Breath Control of Amusement Rides

Joe Marshall, Duncan Rowland[1], Stefan Rennick Egglestone, Steve Benford, Brendan Walker, Derek McAuley
Horizon Digital Economy Research & The Mixed Reality Laboratory
The University of Nottingham, UK
{jqm, dar, sre, sdb, }@cs.nott.ac.uk, info@aerial.fm, drm@cs.nott.ac.uk
[1]current affiliation: Lincoln School of Computer Science, University of Lincoln, UK, drowland@lincoln.ac.uk

ABSTRACT
Emerging robotic technologies are enabling the control of individual seats on rollercoasters and other thrill rides. We explore the potential of breathing as an effective and engaging way of driving this. Observations and interviews from trials of an enhanced bucking bronco ride show that breath-control is fun, challenging and intelligible, and reveal riders' tactics as they battled the machine. We conclude that breath control is feasible and appropriate for controlling rides, unpack its important characteristics, and consider how it might be built into future ride systems. We argue that the combination of voluntary and involuntary factors in breathing is especially appealing for controlling rides as it balances game-like elements of skill and learning against the thrill of surrendering control to the machine.

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Breathing, breath control, amusement ride, biosensing, affective computing, bucking bronco, thrill, themepark

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI)

General Terms
Design

INTRODUCTION
The earliest fairground rides were small-scale affairs in which human operators directly controlled speed and duration in response to riders' expressions of excitement and fear, especially screams [1]. Some even allowed fine-grained tuning such as when 'gaff lads' who collected money on 'waltzers' gave a carriage an extra spin. Driven by a desire for ever greater thrills, coupled to demands for increasing throughput, ride technology has since evolved into large-scale computer-controlled 'thrill rides' (rollercoasters and large 'spin rides') that provide riders with an identical experience. However, a new generation of ride technologies is emerging in which computer-controlled robotic systems steer individual carriages or seats. The Robocoaster G1, for example, consists of a pair of seats on the end of a large flexible robotic arm, while the G2 and G3 attach several arms to shuttles to create a rollercoaster in which small groups of seats can be moved around the track as the ride unfolds [22]. Looking forwards, future rides are likely to deliver thrilling but also highly personalized experiences. They might even learn about riders' reactions and adapt themselves on subsequent visits.

The key question now becomes: on what basis might such real-time control be achieved? How can a human interact with a robotic system that is pushing them around under high G-forces when they are also feeling excited or scared? What form of control might enhance the experience of a thrilling ride? One strategy is to give riders voluntary control over some aspects of their movement, allowing them to partially steer their own seats. An alternative is to use biosensing to measure the rider's involuntary responses and automatically adapt the ride accordingly, mirroring the role of the traditional human operator.

In this paper, we explore how both strategies can be combined through the use of breath control. We have four motivations for this: breath control offers an intriguing balance between voluntary and involuntary control; it responds to the ride pushing back at the rider, creating a direct physical feedback loop between human and machine; riders can be highly aware of their own breathing; and it may be feasible to measure it with sufficient reliability, even under the extreme conditions of an amusement ride. We have therefore developed a small-scale prototype ride and conducted public trials in order to explore the opportunities and challenges associated with breath-controlled rides. Our contributions are to demonstrate the feasibility of this approach; to explore what kinds of control are possible and how they feel; and then to consider how the approach might be deployed on future rides. More generally we seek to extend HCI's appreciation of the nuances of breath control as an interaction technique and to highlight the potentially productive tensions between voluntary and involuntary control of interactive systems.

RELATED WORK
Although amusement rides are a popular and commercially significant form of entertainment, they have received scant attention within HCI and related fields. Previous work has focused on designing virtual reality rides [19], technologies for controlling animatronics, lighting and sound on 'dark rides' [7], and revealing riders' physiological responses to spectators [24]. Our paper adopts a distinct focus on how

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humans can interact with robotic ride systems to influence the physical movement of the ride as part of a thrilling and yet also personally responsive experience.

There is, in contrast, a far more established body of research into breath as an input mechanism, falling into two main categories: assistive technologies that adapt user interfaces to specific abilities; and expressive devices that enable dynamic control of creative applications. Assistive interfaces include keyboards for use by individuals with motor impairments such as tetraplegia; simple 'suck-puff' switches allow letters to be selected from an on-screen keyboard, while more recent advances use piezo film sensor arrays to detect flow [12]. Along with more accurate control of screen-based interfaces [8], improved sensitivity and reliability of sensors is now enabling breath to control physical artifacts such as powered wheelchairs [30]. Turning to creative applications, breath controllers have augmented traditional wind and brass musical instruments (e.g., the Yamaha BC3A Breath Controller [29]) and been incorporated into new kinds of instrument [2]. Breath control has been put to other creative uses too: for controlling computer games [13, 31]; for navigating an immersive virtual world through the metaphor of diving [5]; and for enabling two-way 'gust-based' communication [23]. Mainstream products have also entered the market, for example the Sensawaft breath controlled mouse [25].

