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AIRSQUEEZE: AN AIR-BASED GAME INPUT DEVICE

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Abstract. *Game input devices are an integral part of player experiences. However, conventional game input devices including keyboard and gamepad support only binary and XY data, thus limiting possible interactions. This paper proposes "AirSqueeze", a novel input device that utilizes air pressure to provide continuous data input. Our user study asking users to play two custom-made games using AirSqueeze showed that AirSqueeze was well-accepted and outperformed conventional game input devices in immersion and usefulness. AirSqueeze can increase game interaction bandwidth and provide a new form of play.*

Keywords: Air-based interaction, Air pressure, Game interaction, Input devices, Immersion, Usefulness

1. **Introduction.** Playing computer games is an enjoyable activity that is loved by many people. One integral game component that contributes to great player experiences is game input devices. Keyboard and gamepad are two most commonly used input devices in video games. However, the traditional input paradigm only supports binary and directional input and thus, interaction bandwidth can be limited. This paper explores a novel input device for the game. Air pressure supports continuous value, as opposed to binary input in keyboard or gamepad. This continuous value is particularly intuitive in games where there is a range of possible values, e.g., hitting a drum with different forces produces a different sound.

In this paper, we present the development of *AirSqueeze* and its working principle. We also explore the effectiveness of *AirSqueeze* for game interaction using two custom-made games and through immersion and usefulness measurements. Comparisons with keyboard and gamepad found that *AirSqueeze* outperformed both devices in immersion and usefulness. This suggests that air pressure can serve as a promising input for game interaction and can provide great potential new and interesting forms of play.

2. **Related Work.** Our work is related to two areas: game interaction and air-based interaction.

2.1. **Game interaction.** Gamepad and keyboard (+ mouse) are two most commonly used input devices in video games. Apart from these devices, there are abundant efforts from researchers to provide new ways to interact with games such as the use of gaze [1], body movements [2], and physiological signals [3] such as facial input [4] and heart rate [5]. One most recent development is the idea of using brain-computer interfaces (BCI) through electro-encepalogram (EEG) signals to control gaming [6]. Similar to these efforts, this work aims to expand the interaction bandwidth of video games and proposes *AirSqueeze* that utilizes air pressure as a new form of game interaction.

2.2. **Air-based interaction.** The idea of using air for interaction has been used in the area of haptic stimulation. For example, researchers have employed mid-air feedback for virtual reality applications [7]. Hachisu and Fukumoto [8] leveraged the property of air suction for a haptic interface. There is also work on using the freeform quality of air to develop shape-changing interfaces [9, 10]. In sum, air has many good qualities for interaction which has not been explored in the game domain. These works focused on providing feedback/output, and little study has investigated the use of air for input interaction, especially for game interaction. This work aims to fill the gap.

3. **Development of Air-Based Interface.** The goal of *AirSqueeze* prototype is to develop a game input device that is able to provide continuous data input. To achieve continuous data input, an off-the-shelf squeeze ball was chosen. The squeeze ball was chosen because it has a form factor that can fit comfortably to user hand and easy to provide push and squeeze interactions. Given that there is no leak in the *AirSqueeze* system, push and squeeze interaction increases internal air-pressure of *AirSqueeze*, and release interaction will return the internal air-pressure to its initial pressure level. Additionally, the material of the squeeze ball is soft and rubber-like, enabling the ball to return to its initial form after squeezed and released, thus eliminating the need of air-pump to continuously give air in order to inflate the ball to its original shape.

