DURMS
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The Effect of Convolution Reverberation Length on Individuals' Felt Emotional Response to Unfamiliar Piano Excerpts

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ABSTRACT

Reverberation refers to the interaction of sound and space. Different spaces have been found to influence different emotion perception and arousal from music. Development in music technology has resulted in convolution reverb, a form of artificial reverb that replicates acoustic and reverberant properties of real-life spaces. The aim of this study is to investigate how reverberation length impacts individuals felt emotional response to piano excerpts, using convolution. Participants (N=29) were split into one of three groups for the different reverberation conditions of our between-subjects design; dry(0s), medium (2.4s) and long (5.7s). Participants completed five trials where they listened to an unfamiliar piano excerpt and provided felt emotion ratings using the GEMS scale. Despite trends within the descriptive statistics, results of separate ANOVAs demonstrated no significant differences of reverberation time for our hypothesised variables: sublimity, vitality, unease, overall GEMS and enjoyment. However, the felt emotion wonder found significance, whereby the long and medium reverb conditions had significantly higher ratings for wonder than the dry condition. These results suggest that despite most variables producing insignificant results, the trends within these data sets demonstrate that the importance of reverberation time to felt emotion reaction is present, however has a small effect.

1. INTRODUCTION

"If all real-world sounds were to be somehow stripped of their cloaking of reverberation it would be a wholly disorienting, dead, almost spaceless and depthless world." Doyle, 2005, p.38

In its simplest from, reverberation (reverb) can be understood as the interaction of sound and space. When a sound is produced from its source, it interacts with its surroundings, creating a complex pattern of reflections that provide the listener with an imprint of the space and in turn creates a sustained sound (Välimaki et al., 2012). Research has suggested at the large importance of reverberation for both animal and human communication (Richards & Wiley, 1980; Schroder, 1980). Musically, reverberation has a large association into the way in which we comprehend timbre, volume and note coloration (Doyle, 2005).

The interrelated relationship between sound and space has thus resulted in the consideration of buildings and spaces as part of an instrument (Bagenal & Wood, 1931). Throughout history the creation of musical spaces has been done so with acoustical design in mind. For example, the creation of large stone churches resulted in large reverberation times which was associated with the 'sacred and magical' (Bjornberg, 2007). It is this ability of reverberation that makes our experience to music malleable, and research has investigated how experience differs across reverberant spaces. A study by Barron (1988) found that preference for concert halls in the UK was strongly related to reverberation time, where there was large dissatisfaction for reverberation times less than two seconds. With regards to rock and pop music, subjective ratings of individuals demonstrated worse ratings for high reverb times and a preference for spaces with 0.6 to 1.2 seconds (Adelman-Larsen, 2010). As music listening has progressed from live spaces into software and technology it has resulted in the ability to map reverberant properties onto recordings.

The progression of music technology has witnessed the creation of reverberant sound properties produced by an artificial medium. This *artificial reverberation* is widely used in modern music to convey a sense of space (Välimaki et al., 2012). However, reverberation effects in popular music often go unnoticed as reverberation takes place independent of conscious awareness (Blum et al., 1967). Stemming from this, there has been an increasing amount of research into the effects of reverberation on several variables such as individual's emotion perception. One such study by Vastfjäll et al (2002) used a between-subjects design to explore how different artificial reverberation times in an auditory virtual environment (AVE) would influence 76 participants ratings of arousal, pleasantness and expressiveness. The results suggest that high reverb times produced significantly more unpleasant reactions than low and middle reverb times, and low reverb times produced significantly more arousal than medium and high reverb times. However, it is be noted that this study used a dimensional scale ranging from 0-100 to measure emotion expression which produced large standard deviations and thus questions the validity. Despite this, similar findings from Trajadura-Jimenez et als (2010) study investigating emotional effects of different sized virtual acoustic rooms showed that participants rated smaller rooms as more pleasant and calmer than larger rooms. Both studies investigated the effect of reverberation using natural and artificial sounds as their stimulus, thus there is a need for further exploration into using musical excerpts as stimuli.

