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Music as Medicine:

Comparison of LUCID's Digital Music Therapy, Generic Functional Music & Self-Selected Music

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Points of Contact:

Zoë Thomson
Chief Science Officer
zoe@thelucidproject.ca

Zach McMahon
Chief Executive Officer
zach@thelucidproject.ca

Aaron Labbé
Chief Technology Officer
aaron@thelucidproject.ca

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Abstract

The use of music for outcomes in neuropsychiatric health is gaining traction in both scientific research and clinical practice. This whitepaper compares LUCID's digital music therapy modality to generic functional playlists and self-selected music in the context of music-based interventions for therapeutic outcomes. The suitability of these three interventions for health and wellness applications is examined along with data from a randomized controlled trial comparing LUCID's digital music system to the top Spotify-curated calm playlist. Results indicated superior effects of LUCID's intervention on self-reported stress (-20.5% vs. -12.3%, p=0.05) and two dimensions of mood: valence (11.6% vs. 3.6%, p=0.05) and activation (-12.6% vs. 2.4%, p=0.01). Considering the growing numbers of individuals experiencing mental health challenges both at and below diagnostic levels and the high levels of comorbidity between these challenges and physical diseases, the applications of highly accessible content-based interventions for stress, anxiety, and mood are meaningful and significant. LUCID will continue conducting clinical research and developing music-based interventions in collaboration with partners in the digital health space to support higher quality of care and improved treatment outcomes.

Background

Theory: Music for Therapeutic Outcomes

Music has long been used to support health and wellness outcomes and is a hotbed of contemporary study. Music-based interventions have shown efficacy for diverse outcomes, including chronic and acute pain (Choi et al.. 2018; Vaajoki et al., 2010; Shabanloei et al., 2010; Good et al., 2005; Smyth et al., 2018; Chai et al., 2020; Jangsirikul et al., 2017), acute stress (Sandstrom & Russo, 2010) and depression (Koelsch, 2010; Angelucci et al., 2007), and can be as effective as benzodiazepines at reducing vital signs of anxiety (Bringman, Giesecke, Thörne, & Bringman, 2009). This is partially mediated through the neurochemical effects of music, including increased levels of endogenous opioids and dopamine (Mallik, Chanda, & Levitin, 2017; Salimpoor, Benovoy, Larcher, Dagher, & Zatorre, 2011). While research regarding the precise nature and mechanism of music's effects on the brain is ongoing, below is a three-pronged hypothesized mechanism of action of music on mental and emotional outcomes:

1. *Music shifts the balance of the autonomic nervous system.*

   Music-listening has been shown to be capable of decreasing sympathetic nervous system activity (Ellis et al., 2010), as well as increasing parasympathetic nervous system activity, enabling physiological functions involved in growth, restoration, and recovery (Jia et al., 2016). This autonomic shifting of resources from sympathetic to parasympathetic may further assist in allowing the user to attain more significant benefit from concurrent or subsequent interventions including Cognitive Behavioral Therapy, mindfulness, or biofeedback.

2. *Music taps into neural centers of memory and emotion.*

   Midline cortical structures such as the medial prefrontal cortex, anterior cingulate cortex, and medial temporal lobes appear to be involved in music-evoked autobiographical memories (Belfi et al., 2018; Janata, 2009). In addition, the limbic and paralimbic systems show significant activity changes associated with music-listening (Bernatzky et al., 2011). By altering activity in these cortical and subcortical brain regions, music interventions may assist users in accessing and processing memories or emotions and attaining more desirable affective states.