Beyond direct control, breathing can also reveal one's physiological and psychological responses to an experience, including levels of exertion, relaxation or anxiety. Here, monitoring breathing is an example of the more general approach of biosensing that is of growing interest to HCI and entertainment computing. 'Exertion interfaces' [16] to boxing [15] and cycling [26] games respond to heart-rate in order to promote exercise. Other games test players' skill at controlling their heart rates, requiring them to move between exertion and relaxation, for example when skiing and then shooting in Pulse Masters Biathlon [18], or when capturing territory on the city streets in the pervasive game 'Ere be Dragons [3]. There is also a body of work on incorporating biosensing into novel performances [17].

We extend this prior work on breath control and biosensing in two directions. First, by focusing on amusement rides, we explore the effects of a direct physical feedback loop in which a robotic system pushes back at the user, affecting their breathing as they in turn, try to control the ride. Second, we focus on the relationship between voluntary and involuntary control of breathing, especially how a creative tension between these may lead to engaging experiences.

THE BRONCOMATIC

Our approach to exploring the use of breath control in relation to amusement rides has been to construct a prototype ride and then study the experiences of riders through observation, interviews and analysis of breathing data captured from a series of public trials.

A key challenge was to design a ride that was realistic enough to be able to test breath control, and yet practical in terms of cost, tourability and safety. We alighted on the idea of extending an existing commercial bucking bronco ride of the kind that can be hired out for public events such as parties. Although not an extreme rollercoaster, a bucking bronco provides a quite intensive physical experience for a single rider (usually sufficient to throw them off) that is controlled in real-time (by a human operator). Bronco rides clearly push back on the rider, throwing them around and demanding considerable physical exertion as well as concentration. More practically, our bucking bronco was small enough to live in our lab during development, portable enough to take to various venues for public trials, and also proven to be safe over many years use at parties and similar events. In short, we felt that the bucking bronco would be a sufficiently realistic platform for testing breath control of amusement rides. An initial test in which we got a human operator to control the bronco based on data that was transmitted from the rider over a wireless network [21] confirmed the practicability of using the bronco and so we began to develop an automated version – the Broncomatic.

Figure 1. Overview of the Broncomatic

Figure 1 shows the physical set-up of the Broncomatic. The ride unit is a standard commercial ride consisting of a large red egg (broncos come in various physical forms from the traditional 'rodeo bull' to more unusual shapes) attached to a base unit in which there are two large motors that generate buck and spin movements. Riders don a breathing sensor in the form of a chest strap, sit on top of the Bucking Bronco and attempt to remain on the ride while it moves around at high speeds. Under normal operation, the ride is controlled by a human operator who uses a joystick and two speed controls mounted on a nearby control unit (left of picture) which adjust how fast the bronco spins around its vertical axis and bucks by rocking forward and backwards. While these are now under computer control in the Broncomatic, the human operator is present to monitor proceedings and press a large red safety cut-off button in case of difficulties. Finally, a large inflatable mat catches riders safely when they fall off – we have had over 100 rides with no notable injuries (Figure 2 shows an example of a quite extreme fall where the rider landed safely).

Figure 2. Falling off the Broncomatic

Controlling the ride

The original bucking bronco ride is certified as safe for public use and has several mechanical and electronic limits built into the control system, including the cut-off switch mentioned previously. In order not to compromise safety, we were keen to avoid directly altering the internals of the control hardware in any way. Our solution was to use the Phidgets physical interface prototyping toolkit [10] to construct a series of physically actuated controllers to push and pull the bronco's existing joystick and 'buck speed' and 'spin speed' dials, directly manipulating them as a human would (see Figure 3 where the small crosshatched circle next to each control is a servo connected to that control). The joystick is connected to 4 servos by tight metal wires, and the dials are connected to a servo each, using gears. As a result of this direct control, our system cannot make the bronco move in any way that a human operator could not, and so we stay within the proven, certified safety envelope of the ride. We also felt that seeing the computer physically controlling the ride would add to the public spectacle of the Broncomatic, enhancing its performativity for onlookers.

We use a MindMedia Nexus 10 Bluetooth device for breath control, which fits in a pouch worn on the body and can transmit data wirelessly. We use a belt sensor, mounted around the rider's chest which determines breathing rate and the speed at which a rider is exhaling or inhaling by detecting chest expansion. The control software for the Broncomatic runs on a nearby laptop, which receives biosensing data over Bluetooth, and is connected to the Phidgets hardware interface which controls the servos on the control panel. This integrator software takes data from the sensor, and runs a Python 'game script' that maps this to the control outputs and also drives a scoreboard shown on a nearby projection screen.