A study by Pätynen and Lokki (2016) used an excerpt of Beethoven's Symphony No 7 to investigate how participants arousal, measured by skin conductance, varied by different concert room reverberation properties, namely geometry. The results indicated that intensity of arousal was greater in classical rectangular shaped geometries. However, it is important to note this study used a correlational design thus it cannot infer causation. Interestingly, this study used a form of artificial reverberation different to the previous cited literature called *convolution* reverberation. Convolution is a form of artificial reverberation which takes a recording of a sound, *impulse response*, in a real-life space and maps out the reverberant properties onto a software (Kantorik, 2014). Therefore, this means that an amateur musician can play in some of the most impressive musical spaces in the world, form the comfort of their own computer. Convolution reverberation provides a large area of study, as research has been able to investigate reverberant properties such as room geometry, and reverberation time of real-life spaces. In terms of its effect on the listener, research has claimed that listeners have a sensitivity to realistic rendering of the aural environment (Gaver, 1993), thus suggesting more of an effect over artificial reverberation.

A study by Mo & Horner (2017) investigated the effects of reverberation time on the emotional characteristics of different musical instruments, using convolution reverb. The study used six different convolutions with reverberation time ranging from 0s-5.44s. The results from a Pearson's correlation showed that halls with longer reverberation times were associated with the emotional characteristics calm, mysterious, romantic, sad and scary. Medium reverberation times were associated with the emotions happy, heroic and sad, whilst short reverberation times were associated with angry and comic emotional characteristics. These replicated previous findings of Mo et al, (2016) which used a similar design using artificial reverb, however the effect of convolution was greater. A limitation to this study's design is that its emotional ratings were measured by a pairwise comparison of different reverb conditions, such that a participant was showed two stimuli of the same instrument and asked which more strongly aroused a given emotion. Therefore, it is difficult if the results suggesting the different reverberation lengths association with emotions was perceived or was forced upon individuals. Furthermore, the stimuli used sustained instrument sounds, and not musical excerpts, making it difficult to infer the findings to the wide range of emotion induced from music.

In this present study we will investigate how reverberation time impacts individuals' felt emotional response to piano excerpts, using convolution reverb. This study aims to bridge the gap in current literature by exploring the effects of convolution reverb length on emotional reaction to musical excerpts, which will allow us to gain an understanding to the use of convolution in mainstream media. Furthermore, we propose a novel insight into understanding the effects of reverberation length by measuring felt emotion, as opposed to perceived emotion, on the Geneva Emotional Music Scale (GEMS). The scale measures nine felt emotions on a 5-point Likert for each excerpt, thus reducing the impact of forcing participants' responses into one given emotion category.

Due to the nature of the number of emotions and variables measured we will group the emotions together into their three 2nd order ranks for our hypothesis. This is consistent with the paper by Lykartsis et al, (2013). Hypotheses are based off previous findings discussed in this introduction.

1. Participants will give significantly higher ratings of sublimity (*wonder, transcendence, tenderness, nostalgia)* for longer reverb times.
2. Participants will give significantly higher ratings for vitality (*power, joyful activation*) for shorter reverb times.
3. Participants will give significantly higher ratings for unease (*tension/ sadness)* for longer reverb times.
4. Long reverb times will have significantly greater overall GEMS scores.
5. Long reverb times will have significantly higher ratings for enjoyment.

2. METHODS

Participants. A total of 39 participants were recruited via convenience sampling. Due to incomplete responses and one participant providing the same rating throughout, we removed ten responses from the data set leaving the total number at 29 (*M* age = 20.9 years, SD = 1.05). 19 participants identified as male, and ten identified as female. All participants had normal or corrected to normal hearing, as was required. The study was approved by Durham University's Ethics Committee.

Stimuli. A total of five piano excerpts which were unknown to the participants were used. Musescore was used for the stimulus search, where we applied filters for original composition, beginner difficulty and piano. The search led us to an amateur composer called *Tommy Burch* (Musescore, 2023). We selected 5 of Burchs's compositions which were called: *some kind of crazy dream, stall*, *brown bottled blue sunshine*, *nights promise*, and *old fool*. The excerpts were selected from the same composer for their relative similarity with regards to tempo (range from 54-110) and key (majority use major 'pop' chords). The MIDI data was downloaded for each of the songs via Musescore. The MIDI data was opened with Apple's Logic Pro X (Apple, 2023) and was convoluted with the *Space Designer* function. The pure MIDI data with all effects removed resulted in our dry condition, which had 0 seconds of reverb. The MIDI data was convoluted to Chamber Room three to create our medium condition, which had 2.4 seconds of reverberation. Finally, to create the long condition, the MIDI file was convoluted to Chamber Room one, which had 5.7 seconds of reverberation. The excerpts were all shortened to approximately 30 seconds, the sections of each song were chosen so that they were more similar to one another. With all conditions there were 15 separate files, where each excerpt had 3 different reverb conditions.

