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Kamala McNevin

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# The Effectiveness of Biomusic as a Communication Tool for Individuals with Communication Barriers

## Abstract

**Background:** Many family members and care providers are unable to communicate with their loved ones and may feel distanced from them due to severe disabilities or injuries that create a communication barrier. Current methods of communication are either obscure and subjective interpretations of body gestures, or technologies that require a certain level of cognition, bodily movement, and functionality to operate. Biomusic is a novel technology that could allow for communication as well as identification of certain emotional states for those that have communication barriers.

**Methods:** An exhaustive literature search was conducted using MEDLINE-Ovid, Evidence-Based Medicine Multifile, Proquest, MEDLINE-PubMed, NCBI, Google Scholar, Health and Wellness Resource Center, CINAHL, Web of Science, and Cochrane using the following search terms: biomusic, children, anxiety, autism, communication disorders, communication barriers, developmental disorders, disabled persons, personhood, affective technology design, NOT music therapy. GRADE criteria were then employed to analyze the quality of the studies.

**Results:** There were 195 articles that were found. Only 2 studies met the eligibility criteria. The first study reviewed was a pilot study that functioned as proof of concept for biomusic and revealed potential for biomusic to create meaningful communication and re-establish personhood. The second study demonstrated that biomusic could be used to determine anxious or relaxed states in typically developing children and children with autism spectrum disorder quickly (within 11.3 seconds), and with high accuracy.

**Conclusion:** The field of biomusic is still in its infancy and more research needs to be performed to determine the abilities and limits of biomusic. The abilities of biomusic to determine emotional states is promising and the studies showed that it can be used reliably. Furthermore, biomusic can be used to re-establish more meaningful interactions between individuals with communication barriers and their care providers.

## Degree Type

Capstone Project

## Degree Name

Master of Science in Physician Assistant Studies

## Keywords

Biomusic, children, communication barriers, developmental disorders, disabled persons, and affective technology design.

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# **The Effectiveness of Biomusic as a Communication Tool for Individuals with Communication Barriers**

**Kamala McNevin**

**Pacific  
University  
Oregon**



***A Clinical Graduate Project Submitted to the Faculty of the  
School of Physician Assistant Studies***

***Pacific University***

***Hillsboro, OR***

***For the Master of Science Degree, 2019***

***Faculty Advisor: Brandy Pestka***

***Clinical Graduate Project Coordinator: Annjanette Sommers, PA-C, MS***

## **Biography**

Kamala McNevin was born and raised in Utah. She attended BYU where she majored in Exercise Science. During her attendance, she was accepted into various groups such as BYU's Innovation Academy for entrepreneurs, a biotechnology/business internship for startup companies, an embryological research assistant studying limb development, the BYU Taekwondo Club, and a physical therapy and personal training internship. She was a Y-prize winner for her business model for distribution of and education on anti-parasitic medications for rural Ugandans. She competed in and took first in a JiuJitsu tournament, was promoted to the Head Senior Assistant in her Physical Therapy and Personal Training internship, and was nominated as the Head of Strategy and lead presenter in her biotechnology/business internship for the startup company TetraGene. She loves innovation and change, is an avid lover of music, exercise, and wellness, and plays the piano adequately enough to keep up with her cellist husband.

## Abstract

**Background:** Many family members and care providers are unable to communicate with their loved ones and may feel distanced from them due to severe disabilities or injuries that create a communication barrier. Current methods of communication are either obscure and subjective interpretations of body gestures, or technologies that require a certain level of cognition, bodily movement, and functionality to operate. Biomusic is a novel technology that could allow for communication as well as identification of certain emotional states for those that have communication barriers.

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**Conclusion:** The field of biomusic is still in its infancy and more research needs to be performed to determine the abilities and limits of biomusic. The abilities of biomusic to determine emotional states is promising and the studies showed that it can be used reliably. Furthermore, biomusic can be used to re-establish more meaningful interactions between individuals with communication barriers and their care providers.

**Keywords:** Biomusic, children, communication barriers, developmental disorders, disabled persons, and affective technology design.

## **Acknowledgements**

To *Adam McNevin*: Thank you for being my fixed point in the swirling chaos of our lives. You have been a pillar of strength for me to lean on and a source of continual joy. I will never be able to thank you enough for the sacrifices you make for me. Thank you for having faith in me and trusting me when no one else did.

To *my parents*: Thank you for helping me to succeed, for letting me be free to decide who I wanted to be and what I wanted to do in life. For raising me with common sense, discipline, passion, and kindness. Thank you for teaching me to be a decent human being. Thank you for being brilliant examples of strength, perseverance, and enduring love.

