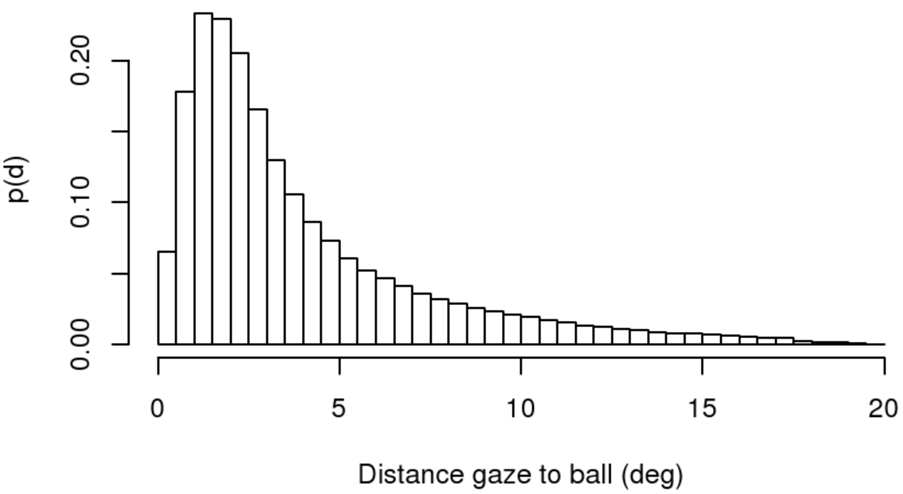

Figure 6. Distribution of distance from gaze to ball for the experts. Most of the time, the ball is at least kept in para-foveal vision.

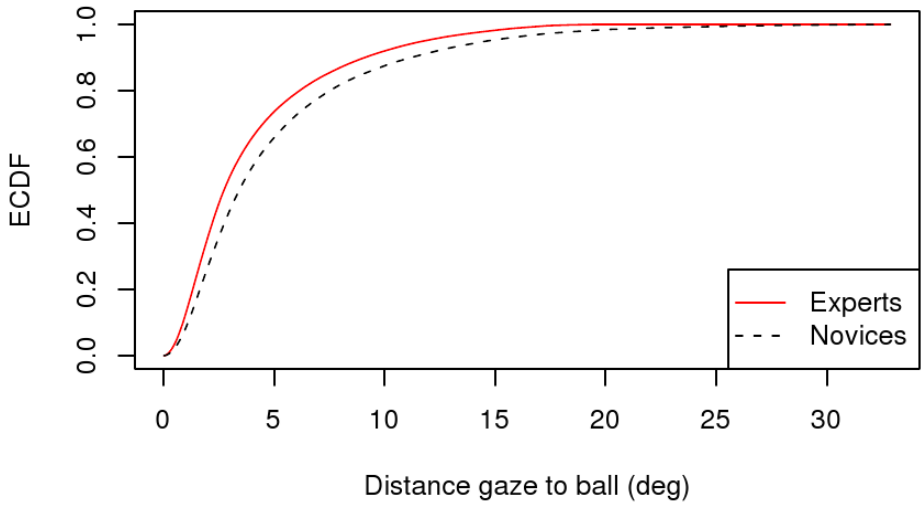

Figure 7. Comparison of distribution of distance from gaze to ball for experts and novices. Experts spend more time looking closer to the ball; this difference is highly significant ($p<<1e-10$, corrected Kolmogorov-Smirnov test).

A further aspect of novice and expert behaviour we investigated was how ball-following changed across the screen. Strictly speaking, it is only necessary to fixate or closely follow the ball whenever it is close to the bottom, because a failure to do so will result in the loss of a game "life". When the ball is further up on the screen, the player's gaze is free to look around, for example to collect extra items; nevertheless, the deflection point of the ball at the top of the screen (or the bottom-most row of bricks) might be a worthwhile gaze position because it is most informative about where the ball will come down again (for example, table tennis players use a similar strategy to predict the ball's trajectory, see Land and Furneaux, 1997). We therefore show the median of the distance from gaze to ball as a function of vertical ball position on the screen in Figure 8; note that this plot only shows horizontal distance because it should be independent of vertical ball position, whereas vertical distance might be affected by border effects (e.g. when the ball bounces at the top border of the screen, subjects might fixate slightly below the expected deflection point to maximize the time the ball is close to the centre of fixation). Also note that we plot only those samples where the subject was not obviously fixating another interesting object, i.e. an extra item.