Design. This study used a between-subjects independent measures design. The independent grouping variable was reverberation which had three conditions: *Dry, Medium, Long*. The dependent variable was rating for felt emotion and enjoyment. Rating for felt emotion was achieved using the Geneva Emotional Music Scale (GEMS) (Zentner et al., 2008). This scale measures felt emotion for nine different emotions: *wonder, transcendence, tenderness, nostalgia, peacefulness, power, joyful activation, tension and sadness*. GEMS ratings were measured using a five-point Likert scale, where a rating of five corresponds to the emotion being very strongly felt. Similarly, enjoyment was measured on a five-point Likert scale.

Procedure. Participants were provided with a link to the survey, which was made and delivered using Qualtrics (Qualtrics, 2023). Once they followed the link participants were presented with an information sheet which provided information about the study. In order to avoid any confounding variables participants were only told the study was looking at felt emotional response to music excerpts from an amateur composer and were not informed about the focus on reverberation. Following this, participants were required to complete a consent form; incompletion of this would terminate the study. A set of demographic questions asked about participants age, gender identification, whether they have normal/corrected to normal hearing and whether they were wearing headphones. Participants were randomly allocated to one of the three reverb length conditions: *Dry* (N=11), *Medium* (N=9), *Long* (N=9). Participants were then presented with a musical excerpt which they had control over playing, thus relistening was allowed. The Likert scales were presented alongside. For the GEMS scale participants were asked "*On a scale of 1-5, please indicate how the musical excerpt made you **feel** for each given emotion*" and would provide ratings for each of the 9 emotions. For the enjoyment, participants were asked "*On a scale of 1-5, please indicate how much you enjoyed listening to the musical excerpt"*. Participants completed five trials with five different musical excerpts.

Data Analysis. Independent ANOVAs were used to test the ratings for all the dependent variables using the software JASP (version 0.17.1, 2023). In accordance with our hypotheses the nine GEMS emotions were grouped together into their second order factors: *Sublimity* (wonder/transcendence/peacefulness/tenderness/nostalgia), *Vitality* (power/joyful activation) and *Unease* (tension, sadness). ANOVAs were also used for the overall GEMS rating and the enjoyment to complete the confirmatory analysis. For the exploratory analysis ANOVAs were completed for all the nine emotions.

3. RESULTS

Descriptive Statistics. Descriptive statistics demonstrate some difference in participants ratings for all the variables between each reverb condition (See Table 1; Figure 1; Figure 2). However, to infer anything from these trends we need to look at the inferential statistics to test significance of the effects.

Table 1. Descriptive statistics showing the mean and standard deviation (SD) for participants' ratings for the confirmatory variables: Sublimity, Vitality, Unease, Overall GEMS and Enjoyment. Responses are split by reverb condition.

	Dry (0s)		Medium (2.4s)		Long (5.7s)	
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*
Sublimity	2.72	0.68	3.00	0.27	3.08	0.32
Vitality	2.27	0.68	2.43	0.49	2.50	0.82
Unease	2.04	0.43	2.48	0.63	2.23	0.32
Overall GEMS	2.48	0.53	2.77	0.28	2.79	0.34
Enjoyment	3.00	0.80	3.24	0.49	3.69	0.91

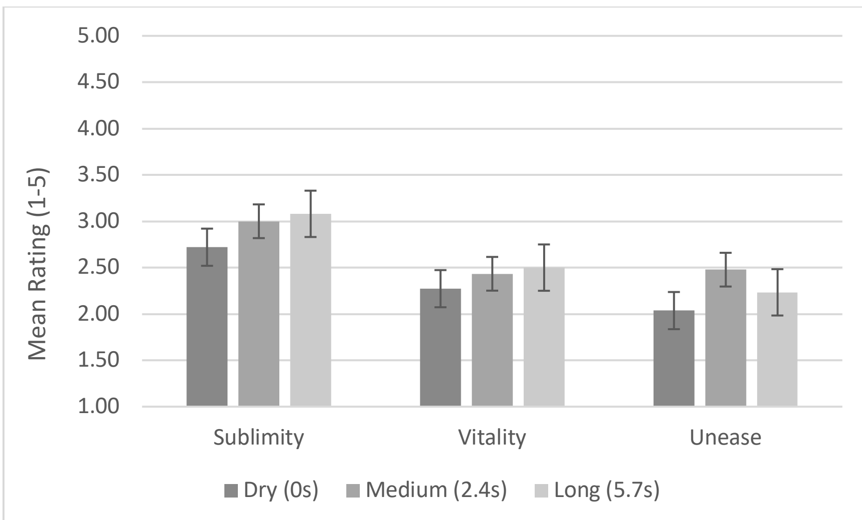

Figure 2. Participants' mean scores for sublimity, vitality and unease. Responses are split by reverb condition. Error bars represent standard error. Error bars represent 95% CI.

