Risky business: Disfluency as a design strategy

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ABSTRACT

This paper presents a study examining the effects of disfluent design on audience perception of digital musical instrument (DMI) performance. Disfluency, defined as a barrier to effortless cognitive processing, has been shown to generate better results in some contexts as it engages higher levels of cognition. We were motivated to determine if disfluent design in a DMI would result in a risk state that audiences would be able to perceive, and if this would have any effect on their evaluation of the performance. A DMI was produced that incorporated a disfluent characteristic: It would turn itself off if not constantly moved. Six physically identical instruments were produced, each in one of three versions: Control (no disfluent characteristics), mild disfluency (turned itself off slowly), and heightened disfluency (turned itself off more quickly). 6 percussionists each performed on one instrument for a live audience (N=31), and data was collected in the form of real-time feedback (via a mobile phone app), and post-hoc surveys. Though there was little difference in ratings of enjoyment between the versions of the instrument, the real-time and qualitative data suggest that disfluent behaviour in a DMI may be a way for audiences to perceive and appreciate performer skill.

Author Keywords

instrument design, disfluency, audience studies

CCS Concepts

•Applied computing → Performing arts; Sound and music computing; •Human-centered computing → *Interaction design;*

1. INTRODUCTION

Keith Jarrett's 1975 recording *The Köln Concert* is a legendary recording of jazz piano performance. The story behind it is often retold: Jarrett, a master of jazz improvisation, arrived at the concert hall to find that an inadequate piano had been delivered that was broken and out of tune. The felt had worn away, the pedals didn't work, the top and bottom registers weren't resonant, and it wasn't big enough to produce the necessary sound for the concert hall.

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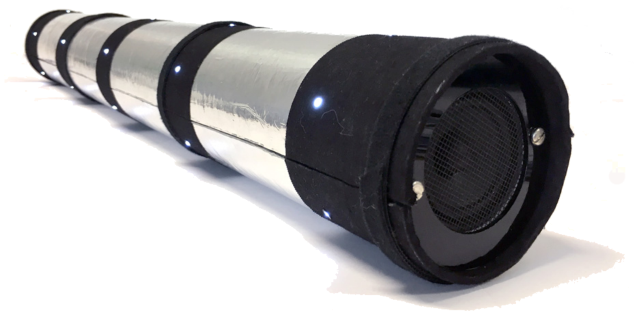

Figure 1: Keppi, the instrument used in this study.

After refusing to play he was convinced to play by the concert organiser. During the concert Jarrett compensated for the limitations of his instrument in various ways: he played in the middle of the keyboard, used rolling left-hand chords, stood up and pounded on the piano to get as much sound out of it as possible. Instead of the piano's limitations presenting a barrier to creativity, Jarrett's real-time negotiation of these limitations produced an enduring work of improvisational genius.

This story has been recounted by Tim Harford on the TED stage [10]. Harford uses the story as an example of messiness and frustration being gateways to creativity, and suggests that contending with unexpected problems can inspire us to new heights of creativity.

Though barriers are indeed valuable, any person simply sitting down at a broken piano will not produce such magical results; it was the combination the limitations and Jarrett's skill that pushed his creative power to new heights. We were motivated, therefore, to determine how a 'barrier' — which in this context we term a *disfluency*, and is defined below — is negotiated by a DMI performer and perceived by the audience, to shed some light on this relationship for DMI designers and practitioners.

This paper details a study that used an instrument called Keppi (see Figure 1). 6 physically identical versions of Keppi were produced, each with a degree of disfluency (*none*, *mild*, and *heightened*). Each Keppi was played during a concert by 1 of 6 experienced percussionists and evaluated by a live audience. We present the results of this study, and discuss why and how disfluency may be useful in DMI practice.

2. RELATED WORK & MOTIVATION

2.1 Defining disfluency

Disfluency is defined in the field of cognitive science as 'the experience of processing difficulty' [15]. In studies this usually takes the form of text that is difficult to read because the font is degraded, unfocused, or the letter forms are difficult to differentiate. Alter et al. published the results of a study [1] in which they tested the influence of text disfluency on the process of mental reasoning, and tested the results of written tests that were disfluent with those that were not disfluent.