3.1. **Hardware components.** Figure 1 shows *AirSqueeze* which consists of two air-pressure sensors (MIS-2500-015G), two three-way solenoid valves (S070 series), two micro air-pumps as air pressure source, and two hand-sized squeeze balls as the interaction device. Figure 2(a) shows electronic components such as air-pump, air-pressure sensor, and solenoid are all electronically connected to and controlled by an Arduino Micro (ATmega32U4). Figure 2(b) shows the pneumatic connection of all of the *AirSqueeze* components. Arduino Micro has a small form-factor and can work as generic keyboard

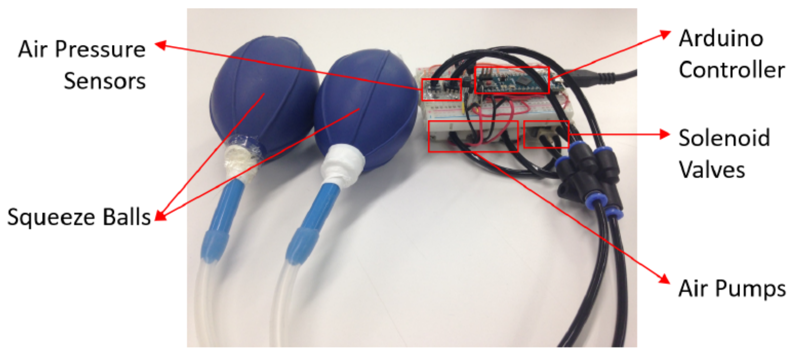


Figure 1. Components of *AirSqueeze*

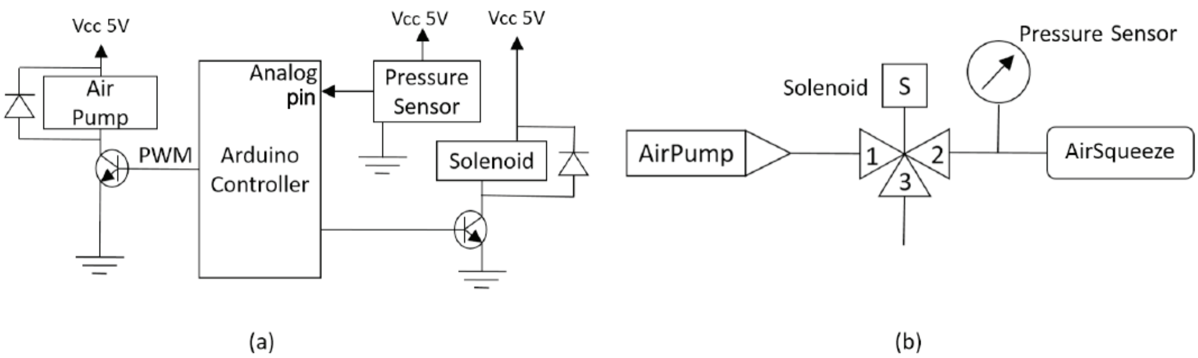


Figure 2. (a) Electronic diagram, (b) pneumatic connection of *AirSqueeze*

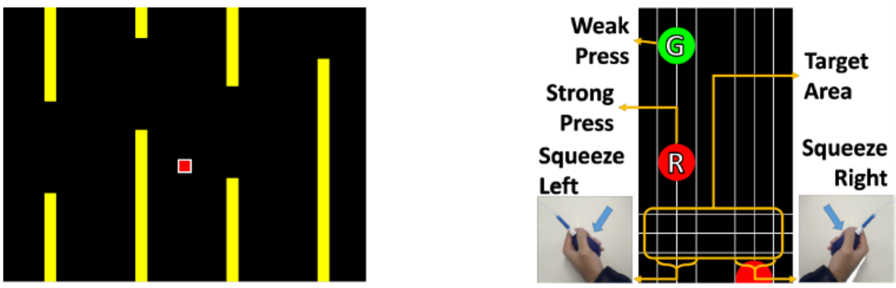
and mouse without additional driver; thus it is convenient to be used for developing input devices. The air-pressure sensor is connected through an analog pin. Since the Arduino maximum current output for each pin is 40mA and power requirement for air-pump and solenoid is higher, both components are connected through digital pin with additional NPN transistor and a diode to control the high current load.