3. *Music can deeply absorb the listener's attention and direct emotional experiences.*

   Pleasant music produces an increase in frontal midline theta power (Bernatzky et al., 2011), which is associated with states of focused attention (Ishii et al., 2014). As such, music can absorb a listener's complete attention and draw them into a rich emotional experience (Hall, Schubert & Wilson, 2016; Sandstrom & Russo, 2013). This is thought to be mediated by the effects of music-listening on activity in mesolimbic structures involved in reward processing as well as the hypothalamus and the insula, which are involved in regulating autonomic and physiological responses to rewarding and emotional stimuli (Menon & Levitin, 2005). From a psychological perspective, this can create a separation between the listener's current experience and their baseline perspective. By diverting the listener's awareness from their typical thought patterns, stressors, and understanding of themselves (especially if they self-identify as someone who faces a chronic condition like anxiety or pain), music-based interventions can mitigate rumination and help the listener experience more positive mental and emotional states. Combined with music's ability to induce a broad spectrum of emotions (Koelsch, 2014; Choppin, 2016; Zentner, 2008), music-based interventions can guide the listener toward states conducive to therapeutic outcome.

Put simply, through deeply absorbing the listener's attention music can produce measurable neurological, mental, emotional, and physiological shifts. Considering that the average American listens to over 25 hours of music per week (Statistica, 2021), music-based interventions have the potential for high engagement and compliance while demonstrating quantifiable improvement for multiple neuropsychiatric outcomes.

Auditory Beat Stimulation

Auditory beat stimulation (ABS) is a family of auditory stimuli designed to induce brainwave entrainment; meaning, neuronal activity synchronizes with the ABS frequency (Vernon et al., 2014). The effects of ABS are contingent on the frequency used. A summary of some relevant areas in which ABS techniques have shown efficacy is outlined in Table 1.

The Future of Music Interventions

With access to digital music services becoming more widespread globally, people are increasingly incorporating music into their daily routines for entertainment and self-improvement alike. Functional music offerings for relaxation, sleep, focus, and performance dominate music platforms like Spotify and Apple Music. This growing acceptance of the use of music for health and wellness is likely to encourage the uptake of more rigorous, effective, and engaging functional music interventions.

Personalized medicine is becoming mainstream in many branches of healthcare; neuropsychiatric wellbeing is no different. The integration of personalization techniques to optimize for the listener's musical preferences and their current mental, emotional, and physiological state is a natural progression from one-size-fits-all music interventions to more potent and absorptive sound-based therapeutics.

Furthermore, the use of big-data techniques to support intelligent music creation and curation is a notable lack in the music industry at present. The use of tools for assisted functional music composition would likely reduce variability in its effects and increase confidence regarding outcomes. As such, quantitative music informatics are likely to become highly relevant in functional music offerings.

LUCID's technology is predicated on the hypothesis that through quantitative measurement and robust machine learning techniques that incorporate personalization, functional music can be optimized to achieve more significant and predictable effects on more specific outcomes. See the 'Solution' section for more details.

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Table 1: Overview of some effects of ABS of varying frequencies.

	Outcomes	ABS Frequency	Sources
Migraine	Reduce attack frequency	12 H, decreasing to 8 Hz	Lovati et al. (2019)
Pain	Reduce perceived pain	6 Hz; range from 8-12 Hz	Zampi (2016); Ecsy et al. (2017), Dabu-Bondoc et al. (2010); Ecsy et al. (2017)
	Reduce pain and primary symptom severity in conditions related to chronic pain	Self-selected frequency	Huang & Charyton (2008)
Anxiety	Reduce anxiety severity	30 Hz decreasing to 10 Hz; 7 Hz; 9 Hz; 10 Hz	Huang & Charyton (2008); McConnell et al. (2014); Isik et al. (2017); Padmanabhan et al. (2005)
Sleep	Induce relaxation; increase theta and reduce beta brainwave power in adults with subclinical insomnia, thereby reducing hyper-arousal state and assisting in sleep induction	6 Hz	Choi et al. (2020)
	Produced deeper sleep, longer N3 phases	3 Hz	Jirakittayakorn & Wongsawat (2018)
	Significantly improved ratings of sleep and wakefulness quality, sleepiness, and motivation	2-8 Hz	Abeln et al. (2014)
Memory	Associated with improvements in long- and short-term memory	15 Hz	Beauchene et al. (2016), Beauchene et al. (2017)
Focus	Associated with improvements in attention and vigilance tasks	40 Hz, 16-24 Hz	Colzato et al. (2017), Hommel et al. (2016), Lane et al. (1998), Reedijk et al. (2015)