The authors found that, perhaps counter-intuitively [6], disfluency produced better test outcomes. They suggest that this is because disfluency demands greater concentration, thereby triggering heightened cognitive function, and that 'experiences of difficulty or disfluency appear to serve as an alarm that activates analytic forms of reasoning that assess and sometimes correct the output of more intuitive forms of reasoning.' In other words, disfluency forces the test taker to slow down and consider the problem, instead of simply relying on their intuition or first impressions. The most useful suggestion here is that it is not a *lack* of fluency that poses a challenge, but rather *too much fluency*; 'easiness' may cause us to under-use our mental capacities, and disfluency supplies the friction necessary to prompt the fuller engagement of cognitive abilities.

This is an interesting argument in relation to DMI performance, which is often exploratory, abstract, and unfolds on stage in real time. The question, therefore, is whether disfluency can trigger heightened levels of playing in DMI players, and, most relevant to this research, whether this would translate into effects perceivable by the audience.

2.2 Disfluency vs. appropriation

There is existing literature within NIME on constraint and appropriation, and it is useful to disambiguate these from the notions of disfluency.

Using *constraint* in DMI design to encourage personal playing style has been well explored within NIME [9, 13], and Zappi and McPherson [17] demonstrated that constraint is a useful way to take advantage of *appropriating* behaviours. Appropriation, investigated earlier by Dix [7], is the notion that people will develop ways to use things that the designer neither intended or anticipated. Zappi and McPherson found that when performers were presented with instruments that had extremely limited functionality, that players developed appropriating behaviours in response to constraint, and the players found this creatively satisfying.

Constraint and disfluency, on the surface, appear to be analogous. Constraint is like disfluency in that it is a limitation, and a performer develops behaviours to contend with it. However, the salient difference between constraint and disfluency is *their stability over time*: An interface will remain constrained in the same way, but disfluency will diminish as the disfluent element becomes known, and behaviours to contend with it become second nature.

In this way, if we accept a definition of improvisation as 'the realisation of action as it unfolds' [11, p. 1], then dealing with an unstable disfluent quantity through one's existing skill and knowledge can be considered a type of improvisation. This further separates disfluency from a constraint, around which a performer can develop a behaviours that can be practised. Disfluency, then, is a continuous state in which the performer both ascertains the limitation, and explores, develops and performs their appropriation, in real time.

2.3 Disfluency: A tool for risk?

Disfluency occurs when limitations are not entirely known and the performer must rely on their existing skill; in this way, it is related to *risk*. Of course, we don't go to musical concerts to watch people mess up or fail, and people didn't come to hear Jarrett play because they heard the piano was terrible and wanted to see what happened. But, perceivable risk may be a reason why this performance is legendary: Though the audience did not know the piano was broken, they saw Jarrett fully engaging his musical and performative faculties, even groaning and stomping as he played. This concert's success might signal that when a performer is engaging with their own skill, their musicianship, understanding, and personal style is fully appreciable.

Fyans et al., in a study examining how audiences understand skill in a DMI performance context [8], found that spectators reported that the performer 'failing to engage with [the DMI] in an embodied way was indicative of a lack of skill'. This finding is reinforced by research in cognitive psychology, most notably Kruger et al.'s finding that audiences report higher ratings of quality, value and liking on work that they perceive to require more effort (also known as 'the effort heuristic' [12]). If effort is a marker for quality, it makes sense that, as Fyans et al. found, that a perceived lack of effort is associated with a lack of skill. In this way, disfluency may be a useful tool for making skill perceivable.

Yue et al. [16] highlight that not only is the simple presence of disfluency is unlikely to produce great results, but that not all types of disfluency are useful [16]. Bjork and Bjork, further specify that it is not the simple presence of disfluency that brings about this heightened state, but rather when disfluency that manifests as 'desirable difficulties' [4]. The question remains, then, of what a 'desirable difficulty' might look like, and how disfluency might produce effects perceivable by the audience.