3.2. **Working principle.** Airduino reads the internal air-pressure information from the sensors. Changes in the internal air-pressure of *AirSqueeze* due to squeezing or pushing *AirSqueeze* can be utilized for input interaction. There are two ways to use the air-pressure information: first, use the raw pressure data directly for a continuous input; second, by defining pressure threshold, the system can be manipulated to behave a certain way if a certain pressure level is achieved.

Turning the solenoid on and off can be utilized to regulate the internal air-pressure of *AirSqueeze*. For the solenoid, in "Off" condition, nozzles 1 and 2 of the three-way solenoid are connected but not with nozzle 3, thus allowing air-pump (if powered on) to increase the internal air-pressure of *AirSqueeze*. Conversely in "On" condition, the nozzle 1 of the three-way solenoid is disconnected from nozzle 2 and connected to nozzle 3 (which is connected to the environment), thus allowing the air to escape reducing internal air-pressure of *AirSqueeze*.

4. **User Study.** We are interested in evaluating the effectiveness of *AirSqueeze* as a game input device. We are also concerned about whether the participants' preference affects the immersion level. We compared immersion and usefulness level of each participant on three different input devices (keyboard, gamepad, and *AirSqueeze*) for playing two specific games. We also recorded participants' performance to investigate whether devices affect the performance.

4.1. **Game selection.** Figure 3 shows two simple games based on popular commercial video games, chopter/flappy bird (Game 1) and rhythm/guitar hero (Game 2), which were developed to demonstrate the capability of *AirSqueeze* as a game input device. Both games were chosen because of their simple task and interaction method, and also they were able to be played well using both keyboard and gamepad. Thus, these games were good choices to evaluate the usefulness of *AirSqueeze* as a game input device.



(a) (b)

FIGURE 3. Game selection: (a) Game 1: flappy bird (chopter) like game, (b) Game 2: two-line rhythm game

Game 1 requires participants to avoid the object by squeezing the *AirSqueeze* to move the square-object up and releasing to move the square-object down. Interaction is the same for keyboard and gamepad (push a button to move the square-object up and release to move it down).

Game 2 requires participants to squeeze *AirSqueeze* with appropriate pressure levels. The game recognizes two pressure levels (weak and strong). In the game, participants will be presented with two types of circles as the target. Figure 3(b) shows the interaction for

Game 2: when red circle arrives in a target area, the participants are required to squeeze with strong pressure; likewise, the green circle for weak pressure. Since keyboard and most gamepads are unable to accommodate pressure sensitive input, participants need to press four buttons for left red, right red, left green, and right green circles.

For Game 1, we recorded time elapse from game start until the red-square hit the yellow obstacle or reached time limit (60 seconds) as the participants performance. For Game 2, we recorded the number of targets missed by the participant and divided it by a total number of targets as the error rate. These performance parameters were recorded in the background and not shown to the participants.

4.2. **Participants and apparatus.** Twelve participants (6 females, $M = 28$ years, $SD = 3.72$) were recruited. Two participants play video games for five to ten hours a month while the rest play less than two hours a month. All participants have experiences using keyboard and gamepad for playing games.

Experiment was conducted using a notebook PC with 64-bit Windows 10, Intel i7-4710MQ processor, and 32 GB RAM. Participants used three input devices shown in Figure 4 to play both games.

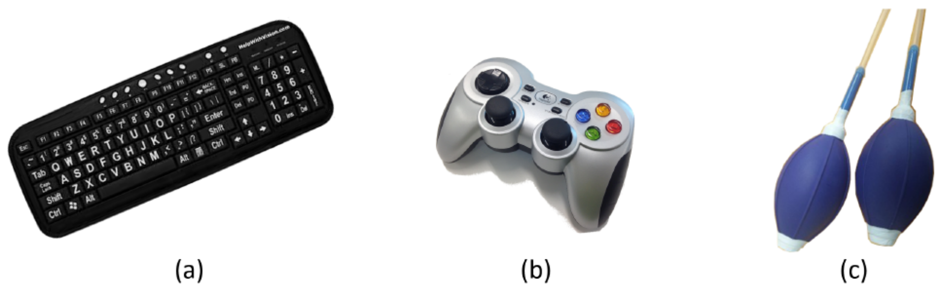


FIGURE 4. Interaction devices used for user study: (a) keyboard, (b) gamepad, (c) *AirSqueeze*