Limitations of Current Music Interventions

Generic Functional Playlists

The use and creation of *functional music* - music and playlists intended to help the listener achieve a particular goal, the most popular of which include relaxation, focus, sleep, and physical performance - is dramatically increasing. Though widely used and easily accessed through digital audio service providers like Spotify, Apple Music, Calm, and Headspace, these music offerings are not optimized for therapeutic outcomes on account of the limitations outlined below.

Lack of Rigor and Supporting Data

The vast majority of functional music offerings take the form of fixed playlists curated by hand with little to no objective basis predicating the song choices and the order of the tracks. Furthermore, most music is composed and produced for entertainment purposes without a well-defined wellness outcome in mind and does not incorporate measurement of quantitative musical features or music-induced emotional responses. As a result, most functional music is not optimized for specific mental, emotional, or wellness targets, particularly because it is not generated to maximally leverage the mechanisms of action of music on mental and emotional outcomes (outlined in the 'Theory: Music for Therapeutic Outcomes' section above). More specifically, music produced by hand without the assistance of data-driven tools, even if created with a specific emotional outcome in mind (such as increasing feelings of calm or assisting sleep induction), is not designed to shift autonomic balance or target highly specific emotional states. Though all music can be relaxing and emotive, most music is not tailored to maximally leverage those qualities in a targeted way.

Furthermore, generic functional music offerings cannot integrate additional sound-based modalities like ABS. This limits the extent to which the benefits of these playlists can be scaled and amplified.

One-Size-Fits-All Solution

The experience of music is highly personal and is governed by many factors, including the listener's musical preferences, demographics, personality (Rentfrow et al., 2011), and perhaps most notably their current mood. Generic functional playlists are limited to a static experience in which no element of personalization is possible, either for the music selections that an individual is likely to enjoy or for their current mental-emotional state. There is evidence to suggest that the positive outcomes of music-listening are significantly more potent when the listener finds the music selection pleasurable (David & Thaut, 1989), which a canned playlist

cannot take into account. Likewise, responses to music are not time-invariant; the same music selection played while the listener is in a state of distress is unlikely to invoke the same reaction as it would if they were in a calm and sleepy state. A static playlist cannot account for such a dynamic response.

Non-Specific Curation Strategy

A static functional music playlist is likely to consist of a collection of tracks perceived by the curator to match the desired wellness outcome (e.g., 'calm', 'focus', etc.). However, as mentioned above, the ordering is likely not considered with any quantitative rigor. Considering music's expressive qualities, this is problematic in the context of a playlist with the goal of guiding the user to a desired mental-emotional state. Suppose the emotional quality of the tracks in the playlist is varying in an unmeasured and undirected manner. In that case, this playlist is unlikely to be maximally successful in helping the listener achieve the target state.

Self-Selected Music

Music is ubiquitously used for both entertainment and functional outcome in many contexts (relaxation, setting a 'tone' in social gatherings, fitness performance, etc.). Self-selected or self-curated playlists constitute much of this use. While this approach addresses the lack of personalization in generic functional playlists, its efficacy is limited in several ways.

The Burden of Choice

One strength of self-selected music is the fact that it will always be liked by the listener. However, this may not be the most effective method at reliably producing targeted outcomes using music. If a user is in a state of distress (i.e., anxiety, pain, etc.), self-selecting the optimal music may itself be stressful or even inaccessible. This places the burden on the user to develop their own 'functional music protocol' by both selecting and curating the appropriate songs for their desired outcome, which they may not be capable of reproducibly performing.