3. INSTRUMENT DESIGN

For this study we designed a percussion instrument called Keppi. Keppi is a cylinder 12cm in diameter and 62cm long, with speakers set in each end. (A round shape was chosen so it would be handled in three dimensional space and less likely to be set on a table.) Inside, a Bela [14] handles all audio and sensor processing. Keppi is played by striking one of its four electrodes, for example by tapping with hands and fingers, or tossing and catching. The electrodes detect hold/release states by capacitive sensing, and networks of piezo elements under each electrode sense strike velocity, and Bela plays back a sample in response to the electrode hit and applies the sensed velocity. Keppi's sound mimics a mallet hitting a concrete tube. On the outside of Keppi there are 5 evenly-spaced rows of white LEDs set into the surface. Each Keppi weighed about 1kg.

3.1 Disfluency in design

All versions of Keppi were identical in size, form factor, interaction, materials and sound, but differing in terms of behaviour. The disfluent behaviour was this: Keppi turned itself off if not moved enough. The disfluent behaviour was added via an on-board accelerometer that continuously sensed Keppi's quantity of movement.

The state of a disfluent Keppi was visible through the 5 rows of LED lights. If Keppi was not moved enough by

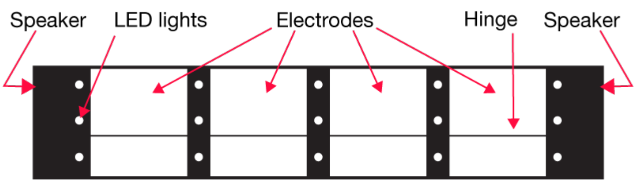

Figure 2: Keppi diagram. Keppi is a cylinder 62cm long and 12cm in diameter.

Performance	DMI behaviour category
Performer A	Category 3 (Heightened disfluency)
Performer B	Category 1 (Control)
Performer C	Category 2 (Mild disfluency)
Performer D	Category 1 (Control)
Performer E	Category 3 (Heightened disfluency)
Performer F	Category 2 (Mild disfluency)

Table 1: The instruments were randomly assigned to the performers, and the concert order was randomly determined.

the performer over time, the rows of lights would turn off in succession, like a tick-down timer. When only the last row was lit the sound would distort, and if all LEDs were off Keppi would not make any sound at all. If Keppi was moved or shaken, the rows of LEDs would light up in succession, a kind of 'charge up' behaviour. This 'tick-down' behaviour was chosen so the state of the instrument would be visible to the player, and would also be visible to the audience.

There were two categories of disfluency: Mild, and heightened. This allowed us to test not only whether the mere presence of disfluency had any effect on audience perception, but also if the *degree* of disfluency had any effect. The mild disfluency instruments turned themselves off slowly, with 1600ms between each row of lights turning off. The instruments with heightened disfluency turned themselves off much more quickly, with 800ms between rows of lights turning off. The control instruments had no 'tick-down' behaviour, and the outside lights were illuminated at all times.

6 Keppis were produced, 2 of each of the 3 behaviour categories. The behaviour categories were as follows:

Category 1: (Control, no disfluent charateristic)
Category 2: (Mild disfluency)
Category 3: (Heightened disfluency)

6 experienced percussionists (5+ years of performing experience, 4 female and 2 male) were recruited for this study. Each player was randomly assigned one version of Keppi 2 weeks before the concert, and asked to prepare a performance that was three to five minutes in length.

The players were asked not to discuss the instrument with their peers, and were not told the details of the study, differences between instruments, or the kind of instrument they received. They were given the instrument, shown how it worked, and invited to compose and perform on it in whatever way they felt resonated with their playing style.

4. THE STUDY

The context of the study was an evening concert, in a performance space with raked seating and a level stage. The study performances were the second act of a three-act concert, which was advertised by email lists and social media. 31 audience members provided complete data sets (meaning they gave both real-time and post-hoc feedback).

4.1 Data gathering

Data was gathered using a methodology for audience study [3] that combines both post-hoc and real-time data. Real time data was used to identify moments of interest in the video footage.

After the first act the study was introduced and the audience was invited to participate. Data gathering was explained, and survey books were distributed[1]. There were

[1]Surveys: https://bit.ly/2GJrAQp

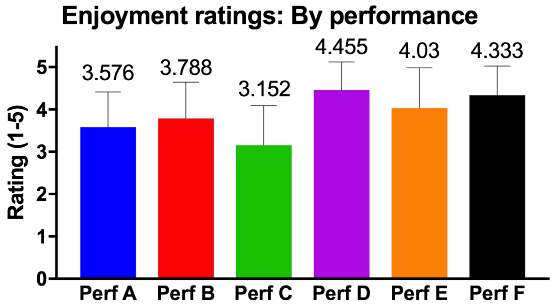

Figure 3: Mean Enjoyment ratings, by performance. Error bars indicate SD.