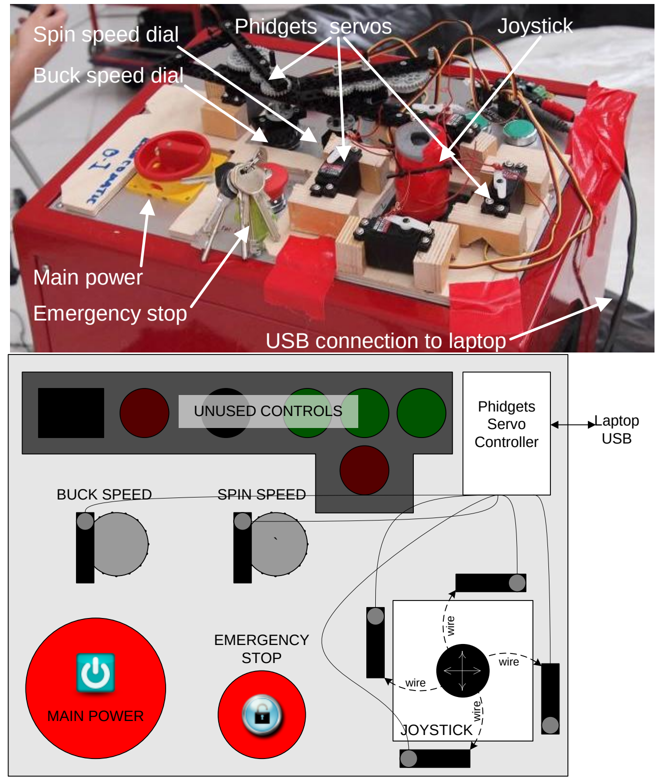

Figure 3. Broncomatic Controller and system diagram

The ride program – the Broncomatic Breathing Game

Our ride program takes the form of a simple game that is intended to explore the potential of breath control under ride conditions that vary from easy to extremely difficult. We implemented a straightforward mapping from the rider's breathing to the horizontal rotation of the ride. Inhaling causes the ride to turn clockwise, while exhaling causes the reverse anti-clockwise rotation. The speed of rotation is modulated by the speed of breathing, so that holding your breath makes the bronco stop, and inhaling or exhaling quickly makes it spin very fast. In order to introduce increasing difficulty into the experience, and also to limit the maximum time people can stay on the ride, the system then gradually and automatically increases the speed of the rotation and also eventually adds bucking to the basic rotation movement. The sequence progresses over three distinct levels. On the first level, which lasts for thirty seconds, breathing makes the bronco turn relatively slowly. On the second, also lasting for thirty seconds, the bronco turns more quickly for the same amount of breathing. On the final level, which lasts until the rider falls off, as well as another increase in spin-speed, the bronco begins to buck, which makes it extremely difficult to stay on.

Finally, the whole ride program is presented as a game in which the player scores more points the more that they breathe (which is presented to them as being based upon the total volume of air that they breathe). This sets up a fundamental tension between needing to breathe more in order to score points, but breathe less to be able to stay on the ride. In order to get a high score, the rider must breathe a lot (meaning repeated large chest expansions), making the ride move fast, which in turn makes it harder to stay on, creating a powerful dynamic and physical feedback loop in which people who want to do well are forced to push themselves harder and harder.

During the game, a large screen provides a public display of the score from the current game and a trace of the breathing sensor data. At the end of a ride, a small sticker printer prints off a sticky label with the rider's game score on it, which they can stick on their lapel. A small trace on the bottom of the sticker shows their breathing sensor data for the last 20 seconds of the ride. This souvenir also makes them a walking advert for the ride.

BRONCOMATIC TRIALS

We ran three trials with Broncomatic. In the first we set up the ride in a public atrium near a busy café and encouraged passersby to ride. Secondly, at a large student networking event, we invited volunteers to try it. In the third trial, we ran the Broncomatic at our lab and recruited a group of eight friends to repeatedly try the ride over several hours. This final test aimed to explore what happened when people rode multiple times and also to see whether spectators being personally known to the rider made a difference. A total of 43 participants took part in the three trials (23, 12 & 8 respectively), they experienced a total of 72 rides (1 person riding 5 times, 7 people riding 4 times, 4 riding twice, and 31 riding a single time). We instructed all riders briefly in the basic ride response of turning with breathing, and told them of the three levels of increasing difficulty.

We recorded video of, and logged the breathing sensor data from, each rider and also conducted semi-structured interviews immediately after each ride, asking about people's experience. A team of three people ran each experiment, one running the Broncomatic software and hardware, one interviewing people after the ride and the third in charge of a hard-wired emergency power button in case of ride malfunctions. This allowed for a relatively high throughput of riders at roughly 1 ride per 2 minutes. Participants were not paid for their time for several reasons: firstly, we hoped the ride was enjoyable in itself, so riders got a fun experience by taking part; secondly, the bronco is quite an intense ride and we did not want to encourage anyone to ride the ride who would otherwise be too scared. Broadly, the aim was to run trials with a demographic typical for riders of other small fairground rides.

For completeness, we note that the Broncomatic was modified slightly between the three trials. In the first experiment, we did not have the large scoring display and found that it was hard for people to have an idea of how good a score they were getting during the ride, or for spectators to see how the rider was doing, so this was subsequently added. After feedback from the second experiment, we modified level 3, to make the buck movement come in more slowly once level 3 started and increasing over the next 30 seconds. This was designed to make the shift from level 2 to level 3 less severe, whilst still maintaining the high difficulty level that limits the time people are likely to stay on the ride.

EXPERIENCING THE BRONCOMATIC

In presenting our findings, we focus on two key questions: what tactics and strategies were riders able to employ, and how did it feel to ride the Broncomatic, especially with regard to control of the ride and of one's own breathing? We draw on the interviews and our observations, presenting examples and illustrating them with quotes and also graphs that show the rate of expansion and contraction of the breathing sensor belt over time. We use this in the ride as an approximation of people's breathing – a negative value shows that someone is exhaling air, and a positive value shows that they are inhaling air. Due to the different sizes of people's chests that stretch the belt differently, sensor readings have to be normalized by the ride software. Consequently, there is no vertical scale on these graphs as the raw values are essentially specific to the rider (and also to how the belt is adjusted). While movement of the chest strap is an approximation of breathing (as considered later in the paper), it is a sufficiently good one for the riders to experience a believable sense of control and for the graphs to show changing patterns of breathing over time.