The Limitations of the Listener

By extension, a human music-listener is limited in their abilities of perception, differentiation, and memory. The combinations of musical features that induce distinct emotional states (as indicated through proprietary data analysis performed by LUCID on real-world datasets) are not easily distinguishable to the human ear. Furthermore, it is not reasonable to assume that a human listener will recall which exact songs in what particular order have been effective for them in the past to reduce their anxiety or attain a specific emotional state as a function of their current mood. As a result, the effects of self-directed functional music selections are likely to be less potent and less reproducible than those of a data-driven music selection and curation process.

The Limitations of Experience

Furthermore, self-selected music is limited by the music that is known to the listener. This is problematic in the context of therapeutic music for two reasons.

First: one may not be familiar with the music that would be the most effective for them to achieve a specific functional outcome, thereby limiting the benefits that they can achieve through self-selected music by the contents of their personal music catalog.

Second: familiar music may anchor the listener in their current understanding of themselves, their state, and their mood, especially if they identify as a person who experiences anxiety, chronic pain, or some other ongoing condition for which they seek relief. In this way, familiar music may inhibit the listener from maximizing their benefit from an experiential intervention such as music. Additionally, novel music heard for the first time has been shown to elicit strong positive emotional responses and activation of the limbic system, similarly to familiar music (Bernatzky et al., 2011); though familiar music can produce potent responses, unfamiliar music can do the same.

Summary

Generic functional music offerings and self-selected music may offer some wellness benefits due to music's intrinsic capabilities to induce emotional responses and reduce stress. However, if an auditory intervention with significant therapeutic benefits and predictable effects is desired, these options are unlikely to be well-suited to the task, based on the infeasibility of holding the user responsible for curating their own functional music as well as the intrinsic limitations of human-curated music interventions.

Solution

Technology: Optimized Curation and Creation

LUCID is a software platform that aims to extract the full therapeutic potential of sound and music. The essence of LUCID is an affective computing environment that consists of three core technologies. The first is a novel audio engineering technique that seamlessly integrates auditory beat stimulation including binaural beats into music. The second leverages psychometric and/or biometric measurement in conjunction with emotional modeling theory to estimate a user's current affective state. In many current embodiments of this technology, an

adapted version of the Russell Circumplex Model (Russell, 1980) has been used (see Figure 1, below). In all cases, the measurements are mapped to the Geneva Emotional Music Scales (GEMS), a measurement tool devised to quantify musically-evoked emotions (Zentner et al., 2008), to link user state assessments to the structure of the emotional data correlated with music in LUCID's machine learning architecture. These measurements are then used as input to a model-based reinforcement learning system that personalizes music curation for particular outcomes in real-time. This model uses 72 quantitative musical features in conjunction with the user's demographic and real-time emotional data to predict the optimal sequence of music to help them attain their desired mental-emotional state.

This affective music recommendation system produces correlated data of musical features and real-world emotional responses to music that is subsequently used in deep learning systems to both optimize the creation of music for specific emotional outcomes and support novel research around how the human body responds to music. These deep learning systems also encompass LUCID's third piece of core technology, the ability to employ data-driven models to create music with the highest possible therapeutic potential for precise outcomes. This is achieved both through a data-driven composition workflow and a generative remix model that transforms existing audio stems into new pieces of therapeutic music. These new mixes are then fed back into the recommendation system, producing a fully closed loop of music creation, music recommendation, affective measurement, and AI model optimization.