4.3. **Design.** The experimental manipulation was *Device* (keyboard, gamepad, or *AirSqueeze*). The participants' preference for a particular input device was a pseudo-independent variable (*Preference*). The dependent variables were immersion which was measured using the IEQ (immersive experiment questionnaire) [11], a 31 items questionnaire with five-point Likert scale items, USE (Usefulness, Satisfaction, and Ease of Use) questionnaire [12], a 30 items questionnaire with five-point Likert scale items, and player performance parameters (scores and error rates).

The IEQ can provide an overall measure of immersion as well as five factors of immersion, which are *cognitive involvement, emotional involvement, real world dissociation, challenge, and control.* We hypothesized that playing the game using *AirSqueeze* would achieve higher immersion rating compared to playing using keyboard or gamepad. The USE questionnaire provides a measure of *usefulness, ease of use, ease of learn, and satisfaction.* We hypothesized that *AirSqueeze* would achieve at least equal or better usability rating compared to keyboard and/or gamepad as a game input device. We measured player performance across five repetitions. We hypothesized that *AirSqueeze* can reach similar performance as other devices within these repetitions. Specifically, we seek to understand how fast users can learn to use *AirSqueenze*.

4.4. **Procedure.** Participants were first informed of the objective and procedure of the study, and how to play both games with each device. Participants were allowed to familiarize with the control of all three devices. After that, participants were asked to play the games in six conditions (2 games × 3 devices) as shown in Figure 5 in counter-balanced order using Latin square. Each game was limited to one minute and repeated five times, resulting in approximately 30 minutes excluding rest time. Participants were not informed that their performance would be recorded, to ensure participants to focus on the device and the game without worrying about score or competition. Participants were asked and allowed to take a rest whenever they feel tired. After all of the conditions were done, participants were required to complete the IEQ and the USE questionnaires and open-ended questions regarding *AirSqueeze*, including their preference of device for playing the games. All procedures took around 1.5 hours.