Riders' Tactics and Strategies

We begin by identifying and comparing various tactics and strategies that were employed by riders during the ride.

Controlled breathing

Most riders tried hard to focus on their breathing: "*you're just concentrating, concentrating so hard*". A lot of them tried to keep a steady breathing pace: "*because I used to do a lot of martial arts, and of course from that, we focus on how to calm your breathing down to a point, so I mainly just tried to focus on that, just calm it down, keep it level and steady*". One rider even rode the ride with their eyes closed to try and stay in control of the ride, emphasizing the idea of being inwardly focused: "*I closed my eyes, and I breathed deeply.*" The graph in Figure 4 shows an example of this steady breathing, where the rider breathed constantly at 26 breaths per minute until they got 12 seconds into level 3, could no longer keep it steady, and fell off.

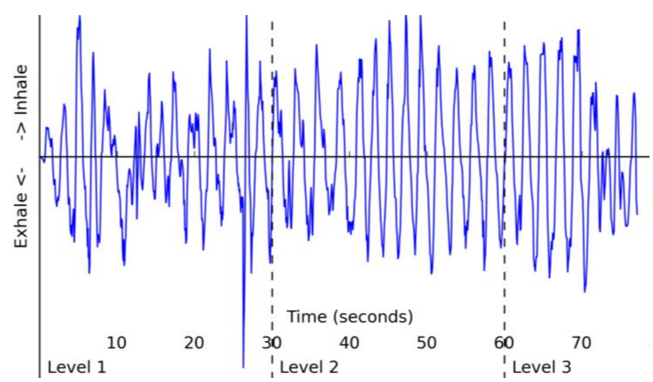

Figure 4. Controlled, steady breathing

Several riders related their breath control tactics to sporting activities: "*I play rugby as well, and when you're playing, when you're really concentrating, you've still got to focus on breathing while you're running the whole time*", "*I used to do a lot of martial arts, and of course from that, we focus on how to calm your breathing down to a point*"

Holding one's breath

Interviewees reported holding their breath at key moments to be a tactic, especially to control the ride as it stepped up to the next level (there was an audible alert on level changes). Figure 5 shows a rider holding her breath as level 2 kicks in at 30 seconds so as to start the level gently. When level 3 started at 60 seconds the extra speed meant that she quickly lost control of her breathing, causing the ride to spin quickly and making her fall off.

Holding one's breath could also be a good tactic to temporarily stop the ride, rebalance and regain control: "*it threw me off, I managed to hold my breath, there was a spin, and I almost lost it, then I held my breath.*" However, while a useful tactic in the short term, breath holding was a self-limiting option in the longer term. Beyond not scoring points, the longer you hold your breath, the harder you need to breath afterwards, and people cannot hold their breath for ever: "*I guess I thought that if I held my breath when I was about to fall off, it might be okay, and that worked for a few seconds, but then I found myself like going, losing blood, you know, needing a breath*". Figure 6 shows a rider who held their breath for 10 seconds (between 20 and 30 seconds) before running out of breath.

It appears that holding one's breath led to a rise in tension as the rider realized that they would have to breathe sooner or later, possibly exacerbated by the physical sensation of gradually running out of breath, a feeling perhaps not unlike approaching a drop in a rollercoaster.

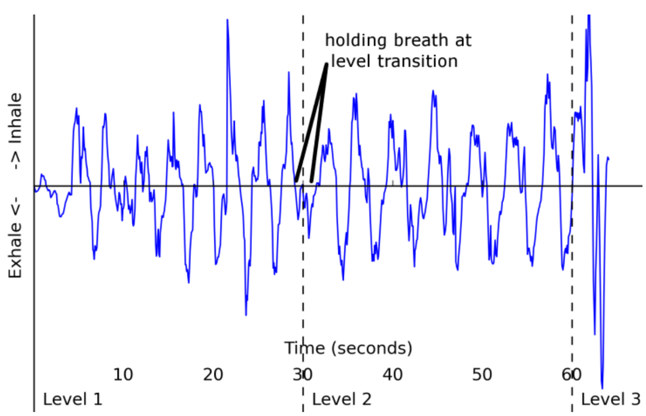

Figure 5. Holding breath between levels

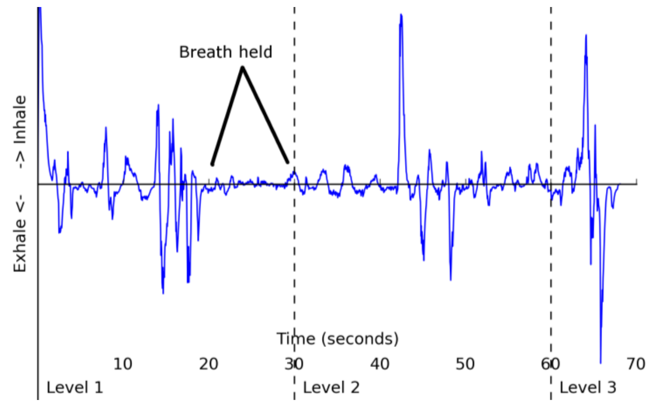

Figure 6. A rider who held his breath

Holding on tight

Sometimes riders gave up on breath control and just held on in the hope that they could continue to do so, particularly at the point they lost control of their breathing, mostly in level 3: "*…level three, like near the end; I was just concentrating on holding on with my legs and arms as tightly as possibly*". Figure 7 shows an example of the odd positions people end up in whilst hanging on. Such positions also have an effect on their breathing that makes the ride less predictable. However, holding on could be a good tactic when all else failed. Figure 8 shows the breathing of a rider who managed to hang on for 60 seconds in level 3, despite being thrown about and breathing wildly.