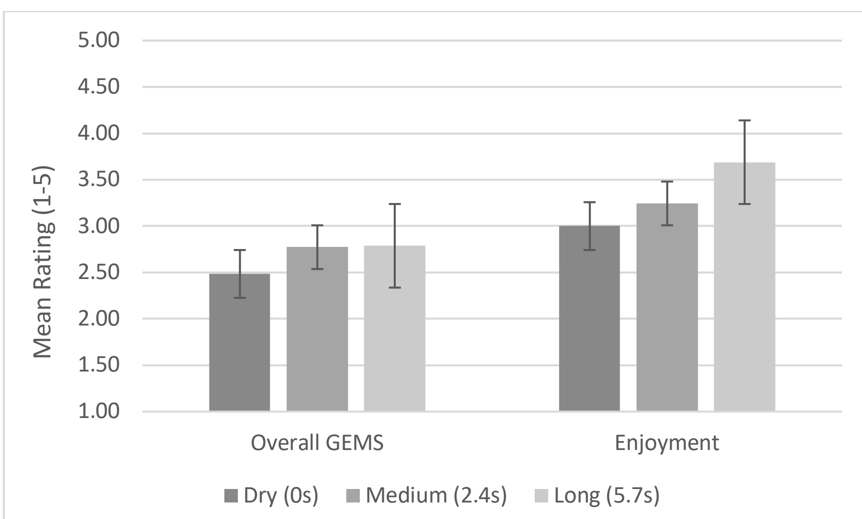

Figure 3. Participants' mean scores for sublimity, vitality and unease. Responses are split by reverb condition. Error bars represent standard error. Error bars represent 95% CI.

Confirmatory Analysis. We ran separate independent ANOVAs for each of our hypothesised dependent variables. We have presented the results of each ANOVA in separate and break down the results where appropriate.

Sublimity. The assumption of normality was met for all three reverb conditions for sublimity (Shapiro-Wilk $p > .05$). Levene's test for equality of variance showed that the assumption of homogeneity was violated ($p = .014$) therefore the Welch correction was used. There was no significant main effect of sublimity rating x reverb condition F (2, 16.82) = 1.17, $p = .335$, $\eta^2_p = .11$. Therefore, no further analysis was required.

Vitality. The assumption of normality was met for all three reverb conditions for vitality (Shapiro-Wilk $p > .05$). Levene's test for equality of variance showed that the assumption of homogeneity was met ($p = .338$). There was no significant main effect of vitality rating x reverb condition F (2, 26) = 0.302, $p = .742$, $\eta^2_p = .02$. Therefore, no further analysis was required.

Unease. The assumption of normality was met for all three reverb conditions for unease (Shapiro-Wilk $p > .05$). Levene's test for equality of variance showed that the assumption of homogeneity was met ($p = .218$). There was no significant main effect of unease rating x reverb condition F (2, 26) = 2.12, $p = .141$, $\eta^2_p = .14$. Therefore, no further analysis was required.

Overall GEMS. The assumption of normality was met for all three reverb conditions for sublimity (Shapiro-Wilk $p >$ .05). Levene's test for equality of variance showed that the assumption of homogeneity was met ($p = .054$). There was no significant main effect of sublimity rating x reverb condition F (2, 26) = 1.18, $p = .189$, $\eta^2_p = .12$. Therefore, no further analysis was required.

Enjoyment. The assumption of normality was met for the dry and medium conditions of enjoyment (Shapiro-Wilk p > .05) however was violated for the long condition ($p = .018$) suggesting a deviation from normal distribution. Therefore, a Kruskal-Wallis test was used. Results from the Kruskal-Wallis test revealed no significant differences between the reverb conditions H (2) = 5.182 $p = 0.075$. Therefore, no further analysis was required.