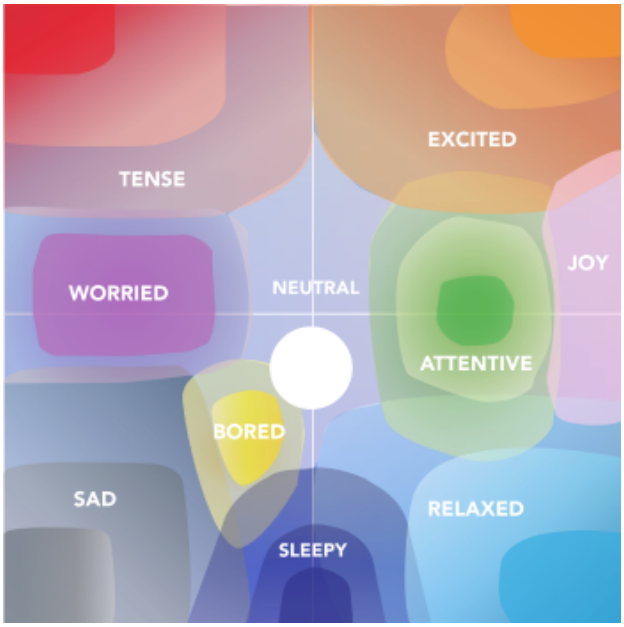

Figure 1: Adapted Russell Circumplex Model of affect.

This music recommendation system is designed to generate music-based auditory sessions for specific therapeutic outcomes. As such, it is better-suited to health and wellness applications than both self-selected music and generic functional music offerings on account of the following features.

A Data-Driven Approach to Increase the Probability of Success

LUCID's AI system uses real-world data and cutting-edge machine learning techniques to optimally compose, produce, master, and curate music for specific functional and emotional effects, as outlined above. As a result, LUCID's system is tailored to applications of music-listening that target a specific health or wellness outcome. This system uses validated emotional models including the Russell Circumplex Model of Affect and the GEMS, which pertains specifically to emotional responses to music. As such, LUCID's system produces music-based experiences that target particular effects at high fidelity, resulting in more predictable and potent responses than could be achieved without the use of this proprietary technology.

A Neural Network for Each User: Personalized Music Selection

As mentioned, responses to music are highly variable both between individuals and within a given individual over time. This variability is largely explained by the individual's personal characteristics (age, gender, location, etc.), musical preferences, and current mood. LUCID's music recommendation system accounts for these factors in the music selection process by including them as system inputs. Over repeated use, the reinforcement learning agent self-optimizes on a network-wide level and a user-specific level based on the responses induced by particular tracks or sets of musical features. This system produces a unique model for each user, increasing the probability of successful listening sessions for each individual over repeated use.

This automated selection and optimization process removes the burden from the user to know and choose the optimal music for specific outcomes as a function of their current mood. As a result, this system overcomes the limitations that a human listener would have in their ability to perceive and remember which music is most effective for them for particular wellness targets.

The Iso Principle: Real-Time Dynamic Curation

LUCID's music recommendation system also uses these real-time insights about the user's mood to curate and order a sequence of songs based on *the iso principle*, a methodology used by music therapists for mood induction. In this technique, the affective properties of the music are initially matched to the listener's mood at the beginning of the session and gradually shift

towards the user's desired mood. This gradual shift from 'current-state' towards 'goal-state' allows the user to adapt to the emotional change, increasing the probability that the music session will result in the desired effects (Heiderscheit & Madson, 2015).

Integration of Auditory Beat Stimulation

As mentioned, LUCID has developed a patented method to integrate ABS into music. This development was largely motivated by the grating and unpleasant auditory characteristics of ABS on its own, reducing usability and compliance despite studies indicating its efficacy in multiple domains. When integrated into LUCID's music intervention using this proprietary technology, ABS produced more significant effects on somatic and cognitive anxiety following a single listening session as compared to both the music intervention and ABS alone. (See **Adult Anxiety Study - Executive Summary** for more details.) As mentioned, the neuropsychiatric effects of ABS are contingent on the selected frequency; LUCID's system can integrate any ABS frequency deemed to be suitable for the desired effects. As compared to self-selected music and generic functional playlists, the ability to integrate ABS stimuli tailored to the outcomes of interest is unique to LUCID's intervention.