Longer term strategies

Those who rode multiple times experienced a learning process, a mixture of getting used to the twin challenges of staying on the bronco and controlling their breathing, whilst also optimizing strategies in order to get the highest score: "*The first time you don't know what to expect and you're kind of just getting the hang of it, second time, tried to control it too much, and it didn't work out, and then the third time, was better because I was just like right; I'm just going to concentrate on [staying on and breathing deep]*."

Figure 7. An example of hanging on

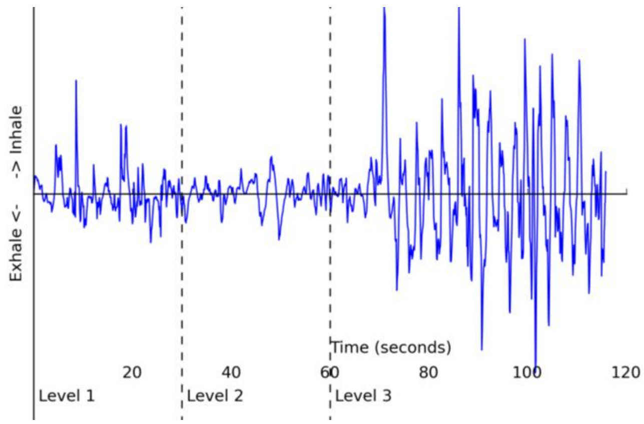

Figure 8. Hanging on while breathing wildly in level 3

This led to whole ride strategies, rather than localized tactics, taking into account the way the game progresses to get the highest score. Several riders noticed that in the first level, it was relatively easy to stay on the bronco, even with quite hard breathing, whilst on levels 2 and 3 it was much harder (the scoring was the same on all levels). This led to an overall ride strategy of breathing as hard as possible to get a good score on level 1, then trying to calm down breathing on 2 and 3: *"First time I tried long slow breaths, to sort of pace it and then I realised that you need to score quite highly in the lower levels, so I think it's a case of exploitation of the system a little bit"*. Figure 9 shows a rider who managed to breathe very hard up to 30 seconds (average of 61 breaths per minute), then calmed down to try and stay on in level 2 and 3 (average of 26 breaths per minute). However, this rider reported feeling quite dizzy after the extreme breathing on level 1, which is probably why they fell off so quickly in level 3. Recorded breathing rates provide further evidence that riders were able to push their breathing rates harder in the earlier levels. For example, in the third experiment, the maximum breaths per minute of any rider were 62 for level 1, 48 for level 2, and 36 for level 3.

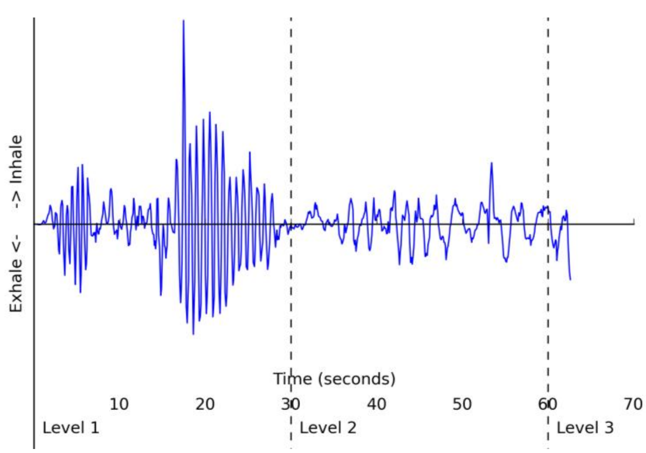

Figure 9. Very quick breathing in level 1

How does it feel to ride the Broncomatic?

We now turn to the question of how it felt to ride the Broncomatic as revealed by our interview.

How did it feel overall?