Exploratory Analysis. There was a significant main effect of wonder ($p = .008$). This effect was broken down using a post hoc comparisons using a Bonferroni correction. Participant ratings of wonder were significantly lower for the dry condition in comparison to the medium condition ($t = -2.91$, $M_{\text{diff}} = -0.68$, $p_{bonf} = .022$, $d = -1.306$) and the long condition ($t = -2.91$, $M_{\text{diff}} = -0.68$, $p_{bonf} = .022$, $d = -1.306$). There was no significant difference between the medium and long reverb condition ($t = 2.03 \times 10^{-15}$, $M_{\text{diff}} = 5.00 \times 10^{-16}$, $p_{bonf} = 1.000$, $d = 8.882 \times 10^{-16}$). (See Figure 4)

Table 2. ANOVA results for all the nine GEMS emotions.

Emotion	df	F	p	η^2_p
Wonder	2, 26	5.82	.008	.31
Transcendence	2, 26	1.92	.168	.13
Tenderness	2, 26	0.54	.591	.04
Nostalgia *	2, 16.24	1.20	.325	.06
Peacefulness	2, 26	0.73	.492	.05
Power	2, 26	0.52	.604	.04
Joyful activation	2, 26	0.07	.937	.01
Tension	2, 26	3.19	.058	.20
Sadness	2, 26	1.31	.286	.09

*Welch correction used due to a violation of the assumption of homogeneity of variance

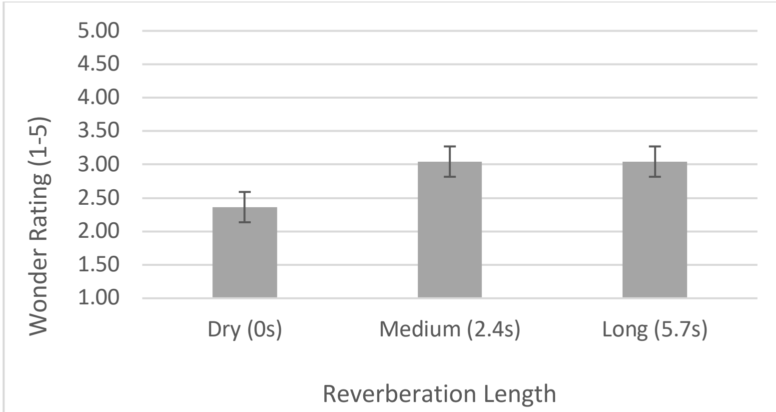

Figure 4. Participants mean scores for wonder. Responses are split by reverb condition. Error bars represent standard error. Error bars represent 95% CI.

4. DISCUSSION

The principal findings suggest that reverberation time has no significant differences in individuals felt emotion for the variables sublimity, vitality, unease, overall GEMS and enjoyment. However, an interesting finding of the exploratory analysis revealed that the participants rating of the emotion wonder reached significance, which showed that ratings of wonder for the long and medium reverberation times were significantly larger than for the dry reverb condition. This is consistent with previous findings of long reverb times beings associated with similar emotions such as mysterious and romantic (Mo & Horner 2017; Mo et al., 2016). Furthermore, this reflects the use of spaces such as churches, with large reverberation times, to create a sense of wonder and spirituality.

Despite the variables outlined in the hypotheses not reaching significance, meaning we cannot infer findings to a larger sample, the descriptive statistics provided insight into the trends within each variable. Results of sublimity demonstrated a slight but clear trend, where longer reverberation times resulted in greater ratings. This trend is consistent with findings for Mo & Horner (2017) who found that the emotions mysterious, romantic and calm were associated with higher reverb times. We predicted vitality to have greater ratings for shorter reverb times, however descriptive statistics demonstrated a slight trend, inverse to our predictions. This does not reflect previous research which has proven across studies that arousal is positively associated with shorter reverberation times (Vastfjall et al., 2002; Mo et al., 2016; Mo & Horner 2017). Descriptive results of unease somewhat demonstrated our predictions where the dry reverb condition had the lowest overall rating. However, the medium reverb condition produced the greatest overall rating, it is important to note this was a very small effect. This contradicts findings that suggest emotions of unease and unpleasantness were associated with longer reverb times (Vastfjall et al., 2002; Jimenez et al., 2010; Mo et al., 2016; Mo & Horner 2017).