7 surveys: 6 post-performance surveys, and 1 post-concert survey.

Real-time data was collected via Metrix (a system designed for this purpose) [3], and at this point the onboarding video for Metrix was screened. The Metrix interface (see Figure 5) had two buttons that allowed audiences to indicate two states: 'I am enjoying this' and 'I saw an error'. (See [3] for a full discussion of this interface and study methodology.)

4.2 Study method

The audience (N=31) watched all six performances. The order of performers (detailed in Table 1) was randomly assigned. The performers stayed outside until their time to play, to avoid influencing by other players. Before they began they were introduced to the audience with their name. Audience members filled out a post-performance survey after each performer, and completed the post-concert survey at the end.

5. RESULTS

5.1 Post-hoc results: Quantitative

The quantitative data reported here is composed of the ratings of Enjoyment for each of the six performances (collected via the post-performance surveys). Enjoyment ratings were on a scale of 1 (not at all) to 5 (very much).

First, the Enjoyment ratings for all six performances were considered (illustrated in Figure 3). A Friedman (paired, non-parametric) test was used to determine if there were differences in ratings of Enjoyment across the six performances, and compared the mean Enjoyment rating of each performance to the mean enjoyment rating of all others. Dunn's correction was used for multiple comparisons. There were statistically significant differences between the 6 per-

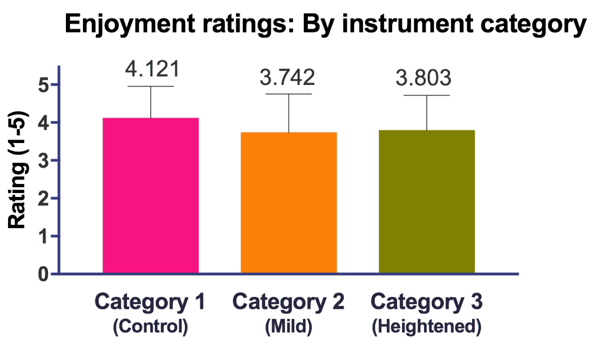

Figure 4: Mean Enjoyment ratings, by instrument category. Error bars indicate SD.

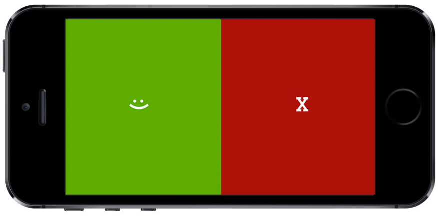

Figure 5: The Metrix interface [3].

formances ($\chi^2(5) = 52.31$, $p<.0001$).

Post hoc analysis showed statistically significant differences in ratings of Enjoyment between the following performances (significance threshold $p<.05$):

Perf. D (mean 4.455) rated significantly higher than the following: Perf. A (mean 3.576, p=.002), Perf. B (mean 3.788, p=.033) and Perf. C (mean 3.152, p<.0001)

Perf. E (mean 4.03) rated significantly higher than Perf. C (mean 3.152, p=.0034)

Perf. F (mean 4.333) rated significantly higher than Perf. A (mean 3.576, p=.0169) and Perf. C (mean 3.152, p<.0001)

Second, ratings of Enjoyment were analysed by instrument category (mean ratings by category are illustrated in Figure 4). A Kruskal-Wallis (unpaired, non-parametric) test was used to determine statistically significant differences in the Enjoyment rating between the three instrument categories. Dunn's correction was used for multiple comparisons. No statistically significant differences between categories were found.

5.2 Post-hoc results: Qualitative

The qualitative data corpus was composed of the responses to the questions in each post-performance survey: 'What did you like about the performance?' and 'What did you dislike about the performance?'. Thematic analysis was performed on this data corpus using an inductive method. First, the data was coded, resulting in 54 codes, which were then grouped into themes. Five themes emerged: Ways of Playing, Instrument, Sound, and Experience Descriptors, and Performer Skill.