We asked riders whether they enjoyed the ride. All but one of the riders was very positive about their enjoyment of the ride, even those who had ridden it three or four times already. One rider had slightly mixed feelings, as he felt it was fun, but drank too much the night before, so was hung-over, and the ride had made him feel sick (not an unusual feeling for some people on amusement rides). For all riders, this was the first time they had experienced a breath controlled ride. It was clearly quite a different experience to other rides, even for those with plenty of amusement ride experience as the breath control seemed to feel unusual: "*It was err, a really strange experience, something I've never, never experienced before, so it was kind of odd"*

Most people found the ride hard, particularly on level 3, where the tilting movement made it much harder for people; as one rider said: "*it's not as jerky as it looks, it's much smoother, and then level 3 happens and it all goes to pot".* The longest any rider managed to stay on was 171 seconds (2 minutes 51s), which included 71 seconds on level 3. The shortest rides were under 15 seconds, with a median ride length of 66 seconds. 66% of rides reached level 3, whilst a small number of people fell off very quickly (15% of rides). The progressive difficulty increase stopped people getting bored, yet allowed them some time to discover how the ride worked: "*I figured out what the mapping was between how I was breathing and what would happen; it was cool. And then, when it changed level, there were things that shifted and I had to readjust again, which was really good, stopped me getting like too confident with it, or bored or whatever.*"

Responsiveness and control of the ride

Responses to the questions "did you feel the ride was responding to you?" and "did you feel in control of the ride?" give an interesting insight into the overall dynamic of the ride. When asked whether they felt the ride was responding to them, only 3 riders said they couldn't tell, with 35 riders feeling it certainly was responding to their breathing. However, whilst riders generally felt that the ride was responding to them, they varied as to how much they felt in control of the ride, with only 9 riders saying that they felt completely in control of the ride, and 16 saying they had a level of control, but not right throughout the ride.

When asked for more detail, several described a progressive loss of control as the levels got more difficult: "*I think at the first stage, I was controlling the situation …. 2, it was in the middle, between me and the machine. Level 3 was err, out of my control. I tried not to breathe!*", "*…the third one I was focusing so much in trying to stay on the thing that I lost all my ability to change direction*". There is sometimes a strong feedback loop between the rider and the ride when they lose control: "*when it speeds up quite a bit, it shocked* *me, and I breathed a bit deeper, so it threw me off.*" Others were tripped up by the link between breathing and talking, for example by laughing: "*I was trying to control it and it was working, but I guess when you start having fun, like in the end, where it just - spun - like that completely, and that was the time when I was laughing myself,"*

Due to the servos and motors, there is inevitably a slight delay in response; this also made people lose control: "*I thought the delay was significant enough so that I felt that I wasn't completely in control of the situation*".

Responsiveness and control of their own bodies

We also wanted to know if riders felt in control of their breathing and movements. We asked whether riders lost control of their breathing at all. Of 41 riders, 20 felt they lost control of their breathing during the ride, whereas 12 stayed in control throughout (9 were uncertain). We also asked whether riders fell off as soon as they lost control. Of the 20 who lost control, 9 said they fell off the bronco straight away. Riders described various tactics that they adopted for trying to stay on the ride when they reached the tipping point of loss of control as we discussed above

Competition with others

After observing some people competing with each other in the first experiment, in the second two experiments, we asked riders whether they felt they were competing with others. Interestingly, several people (9 of the 16 people who answered this question) did not feel that they were competing in any way with anyone else and were instead viewing the ride as a personal challenge: "*mainly with myself, rather than with other people ... for me I think it was much more about, trying to see that the balance is right*". The other 7 were more directed at getting the high score – "*Yeah definitely, [going for a high score] yeah, that's my thing*". As well as trying for a long ride or a high score, some people chose to ignore the game and play around with the ride just for the joy of controlling the ride: "*seeing how much I could turn it on the early levels, so just taking big, deep breaths, see how far it would go, and then breathe out as much as possible. Then on the last couple, I was just kind of trying to breathe in more than out, to try and get it to turn back round. Which didn't work.*"

Noticing spectators

We were interested to know how riders felt about having their breathing put on public display. Interestingly, no-one said anything negative about this; people's feelings were a mixture of neutral ("*Not really bothered*") and actively positive comments: "…*having people watching, I mean family are here today, and quite a few students who may know me, colleagues, that, that adds quite a lot to the experience.*", "*Good fun, enjoy being a spectacle, what can I say, I'm a bit of a joker.*" People didn't seem to mind their breathing being broadcast to spectators at all, perhaps because they didn't see any real privacy issue around it: "*It didn't worry me too much, because, I don't think that ... there's not a lot that you can kind of infer from breathing", "I wasn't really too fussed about people seeing my breathing, because I don't think, I don't really think that it's a private matter I guess*". However, one rider had been concerned about revealing the state of their health in advance of the ride: "*I'm a smoker, and I've got a cold at the moment, so I was thinking, I'm gonna be terrible at this, because I'm pretty unhealthy in that sense*".

Interestingly, despite at times there being large groups of people around the Broncomatic and people taking flash photographs etc., many riders said that they did not notice them at all, due to being so focused on the ride: "…*it's just the adrenalin rush and that's it. I just zone out*", "*I could hear them, but I didn't really notice them, because I'm too busy concentrating on the actual ride*". Having to concentrate on breathing as well as staying on took a lot of mental energy: "*I think in fact, the feedback mechanism takes the focus off everyone else. Because you're thinking that, you've got other things to think about.*" It may be that, by asking riders to focus internally on their breathing, we make them less aware of external factors such as spectators.

However, spectators could have an impact. Some shouted at riders in an attempt to distract them, for example trying to make them laugh, which fed into the ride feedback loop, making it harder: "*I noticed [name], asking me how to, telling me to kind of laugh, or not to laugh ... and then, that did affect me then, so I started smiling, and breathing a bit deeper, started moving faster, so [name] saying that to me, then did affect the way that the ride moved as well.*"

DISCUSSION

In discussing our findings we consider the extent to which our trials with the Broncomatic demonstrate the feasibility of breath controlled rides; identify key characteristics of breath control; explore how breath control might be incorporated into future rides; and reflect on the general nature of negotiating control with autonomous systems.