This study used the variable *overall GEMS score* as a means of grasping individuals felt overall emotionality of an excerpt, which aimed to infer which reverb conditions produced the largest emotional reaction. No study before has measured overall GEMS score in relation to the effects of reverberation, thus our prediction was based off our other hypotheses and previous research depicting high ratings for a larger number of emotions for long reverberation times. Descriptive statistics for this demonstrated a clear trend whereby the long reverb condition had the greatest overall GEMS followed by the medium and the dry conditions, yet as previously mentioned this did not reach statistical significance.

Similarly, this study sought to measure individual's enjoyment of the musical excerpt by using a 5-point Likert, thus different from the rest of the variables this did not measure a felt emotion. Descriptive statistics demonstrated a clear trend for enjoyment, where longer reverb times were associated with a greater level of enjoyment across the five musical excerpts. This trend was in line with our prediction, however, did not reach significance.

Inconsistencies within our findings in relation to previous research and our hypotheses can be explained by the differences in design of the studies. The majority of studies previously cited have used correlational designs, which means that their findings can only suggest correlation as opposed to causation. As our design was experimental, perhaps one of the main reasons for our insignificance could be due to our study hypotheses being based off correlational data. Therefore, whilst our data did demonstrate trends within each variable, consistent with previous correlational findings, the effect of the trends was not large enough to reach statistical significance.

As this study is one of the first to test the effect of convolution reverberation length in an experimental design, we posit that the effects of convolution are small due to the subtlety of reverberation. Previous literature on the effect of reverberation has often placed individuals into real-life spaces or used some visual cues alongside the music (Vastfjäll et al 2002, Trajadura-Jimenez et al, 2010) which has resulted in our understanding of reverberation having strong effects on emotion perception and arousal. Comparing this to our design, where only an auditory cue was given, it produced small effects on felt emotional response. Therefore, like how reverberation is the interaction of sound and space, perhaps our experience of this phenomenon is strongest when the listener is provided with both visual and auditory cues. This would explain the understanding that stone churches elicit emotions of the sacred and magical (Bjornberg, 2007), as a combination of both the sound but also the religious and decorative setting that these sounds are heard in which in turn influence the listeners arousal. We suggest that further study should investigate the impacts of reverberation on listeners arousal and emotion perception, with and without visual cues.

One of the main strengths of our design was that we used a between-subjects independent measures design. Participants were unaware of the experiments main goal and were told to rate felt emotions of an amateur composer. Therefore, this reduced any potential bias for demand characteristics, which could potentially explain some of Mo & Horner's (2017) findings. In turn this meant that a large limitation of our study was that participants therefore were comparing and adapting responses across the different excerpts as opposed to the different reverb conditions. Whilst emotion ratings are certain to differ between excerpts, collecting an average rating across all the five excerpts was done to avoid this confound. Another large limitation which came from the between-subjects design was our sample size, which after removing incomplete responses, was too small. This means that our findings lack representativeness, as they do not accurately represent the population they were obtained from. Furthermore, they lack generalizability, considering they were all university students.

This experiment used three reverb conditions; dry (0s), medium (2.4s) and long (5.7s). This differed to previous research as the long condition had a greater reverberation time than any of the previous studies. However, the majority of previous research includes a short reverberation length condition, often around one second long, and the dry condition would be used as a control. A future consideration of this study would be to use a short reverberation condition, as generally ratings for the dry condition were often the lowest, which could be explained by how unnatural a noise without any reverberation sounds. If this were to be implemented in future research, this study requires a much larger sample size for both the extra group, but also to reduce the limitations as were experienced in this study.

Convolution reverberation has presented itself as an emerging branch of research in the field of music psychology and is one that requires much attention in future research. Whilst this study has only looked at the effect of reverberation length using convolution, there are many more variables to be investigated. For example, as Patynen and Lokki (2016) demonstrated, the exploration into room geometry using convolution, demonstrated individuals preference for rectangular rooms. Likewise, this study looked at the effects of reverberation length on similar piano excerpts from one amateur composer. Therefore, the opportunities of future research are almost limitless when looking at the effects of convolution on different music genres and composers.

In conclusion, the findings of this study promote the importance of reverberation to our experience of sound and music. Whilst all bar one of our findings did not reach significance, the descriptive statistics demonstrated slight trends in the data, concurrent with previous findings. Reasons for our insignificance can be largely put down to both the limitations of our study, and to the potential small effect of convolution reverberation which has been experimentally proven in this study. This study suggests many future considerations for further research to investigate this new frontier in the field of music psychology.

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