Randomized Controlled Trial Data

LUCID vs. Generic Calm Music

Methods

Participants and Study Design:

40 participants (mean age: 25.05 years, 22 males, 17 females, 1 undisclosed gender) were recruited for the preliminary data collection of this study. These participants were recruited from the general population using Prolific (www.prolific.co), a remote research platform for digital recruitment and data collection, and were pre-screened for moderate anxiety symptoms using the STICSA trait and cutoffs reported in a previous study (Roberts, Hart, & Eastwood, 2016). This population was selected based on the hypothesis that a single intervention use is likely to be most effective for participants with moderate trait anxiety. Participants with low trait anxiety are more likely to present with low levels of acute state anxiety and due to this low effect size, a very large sample would likely be needed to observe statistically significant effects. Conversely, participants with severe anxiety may find the first use of any experiential therapy to be anxiety-inducing, and may show more consistent effects in a longitudinal study. This hypothesis was supported by the results of a previous randomized controlled trial, in which the most consistent and meaningful results were observed in participants with moderate trait anxiety following a single use of LUCID's intervention.

Outcome Measures:

The primary outcome measure of this study was self-reported stress, using a visual analog scale (VAS) and the question: 'Indicate how stressed you feel in this moment.'

Secondary outcome measures included the Self-Assessment Manikin (SAM) (Bynion & Feldner, 2017), which measures emotion on two axes: valence, indicating positivity/negativity, and arousal, indicating high/low activation.

Interventions:

1 - LUCID's Digital Music Therapy with Integrated ABS

The embodiment of LUCID's technology used in this study consists of two components:

1. LUCID's music catalog, which was created and labeled using insights from our deep learning algorithms regarding the emotions that are likely to be induced by a piece of music. These algorithms are further leveraged by in-house composers to tailor musical composition and production to specific emotional outcomes.
2. This music is then curated using LUCID's deep reinforcement learning Affective Music Recommendation System, which produces a personalized music sequence with the highest probability of the listener transitioning from their current emotional state to their desired emotional state. In addition to the user's current mood state, this reinforcement learning model also includes inputs regarding the user's age, musical preferences, and baseline anxiety levels and can be further optimized for a specific use-case through the addition of other inputs. In the case of this study, 25-minute experiences were curated for each participant.

2 - Generic Calm Playlist

To maintain objectivity in selecting the comparator music condition, the Spotify-curated relaxation playlist with the largest number of followers was selected. This playlist, 'Calm Vibes' had over 750,000,000 followers at the time of this study. The first tracks on the playlist amounting to approximately 25 minutes were purchased and compiled into a single audio stream.

Results

LUCID's music intervention produced more significant reductions in stress (VAS) and activation (SAM) and more significant increases in positive mood (SAM) as compared to the generic calm playlist. (See Table 2 and Figures 2-3.) No adverse events were reported.

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Table 2: Changes and comparisons in primary and secondary outcomes.

	LUCID Music Recommendation System and ABS (n = 24)	Spotify (n = 17)	One-tailed p-value	Cohen's d
Change in stress VAS	-2.25 (-20.5%)	-1.35 (-12.3%)	0.05	0.63
Change in SAM-Activation	-0.63 (-12.6%)	0.12 (2.4%)	0.01	0.81
Change in SAM-Valence	0.58 (11.6%)	0.18 (3.6%)	0.05	0.54

Discussion

These results support the hypothesis that LUCID's music intervention is more effective than popular generic functional playlists for outcomes including stress and mood. Coupled with the fact that LUCID's intervention is highly adaptable, including the capability of adding inputs to the machine learning models and performing transfer learning to optimize for different outcome measures if appropriate, this architecture presents distinct advantages compared with conventional functional music offerings.