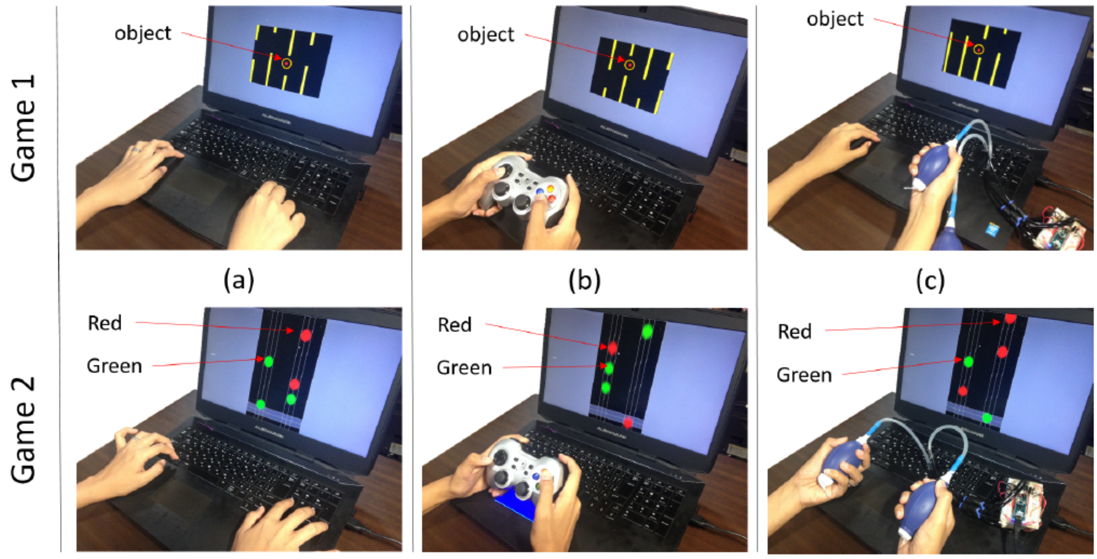


Figure 5. Experimental setup. Playing Games 1 and 2 using keyboard (a), gamepad (b) and *AirSqueeze* (c).

5. **Results and Analysis.** We investigated immersion, usefulness, and user performance for different game input devices. All data conformed to two requirements for parametric evaluation, namely, normal distribution using the Kolmogorov-Smirnov test and equality of error variance using Levene's test. For the ANOVAs, we tested sphericity using Mauchly's test and used a Greenhouse-Geisser adjustment when the Mauchly's test was significant; this adjustment can result in fractional degrees of freedom.

5.1. **IEQ.** Table 1 shows results for each IEQ component (total immersion, cognitive involvement, emotional involvement, real world dissociation, challenge, and control). The results show that the participants achieve higher total immersion when they play with *AirSqueeze* ($M = 97.61$, $SD = 12.98$) regardless of their preference compared to keyboard ($M = 90.97$, $SD = 10.11$) and gamepad ($M = 94.46$, $SD = 6.49$). The results also show that participants who prefer to use *AirSqueeze* ($M = 102.47$, $SD = 4.39$)

Table 1. Total immersion and its components when playing using keyboard (K), gamepad (G), and AirSqueeze (A)

	Play with K						Play with G						Play with A					
	Prefer K		Prefer G		Prefer A		Prefer K		Prefer G		Prefer A		Prefer K		Prefer G		Prefer A	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
TI	98.8	6.30	79.6	21.72	94.5	21.45	95.1	4.67	87.7	20.82	100.6	17.42	93.1	12.87	87.5	13.44	112.3	12.68
Cog.I	33.6	1.52	26.4	6.78	29.4	5.97	31.4	2.88	29.6	5.22	32.0	6.06	31.2	3.56	29.2	3.83	35.7	3.86
Emo.I	17.6	4.51	13.6	5.61	16.3	5.02	16.3	3.03	14.4	6.71	17.6	3.91	16.1	5.82	16.2	3.97	21.2	4.40
RWD	21.4	1.82	17.1	5.78	21.9	5.82	22.2	1.92	19.0	5.63	23.2	4.57	20.6	2.67	18.7	6.13	25.4	4.01
Cha.	9.8	1.92	8.0	2.06	10.6	2.37	9.6	2.07	8.4	2.55	9.9	2.33	9.8	1.64	9.1	2.03	10.9	1.91
Con.	16.4	0.89	14.4	4.82	16.4	5.17	15.6	2.51	16.2	4.06	17.9	4.18	15.4	3.13	14.3	2.45	19.1	3.25

Total Immersion (TI), Cognitive Involvement (Cog.I), Emotional Involvement (Emo.I), Real World Dissociation (RWD), Challenge (Cha.), and Control (Con.)

achieve higher total immersion regardless of the *Device* used for playing the games, compared to participants who prefer keyboard ($M = 84.91$, $SD = 4.54$) or prefer gamepad ($M = 95.67$, $SD = 4.34$).