Breath control of rides is feasible

Our findings indicate the broad feasibility of breath control in adaptive amusement rides. Technically, our ride was reliable and it appears that even current chest-strap technologies offer sufficient accuracy and responsiveness to control rides. We also propose that the Broncomatic delivered a good ride experience. Not only did nearly all riders enjoy the ride, but it felt appropriately responsive, challenging and was open to various different tactics and strategies. The ride was responsive in the sense that riders understood how to control it and felt that it was capable of delivering a direct and intelligible response at times – i.e., it could be made controllable by a rider with sufficient skill rather than feeling random or wildly unresponsive. However, the success of the ride also lay in riders not always being in control, not least due to having only partial control over their own breathing. Key here was the ride physically pushing back on the rider, affecting their breathing and hence their control. The Broncomatic also appears to encourage some riders to focus in on their breathing. Even this one dimensional control – breathing in and out – gave rise to a variety of tactics which riders could then incorporate into broader strategies as they learned how to respond over multiple rides. Finally, we saw spectators adopting various tactics to affect the riders' breath control.

The key characteristics of breath control

We now reflect on the underlying characteristics of breath control that afford distinct opportunities and challenges for designing rides (and possibly other experiences). Firstly, breathing is one of the few corporeal functions that are part-controllable by conscious effort and part under control of the autonomic nervous system. It is, for example, possible to deliberately hold one's breath, denying the body of oxygen (hypoxia), but only to the point of unconsciousness whereupon automatic systems safely embedded in the medulla and pons deep within the brain take over. Conversely, hyperventilating removes carbon dioxide from the blood, making the blood more alkaline which in turn signals the blood vessels that supply the brain to constrict (again leading to hypoxia) [27]. Various regulatory mechanisms respond to environmental conditions (e.g., a decrease in levels of oxygen in the air) or levels of exertion. Psychological factors also come into play – when people are scared, excited or otherwise aroused, their respiration rates become quicker [6], which at extreme levels may lead to hyperventilation. As well as feelings affecting breathing, controlled breathing can affect how people feel; for example the 'EmRoll' emotional game [31], exploits the fact that slow breathing can make players feel more relaxed.

Yet, there is also the possibility for very fine grained direct control over breathing as we see when playing musical instruments or in the everyday activity of speech, although even here involuntary workings can be exposed such as hiccups or yawning. It is this wide range of control, from completely voluntary to involuntary, from immediate to longer term, from fine grained to coarse, and from environmental, to bodily and psychological, that makes breathing so powerful as a control mechanism, and possibly more flexible than other forms of biosensing such as heart rate or GSR which may be less immediately controllable and responsive.

Breathing also has highly a distinctive feel to it. Riders can become very aware of breathing and so be able to tune into the experience, again more directly than with say heart rate. It may even be visible to spectators. The feeling of holding breath soon becomes incredibly powerful and adds tension to an experience. Finally, people can train in breath control, which is an integral part of many practices such as yoga, meditation, singing, diving, swimming, shooting and martial arts. This is not to say that other ways of sensing response to an experience are not of interest, but rather that breath control is an especially powerful one in several regards, and that designers should be aware of the fine nuances of using it.

One interesting point about how our system uses breath control, is that it does not have any emotional model or interpretation, using breathing data as a direct input, yet creates strong emotional responses in the rider. This suggests that we can successfully create 'affective loop' experiences [11], where there is a feedback loop between the rider's emotions and the system, without the emotional models used in most previous systems which aim to be emotionally responsive by measuring or visualizing user's emotional state (eg. Stresscam [20] uses thermal imaging data to measure levels of stress, the eMoto pen [11] allows users to visualize their emotions as colours, based on an emotional model interpreting gestures that they input.)

Incorporating breath control into future rides

With this in mind, we consider how ride designers might practically utilise breath control. What tactics can they emply and how can rides measure breathing?

Tactics for ride design

Based on our experience with the Broncomatic and our reflections on the general characteristics of breathing, we propose some practical tactics for using breath control. The first three focus on how the rider can control the ride:

- Encourage the rider to hold their breath at key points such as before a major drop or movement. The tension of holding up the ride by breath alone may be powerful, and the feeling of having to let go soon overwhelming.
- Use controlled rhythmic breathing to initially raise the thrill level of the ride (e.g., gradually raising a drop tower but only while the rider remains calm), or to synchronise with the timing and movement of the ride (e.g., deep breathing drives ever deeper swinging)
- Use rapid breathing to power-up both rider and ride, leaving them pumped up and ready for the next phase.

The next five tactics allow the ride to push back at the rider:

- Use physical movement and exertion to make the rider breathe harder and less regularly and so lose control.
- Gradually increase tension to make the rider increase breathing in preparation for 'fight or flight', e.g., when slowly elevating the ride before rapid movement.
- Use sudden shocks to make them draw and hold breath.
- Heighten a rider's awareness of their breathing by enclosing them, or through sound and visual effects.
- Encourage riders to shout or scream in order to trigger a response, including enabling spectators to do this

We also draw attention to the wider potential of designing 'sticky' rides that remember a rider's previous experiences and adapt the next one accordingly in order to reward repeat visits. Rides might also reward riders who train themselves to control their breathing in various ways.