5.2.1 *Skill-related comments*

Mentions of skill were present in the 'like' responses of all performances, but were particularly prevalent for Performances A, D, E and F. Mentions of skill were present for the 'dislike' responses only of Performance C.

5.2.2 *Differences between instrument conditions*

The qualitative data themes were compared between the instrument test conditions. Though all three instrument conditions had responses related to the theme of Way of Playing for the 'enjoyment' question, the Category 1 (control) instruments did not have mentions related to physicality. Category 2 (mild) and 3 (heightened) responses mentioned physicality.

5.3 Real-time results

Real-time data was collected using Metrix. Due to the high incidence of 'Enjoyment' tap events, these are grouped into 5s time bins, and 'Error' events into 1s bins. For each participant, any more than 1 tap per time bin were discarded.

The real-time data was visualised to give an overall sense of audience reaction during the performances (see Figure 6 for an example). 'Enjoyment' events tended to accumulate over time, whereas 'error' events had a sudden onset and dropoff.

Figure 6: Visualisation of Metrix data for Perf. D. Top: Enjoyment button. Bottom: Error button.

5.3.1 *Real-time data and the video footage*

All performances were recorded on video. The real-time data was synchronised with the video footage via an audible click made at the time Metrix was made active.

The real-time data was used to examine the video for indications of moments of audience agreement about 'enjoyment' and 'error'. This was done by determining times of audience agreement in one or more time bins (called 'events'), and coding the video at these times. Events were determined using the following criteria:

Enjoyment events: An event started when 6 or more audience members indicated 'enjoyment' in a particular 5s time bin. The event starts from this bin and ends on the next bin where the number of audience agreements is less than 6, or is 5 less than the start value.

Error events: The threshold of audience agreement in a 1s time bin was 2, or 3 agreements over 4 consecutive time bins. The event starts from the first bin and ends when there have no error events for 2s.

The 'enjoyment' and 'error' events were then visualised on the video footage to facilitate coding (see Figure 7).

Figure 7: Video still with events from real-time data indicated (pictured are the third 'enjoyment' event and fourth 'error' event).

The video was coded at times of 'enjoyment' and 'error' events, and after coding, the codes were grouped together into themes. Coding of 'enjoyment' and 'error' events was done separately, as there is no relationship intended between the two terms, and audiences have been found to treat the terms as independent and not as binary opposites [3].

5.3.2 *Themes of 'enjoyment' events*

The codes generated from the video documentation at the times of 'enjoyment' events clustered around the following themes:

1. **Novelty:** Change of motif, new elements
2. **Pattern:** Rhythm, repetition, returning to motif.
3. **Player action:** Actions that display intention, or display technique/skill.
4. **Time-based features:** Establishing themes, moments of flow/build-up.

The highest-rated performances (Performance D, E and F) all included 'enjoyment' events related to player action, and specifically to skill, such as fast or complex rhythms.

The lowest-rated performance, Performance C, had 'enjoyment' events clustered around time-based features such as the establishment of rhythm, but had only 3 'enjoyment' events overall. Performances A and B had enjoyment events that mostly featured change, such as a new element or method of interaction.

5.3.3 *Themes of 'error' events*

The codes from the 'error' events were clustered around the following themes:

1. **Inference of performer action:** Moments of hesitation, performer seems unsure, unclear intention
2. **Interrupted expectations:** Breaks in rhythm, changes, unexpected elements, sound distortion
3. **Technical errors:** The performer adjusting the instrument, gestures that do not make sound, moments of struggle with the instrument.

'Error' events tended to be predominantly related to themes of interruption, such as moments where the rhythm was inconsistent. The theme of performer action was also salient, and moments where performers were unsure, or hesitated, tended to be marked as errors. Technical errors such as the instrument not sounding or the performer not being confident and fluent in their handling of the instrument also tended to be considered errors.

Though all instrument types had 'error' events related to rhythm inconsistencies and technical errors, the performances using Category 1 (control) instruments (Performances B and D) had 'error' events related to judgement of performer action, such as hesitation and intention.