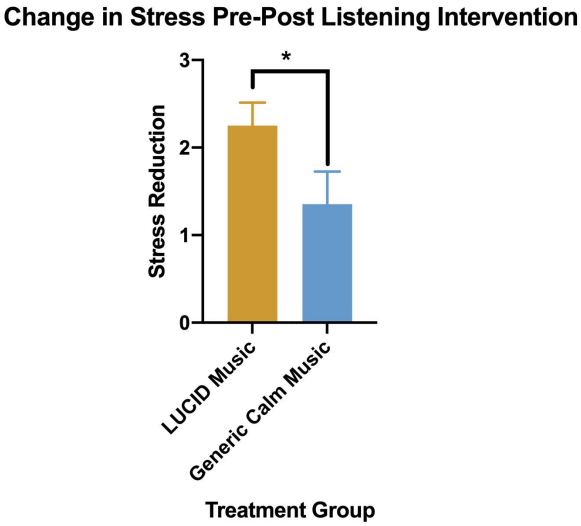

Figure 2: Reduction in stress (VAS).
(* indicates p≤0.05.)

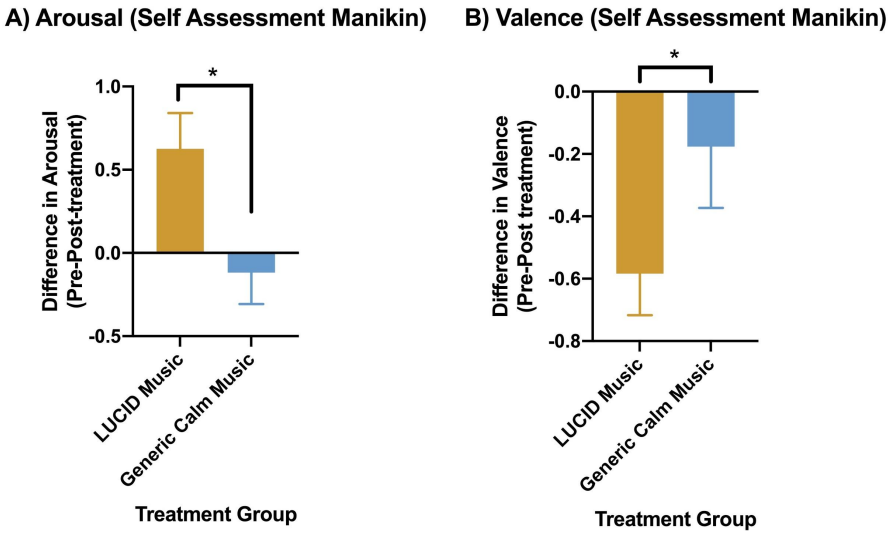

Figure 3: Reduction in Self-Assessed Mood (SAM).
(* indicates p≤0.05.)

Adult Acute Anxiety Study (Brief Overview)

The use of LUCID's technology for acute anxiety reduction was evaluated in a randomized controlled trial (n=264) as compared to pink noise, an active comparator that is routinely used in studies of auditory interventions (Zhou et al., 2012). Acute anxiety was measured using the State-Trait Inventory of Cognitive and Somatic Anxiety (STICSA) state scale (Roberts, 2013). Results indicated that in moderately-anxious adults, a single 24-minute listening session using LUCID's custom-created content and music recommendation system was significantly more effective than pink noise at reducing somatic state anxiety (13% vs. 6%, p=0.04) and cognitive state anxiety (21% vs. 15%, p=0.05). These results were presented at McMaster's NeuroMusic Conference in November 2020, and submission to peer-reviewed journals is in progress. A comprehensive informal write-up of the study design and results is publicly available in a separate **Executive Summary**.

Future Work

Though statistically significant results and good effect sizes were attained in the small randomized controlled trial comparing LUCID's digital music intervention to the top Spotify-curated calm playlist, a larger sample may be collected to achieve slightly higher effect sizes for publication purposes. If appropriate, this data may be presented at conferences and formal write-ups may be submitted to peer-reviewed journals.

More generally, LUCID intends to continue building a diverse and robust portfolio of clinical evidence. This includes a longitudinal study with biometric measures assessing effects on chronic anxiety symptoms (currently in the planning stage), a comparison of LUCID's music intervention and self-selected music, and a pilot study examining effects on anxiety in a cohort with significant chronic pain symptoms.

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