How these tactics are used will depend on the available ride technology. For emerging technologies that afford flexible control over individual seats, it is a case of designing a ride program that mixes them in appropriate ways. For example, the Broncomatic leads riders to experience increasing levels of difficulty whilst they learn to control the movement, before the ride gradually introduces its own movements, inexorably leading them to the point of loss of control. It may also be possible to use some of these tactics with current ride technologies, e.g., raising drop towers, pausing before drops or controlling swings as mentioned above. The harder challenge here is that current rides do not provide individual seat control, so there is the problem of how to adapt for a whole group of riders. There may be entertaining possibilities in allowing one person to control a ride for everyone else, especially if they can communicate. Perhaps the most timid rider takes control with others encouraging them, or the bravest with others pleading?

Of course, it will be important to use these tactics safely. Rides are carefully designed, tested and inspected to ensure appropriate levels of physical safety and judge an appropriate level of thrill or scaring. The additional challenge of breath control lies in potential interference with breathing. It may be important be allow rapid disengagement if there is any risk of uncontrollable hyperventilation, while sensing technologies – as we now discuss – must guard against overly restricting breathing or, for respirators, transmitting infections . Designers must also warn people with breathing difficulties about possible risks.

Negotiating control with the Ride

The Broncomatic is interesting and successful precisely because it affords a balance of control between rider and ride, with each being able to influence the other as part of a feedback loop. Key to this is that the rider does not have full control over the ride or themselves and has to battle with two autonomous systems (ride and body) until they reach the tipping point between control and loss of control that is the climax of the experience.

We propose that this negotiation of control and balance of the voluntary and involuntary is especially important for building adaptive amusement rides. Rides are in large part about the pleasures of surrendering control, either to a human operator, or more recently by being strapped into a powerful machine from which there is no escape until the ride has finished. Rides may be about confronting fears and passing through 'rites of passage' as much as they are about the visceral pleasure of the experience, and it is important not to remove this element in trying to make them more personally adaptive. Thus, while the Broncomatic includes elements of computer games in terms of levels of difficulty and scoring points, it would be a mistake to think of it in terms of being a game that is solely about skill and mastery. Rather, designers need to introduce adaptation but without compromising the principle of surrendering control.

Measuring breathing on rides

We now consider how to sense breathing on a ride. There are many different ways to achieve this non-invasively [9]. Most thrill rides already involve the rider being strapped into a safety harness integrated with the seat unit. One possibility that might involve relatively little additional disruption and delay would be to integrate elastic chest-sensor straps into the harness or to require the rider to fasten one more strap to turn on the breath control feature of the ride. An alternative might be to use clothing with sensors embedded (such as shirts for breathing and heart rate [4]). Riders could then purchase their own monitoring devices to communicate with various rides. A more radical alternative is to use a respirator-style sensor as part of a mask. Although at first sight requiring users to wear masks might appear to be an unlikely approach, this could bring the advantage of making the user even more intensely aware of the sound and feel of their own breathing, further increasing tension for horror-themed and other scary rides. The mask might also provide a platform for embedding microphones to capture riders' responses for generating souvenirs or broadcasting to spectators following the approach of Schnädelbach et al [24]. Our ongoing work is exploring the feasibility of this approach and, at the time of writing, we have just fabricated and are testing a set of breath-control gas masks for use in a major horror-themed experience (Figure 10). Flow rate sensors are used to monitor breathing flow rate, in the side filter of the mask. A phial containing silica gel is used to remove water from exhaled air before reaching the moisture-sensitive sensors. The filter at the front of the mask also allows air flow, so only a small (but stable) percentage of the air goes through our measurement system, and breathing is not restricted.

Figure 10. Respiration sensing, Wi-Fi enabled gas mask

As an additional note, the benefits of surrendering control have been discussed in other contexts: by Woodruff and colleagues in their studies of the use of home-automation systems to assist in the observance of the Jewish Sabbath [28], and also with relation to automated agents such as autopilots and car navigation systems [14]. Our study suggests that it can also feel exciting or stimulating to at least partially surrender control to a robotic system. We observe that such interactions actually involve reconciling two autonomous systems – machine and body – that are in a feedback loop, which is of particular relevance to ongoing research into biosensing. Modalities such as heart-rate and GSR will also be subject to both voluntary and involuntary control, and any applications of these will need to carefully consider what aspects of control are surrendered to what degree and how this might feel to the user.

CONCLUSIONS

Our experience with the Broncomatic suggests that breath control is a viable and interesting way of driving individually responsive amusement rides. Even a simple mapping of breathing, measured by a commercial chest-strap sensor, can provide an engaging, challenging and yet intelligible ride experience. Breath control is especially interesting because it balances voluntary and involuntary control, enabling the ride to physically and psychologically 'push back' at the rider while they struggle to control it and themselves. Ride designers can also exploit a wide variety of breath control tactics. The net result is new forms of ride that have game-like qualities in terms of skill learning, and adaptation, and yet retain the distinctive and thrilling quality of surrendering control to the machine.

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