6. DISCUSSION

6.1 A design feature isn't enough

The quantitative data, composed of the ratings of Enjoyment for each performance, showed that some individual performances were rated significantly higher, but there was no clear preference for disfluent instruments. When the ratings were compared by instrument category, they were not significantly different. The two performances with the highest mean ratings, Performance D and Performance F, were Category 1 (control) and Category 2 (mild disfluency) instruments, so the presence of disfluency did not appear to positively affect post-hoc audience ratings of Enjoyment.

This is consistent with previous work has that found that the instrument itself has little effect on audience perception of DMI performance [2], and reinforces the suggestion that simply making design disfluent is not always useful [16].

6.2 Audience perception of skill

This lack of significant preference for any instrument suggests that the degree of *visible risk* may not be very important to audiences, or rather, that audiences don't hold visible risk as a priority. The qualitative data, however, showed that audiences were sensitive to the performer's *skill* for the disfluent instruments. For Performances A, E, and F skill was mentioned in a positive sense. For Performance C — the performance that, in the qualitative data, was rated significantly lower rated than most others — skill-related dislikes were present.

Though the audience being able to perceive disfluency and the risk that comes with it does not seem to be necessary, this study audience was remarkably sensitive to the presence of skill. They recognised and commented upon the skill in all of the performances using disfluent instruments. This supports Fyans and Gurevich's definition of skill [8] as an embodied phenomenon, and a combination of control and effort, and suggests that disfluency may be a way of making control and effort visible and appreciable by audiences.

Performer C played a Category 2 instrument (mildly disfluent), and was the lowest-rated performance. The audience noticed his lack of effort, and that they were inexpert in handling the instrument. In the video documentation the audience indicated many 'error' events, and in review of the video they are noticeably less fluent with it, holding it in one hand and playing with the other, not employing any of the creative physical playing methods employed by the other performers.

In this case, it may be that disfluency has had a deterimental effect, and rather than being what Bjork and Bjork would call a desirable difficulty [4] — one that matched and challenged their ability and style, and that they could leverage their skill to contend with — it was simply a difficulty, and this was perceived by the audience as a deficit of skill.

For the other 5 performers, their skill and their instrument's behaviour happened to be better-matched. The fact that one performer did not cope well with disfluency does suggest that the mere presence of disfluency is not a creative panacea: it has to be the right kind of disfluency, matched to the right level of skill. This also aligns with Cskiszentmihaly's work on *flow*, his central tenet being that, in order to reach a 'flow state', skill and challenge must be in balance [5].

These results further suggest that though Jarrett's performance choices in the Köln Concert may have been influenced by the disfluent piano, the success of this piece may be instead because this presented an opportunity for the audience to appreciate his masterful level of skill.

6.3 Disfluency: Effects on performance outcomes

Though this study focuses on audience perception and not the performer, the performers' choices around the instrument are notable.

These six performances displayed a huge diversity of playing methods:

Performer A (heightened): created complex counter-rhythms by stomping their feet while playing
Performer B (control): struck Keppi with their hands and bare feet
Performer C (mild): incorporated a shaking motion

Performer D (control): balanced Keppi between two chairs, played with fingers like a piano
Performer E (heightened): played seated and kept Keppi moving by bouncing it against their bare knee, creating a rhythmic drone
Performer F (mild): incorporated a swinging motion

It is possible (though by no means certain) that disfluency played a role in this diversity. Contrasting the control performances with the performances on disfluent instruments, there were a number of strategies that may not have been employed were it not for the requirement to keep the instrument moving (such as the knee-bouncing in Performance E, or the swinging of the instrument in Performance F). Performances A, E and F, all with disfluent instruments, incorporated the tick-down movement of the lights into the performance.

An informal survey after the study asked the performers what they liked about the instrument, and all respondents who had a version with disfluent behaviour cited this as a positive aspect:
Performer A (heightened): 'I liked that I had to be active to make it work.'
Performer C (mild): 'The necessary movement leads to movement in rhythm.'
Performer E (heightened): 'I did like the aspect of it having heft, and needing to be explored. I enjoyed that it took some effort to play and come to grips with.'
Performer F (mild): 'I liked the limitation set on it where it had to be constantly moved. I've always found that limitations result in increased creativity on the performer's part.'

This feedback adds another layer of depth to the finding that audiences appreciate effort and control: while we cannot determine whether these 4 performers view the disfluent behaviour of Keppi as an obstacle to overcome or a characteristic to be learned, the response shows that performers also positively engage with challenges that require them to leverage their existing skill.