We conducted a two-way repeated measure ANOVA with IEQ parameters as the dependent variables: *Device* (3 levels, within-subjects) × *Preference* (3 levels, between-subjects). The result showed that there was main effect on *Device* ($F_{10,76} = 2.466$, $p = 0.013$, $\eta_p^2 = 0.245$, Wilks' $\lambda = 0.570$). However, there was no main effect on *Preference*, while the interaction effects were marginal ($F_{20,127} = 1.548$, $p = 0.076$, $\eta_p^2 = 0.166$, Wilks' $\lambda = 0.485$). In terms of immersion components, main effect of *Device* was found for cognitive involvement ($F_{2,42} = 6.213$, $p = 0.004$, $\eta_p^2 = 0.228$) and total immersion ($F_{4,42} = 3.094$, $p < 0.05$, $\eta_p^2 = 0.228$). Also there was interaction effect of *Device* and *Preference* on cognitive involvement ($F_{4,42} = 3.094$, $p < 0.05$, $\eta_p^2 = 0.228$). There was no main effect nor interaction effects for emotional involvement, real world dissociation, challenge, and control components of immersion. Post-hoc pairwise comparison using Bonferroni's test show that significantly different results were found between keyboard and *AirSqueeze* for cognitive involvement ($p < 0.05$) and between gamepad and *AirSqueeze* for the total immersion ($p < 0.05$).

These post-hoc results suggested that playing using *AirSqueeze* can improve users' immersion level significantly compared to the gamepad. Although the difference between *AirSqueeze* and keyboard was not significant, the result was marginal.

5.2. **USE questionnaire.** Table 2 shows participants' ratings regarding the interaction devices' Usefulness, Ease of Use, Ease of Learn, and Satisfaction. Overall, the results showed that mean values for *AirSqueeze* were higher than keyboard and gamepad in all components of USE.

TABLE 2. Mean scores of USE components

	Keyboard		Gamepad		AirSqueeze		ANOVA	
	M	SD	M	SD	M	SD	F	η_p^2
Usefulness	2.65	0.21	3.27	0.08	3.34	0.16	6.348**	0.366
Ease of Use	3.30	0.25	3.93	0.18	4.04	0.18	5.499*	0.333
Ease of Learn	3.19	0.26	3.67	0.24	3.98	0.23	6.359**	0.366
Satisfaction	2.62	0.31	3.35	0.18	3.80	0.19	8.152**	0.426

$*p < 0.05$, $**\,p < 0.01$

A one-way ANOVA showed that there were significant differences on which device to use for playing the games on the combined components of USE ($F_{8,38} = 2.200$, $p < 0.05$, $\eta_p^2 = 0.317$, Wilks' $\lambda = 0.467$). Significant difference is also found for Usefulness, ($F_{2,22} = 6.348$, $p < 0.01$, $\eta_p^2 = 0.366$), Ease of Use ($F_{2,22} = 5.499$, $p = 0.012$, $\eta_p^2 = 0.333$), Ease of Learn ($F_{2,22} = 6.359$, $p < 0.01$, $\eta_p^2 = 0.366$), and Satisfaction ($F_{2,22} = 8.152$, $p = 0.002$, $\eta_p^2 = 0.426$). Post-hoc analysis using Bonferroni's test showed that there were significant differences between keyboard and gamepad for Usefulness ($p < 0.05$), between keyboard and *AirSqueeze* for Ease of Learn ($p < 0.05$), between keyboard and gamepad for Satisfaction ($p < 0.05$), and between keyboard and *AirSqueeze* for Satisfaction ($p < 0.05$).

These results revealed that the value was relative to the usefulness of the devices for the specific games, not for general use or games. The results suggested that *AirSqueeze* was easier to learn to use and provided higher user satisfaction when used for playing the games compared to the keyboard. Nevertheless, it is important to note that this result applies only to our games or alike but not the general games.