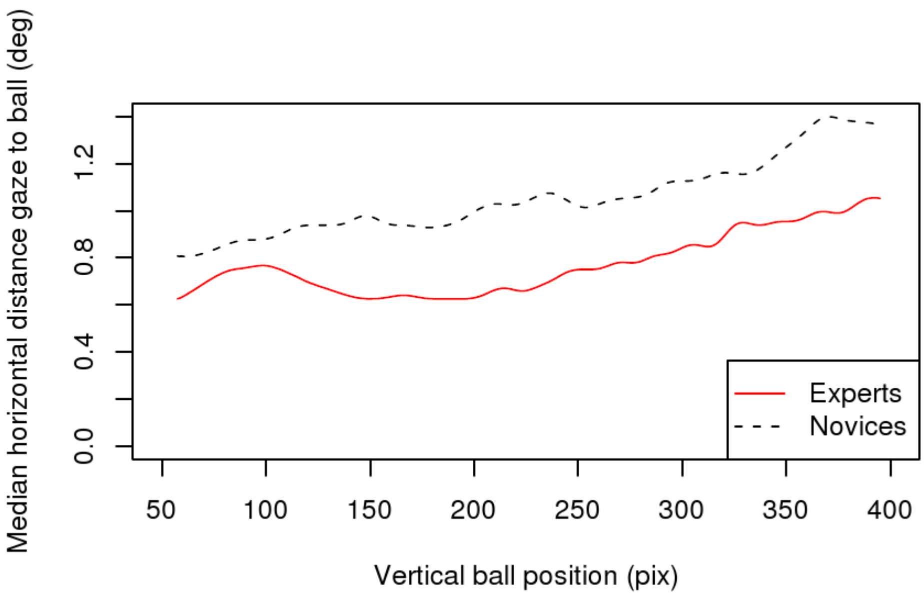

Figure 8. Median horizontal distance of gaze to ball as a function of vertical ball position. Ideally, this distance should be minimal at the bottom of the screen; note the local peak in distance for the expert group shortly before the ball needs to be hit by the paddle.

Indeed, novices look closest to the ball only at the bottom of the screen, when they need to hit the ball with the paddle, and horizontal distance increases almost monotonically towards the top of the screen. For experts, however, the picture is not quite as clear: although the distance is at its maximum at the top of the screen, it is relatively small slightly below the middle, and there is even an increase close to the bottom, just before the paddle hits the ball. This local peak close to the bottom was found in all the individual experts' recordings and we can only hypothesize about a possible explanation. Experts might not follow the ball on its way towards the bottom with a pursuit movement, but predict the landing point on the paddle (this sounds very simple; in practice, however, it is quite difficult to maintain fixation in the absence of a fixation target at the bottom of the screen -- and in the presence of a behaviourally relevant, moving stimulus close to the fovea!); this would also help to deliberately hit the ball with one of the sides of the paddle to return the ball in a certain direction.

4.5 Distribution of Saccadic Landing Points

In a final analysis of eye movement strategies, we investigated where experts and novices direct their saccades. Figure 9 shows the empirical cumulative distributions of the vertical components of saccadic landing points: whereas experts and novices seem to make a similar number of saccades towards the bottom of the screen, the gaze of experts jumps more often slightly above that. This highly significant difference (p<2.6e-5, Kolmogorov-Smirnov test) is in line with the difference in horizontal distance to the ball close to the bottom of the screen as depicted in Figure 8: experts seem to employ a different strategy just before the ball hits the paddle.

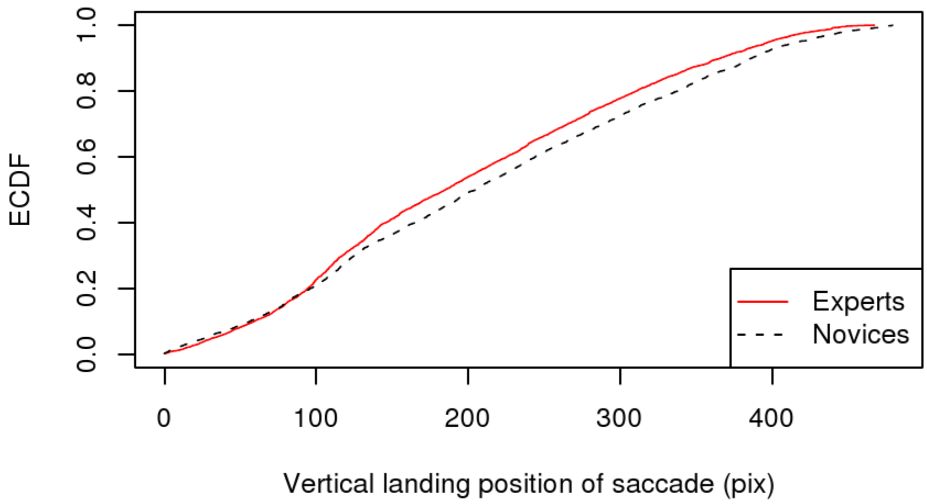

Figure 9. Empirical cumulative distribution function for vertical landing positions of saccades. Experts make fast eye movements towards a region slightly above the bottom line more often (p<3e-9, Kolmogorov-Smirnov test).

5. Conclusion

We have presented modifications to the open-source game LBreakout2 that allow the game to be controlled with gaze. Even though both the graphics and the game play of LBreakout2 are very simple, our test subjects found “playing with eyes” highly enjoyable.

We also described how playing with gaze affects eye movement statistics and how eye movement strategies change with training. Specifically, we have shown that expert players are fixating a position close to the ball more often, spend more time looking at good extra items, and apparently seem to employ a different strategy to predict where the ball will come down just above the bottom line.

Finally, we have also presented results that show that gaze-based interfaces can be superior to traditional input modalities even for users that have had no previous training with such interfaces. At first, these results seem to be at odds with previous work on gaze-controlled computer games, which found that gaze control does not perform as well as mouse control (Smith & Graham, 2006; Isokoski & Martin, 2006). However, Breakout has a particularly simple and intuitive game play that makes it ideally suited for gaze playing. Future work will have to address how such natural gaze input can also be successfully used in more complex game scenarios and how games can be designed specifically for gaze input.

6. Acknowledgements

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