6.4 Implications for DMI designers

Though the audience did not respond specifically to the instrument's disfluency creating *risk*, a disfluent instrument did tend to gather more comments about performer *skill*. The implication for DMI designers, then, is that instruments that offer the opportunity for displaying effort and control would be useful for audiences. Fyans et al.'s suggestion of skill being a combination of control and effort [8] was reflected in this study, as the video coding showed that moments of flow or physical engagement were particularly enjoyed by the audience.

7. CONCLUSION

This paper details a study of the effects of disfluent design on audience perception of DMI performance. One instrument was designed, and six were produced in three versions: no disfluency, mild disfluency, and heightened disfluency. Six experienced percussionists composed on one of these instruments, then performed for a live audience (N=31). Data was collected in the form of post-hoc surveys and real-time feedback. The results suggest that, at least with a small sample, simply incorporating disfluency into DMI design does not have a significant effect on the audience's reported enjoyment, but does allow the audience to recognise performer *skill*. The implication for DMI designers is that, although a disfluent characteristic does not automatically heighten audience enjoyment, understanding how a DMI can allow the performer to display effort and control can contribute to audience appreciation of performer skill.

8. ACKNOWLEDGMENTS

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9. REFERENCES

[1] A. L. Alter, D. M. Oppenheimer, N. Epley, and R. N. Eyre. Overcoming intuition: Metacognitive difficulty activates analytic reasoning. *Journal of Experimental Psychology*, 136(4), 2007.

[2] S. M. A. Bin, N. Bryan-Kinns, and A. P. McPherson. Skip the pre-concert demo: How technical familiarity and musical style affect audience response. In *Proc. NIME*, 2016.

[3] S. M. A. Bin, F. Morreale, N. Bryan-Kinns, and A. P. McPherson. In-the-moment and beyond: Combining post-hoc and real-time data for the study of audience perception of electronic music performance. In *Proc. Interact*, 2017.

[4] E. L. Bjork and R. A. Bjork. Making things hard on yourself, but in a good way: Creating desirable difficulties to enhance learning. *Psychology and the real world*, 2, 2011.

[5] M. Csikszentmihalyi. *Flow and the psychology of discovery and invention.* Harper Collins, 1996.

[6] C. Diemand-Yauman, D. M. Oppenheimer, and E. B. Vaughan. Fortune favors the bold (and the italicized): Effects of disfluency on educational outcomes. *Cognition*, 118(1), 2011.

[7] A. Dix. Designing for Appropriation. In *Proc. British HCI.* BCS, 2007.

[8] A. C. Fyans and M. Gurevich. Perceptions of skill in performances with acoustic and electronic instruments. In *Proc. NIME*, 2011.

[9] M. Gurevich, P. Stapleton, and P. D. Bennett. Designing for style in new musical interactions. In *Proc. NIME*, 2009.

[10] T. Harford. How messy problems can inspire creativity. Ted Foundation, 2015.

[11] K. N. Kamoche, M. P. e Cunha, and J. V. da Cunha. Introduction and Overview. In *Organisational Improvisation.* Psychology Press, 2002.

[12] J. Kruger, D. Wirtz, L. Van Boven, and T. W. Altermatt. The effort heuristic. *Journal of Experimental Social Psychology*, 40(1), 2004.

[13] T. Magnusson. Designing constraints: Composing and performing with digital musical systems. *Computer Music Journal*, 34(4), 2010.

[14] A. P. McPherson. Bela: An embedded platform for low-latency feedback control of sound. *Journal of the Acoustical Society of America*, 141(5), 2017.

[15] D. V. Thompson and E. C. Ince. When disfluency signals competence: The effect of processing difficulty on perceptions of service agents. *Journal of Marketing Research*, 50(2):228–240, 2013.

[16] C. L. Yue, A. D. Castel, and R. A. Bjork. When disfluency is - and is not - a desirable difficulty: The influence of typeface clarity on metacognitive judgments and memory. *Memory & Cognition*, 2013.

[17] V. Zappi and A. McPherson. Dimensionality and Appropriation in Digital Musical Instrument Design. In *Proc. NIME*, 2014.