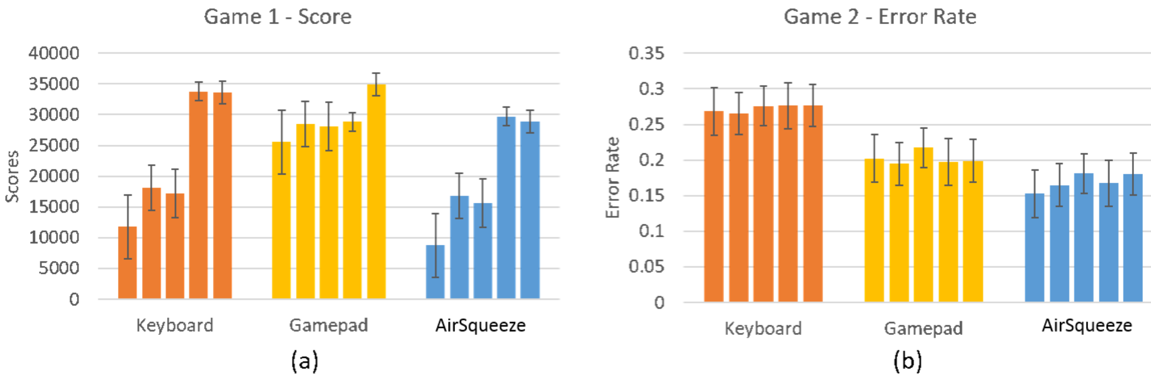


FIGURE 6. Performance parameter for repetition 1 to 5: mean score (a), error rate (b)

5.3. **Player performance.** Figure 6 shows participants' score for Game 1 and error rate for Game 2 for five repetitions while using keyboard, gamepad, and *AirSqueeze*. Two-way repeated measures ANOVAs were run for Game 1 score and Game 2 error rate as dependent variables, and with *Device* (3 levels, within-subject) $\times$ *Repetition* (5 levels, within-subject) as independent variables.

The ANOVA result for Game 1 showed that there were main effects of *Device* ($F_{2,22} = 5.666$, $p = 0.01$, $\eta_p^2 = 0.340$) and *Repetition* ($F_{2,22} = 5.809$, $p = 0.001$, $\eta_p^2 = 0.346$) to the score; however, there was no interaction effect found. Post-hoc pairwise comparison revealed that there were significant differences between gamepad and *AirSqueeze* ($p < 0.005$), repetition 1 and 4 ($p < 0.05$), repetition 1 and 5 ($p = 0.01$), repetition 2 and 5 ($p < 0.05$), repetition 3 and 4 ($p < 0.05$), and between repetition 3 and 5 ($p < 0.05$). These results suggested that participants' learning curves for keyboard and *AirSqueeze* were the same, and participants can achieve similar performance for all *Device* after the fourth repetition, and thus four repetitions was adequate for participants to learn how to use *AirSqueeze* to achieve similar performance with gamepad interface.

For Game 2, ANOVA showed that there was main effect on *Device* only ($F_{2,22} = 19.354$, $p < 0.001$, $\eta_p^2 = 0.366$). This suggested that the error rate was highly impacted by the device difference. Pairwise comparison with Bonferroni's test suggested that both gamepad ($p < 0.005$) and *AirSqueeze* ($p < 0.001$) have significantly lower error rate compared to keyboard. This implies that playing Game 2 using *AirSqueeze* can achieve similar performance as playing the game using gamepad.

6. **Conclusion and Future Work.** Our study concludes that although preference has an effect on user immersion, playing games using *AirSqueeze* achieves higher levels of immersion and USE scores compared to keyboard and gamepad. We also confirmed that four repetitions are adequate to learn how to play games using *AirSqueeze* to achieve scores on par with gamepad. These results suggest that air-pressure can be utilized as a game input device that can promote deeper immersion when used with certain games. Currently, *AirSqueeze* is connected to PC through a cable and has limited space for movement. We can add greater freedom by applying wireless connections to *AirSqueeze* instead of cable connections. *AirSqueeze* can also be used to further expand current gamepad devices by redesigning the shape of *AirSqueeze* so it can be attached to the back of a gamepad as an add-on device to enable squeezing interactions in gamepads and other game input devices.

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