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## List of Abbreviations

ASD	Autism Spectrum Disorder
EEG	Electroencephalogram
GRADE	Grading of Recommendations Assessment, Development and Evaluation
PMD	Profound Multiple Disabilities
RCT	Randomized Controlled Trial
STAI	Spielberger's State Trait Anxiety Inventory

# **The Effectiveness of Biomusic as a Communication Tool for Individuals with Communication Barriers**

## **1. BACKGROUND**

Communication is an integral part of society and relationships. The ability to communicate proffers us opportunities and abilities nigh impossible to obtain without some way to communicate. While being able to express opinions or ideas verbally or in written form might be the first and most obvious form of communication one's mind might think of, we must remember that multiple varieties of communication exist. A normal person may communicate verbally or nonverbally thousands of times a day without thinking. Often, we can communicate an idea or a feeling by a single word, phrase, nod, or something as simple as a breath. However, as medicine advances and our abilities to sustain or preserve life improve, we face new communication dilemmas. Although we may spare a life, the quality of that life for the patient, their family members and care providers may drastically change.<sup>2</sup> While we've seen remarkable improvements in life sustaining treatment, we still need more improvements to ensure that patients regain their quality of life. Many individuals who survive fatal events may be unable to participate in free and easy communication that others engage in daily. Due to its ubiquitous nature, communication could arguably be one of the first and most important measures that individuals need to establish in these scenarios. A discussion of why communication is so vital follows.

## 1.1 Importance of Communication

For us to engage in communication and feel that it is valuable and worthwhile, our communicative efforts must be met with *reciprocity* and *co-presence*. Molm et al<sup>3</sup> described reciprocity as “...the giving of benefits to another in return for benefits received....” In other words, an event where a “social exchange” occurs.<sup>17</sup> Thus, we perceive social interactions as a proverbial “give and take” scenario. If we continually give without receiving or vice versa, the interaction affords us no value, and therefore we may not pursue the interaction further, or with the same vested interest.

We base our interest and value of social interaction on how other individuals reciprocate our actions. We are constantly gauging the level of responsiveness to our communicative efforts during social interaction; entering responses into a mental and emotional feedback loop.<sup>4</sup> If we share something we deem as personal or important with another person, we expect that person to share something of equal importance with us.<sup>5</sup> The more other individuals display this type of anticipated behavior, the more we perceive the “other” as being interactive and engaged during conversation. Thus, we elevate our communicative and social efforts.

Similarly, we need co-presence to find value in any social interaction. Co-presence requires that others be aware and present in time and space to facilitate a mutual feeling of togetherness and form the foundation of a bond. When individuals can attend to their surroundings and engage in communication by being actively aware and mentally and emotionally available to one another, it further strengthens the communicator’s resolve to participate in the social interaction.<sup>6</sup> We need the

communicative elements of co-presence and reciprocity, among others, to establish *personhood*.

## 1.2 Importance of Personhood

Tom Kitwood<sup>7,8</sup> defined personhood as “...a standing or status that is bestowed upon one human being by others, in the context of relationship and social being”.

Personhood may be better understood by its roots. C.H. Cooley originally coined the idea of personhood in his theory: *The Looking-Glass Self*, which explores the idea of self.<sup>9</sup> We base our ideas of who we are from the feedback we get from social interactions, and what others have told us about ourselves. Thus, we use our social interactions as a metaphorical looking glass, where social perceptions or comments from others about our inherent qualities and traits are reflections of who we are. We then use this feedback as a reflection of our self to see who we really are through other’s perceptions, statements, and behavior towards us. Often, repeatedly telling an individual that he or she possesses a certain quality could influence that individual to emulate that quality. Likewise, if a group of friends perceives one individual as a daredevil or thrill seeker, that individual is more likely to exhibit those behaviors because “daredevil” or “thrill seeker” are the reflections of himself that he sees in the social looking-glass. Ergo, he will reinforce the image through actions. We rely on feedback, comments or opinions of others we value to formulate an idea of ourselves. The individual beliefs of who we are, who we think we are, and how others perceive us are inextricably intertwined with sociality.<sup>10</sup>

These social interactions with others instill within us a sense of self-identity, inclusion, and value to society—the basis of personhood. Others will unconsciously award us personhood based on our ability to actively participate in communication and socialization because they value the input that we can provide about ourselves, thus making the interaction rewarding to all parties involved.

When an individual “receives” personhood through effective communication skills via co-presence and reciprocity, it awards that individual with recognition as another human being. The individual then receives acknowledgement from others and forges a new relationship with those involved in the social interaction. The two individuals involved in the interaction establish a mutual bond and understanding. Fortification of this bond occurs with repeated interactions. Over time, this newly forged bond can allow for the roots of much stronger and more intimate human relationships to take place.<sup>11,12</sup> Because we use ourselves as a reference point for how others should respond or act, it is logical that we assume and allow for certain behaviors, responses, and interactions from others. An example of established co-presence and reciprocity would be our interactions with longtime friends. Our conversations with good friends are rewarding and beneficial to us. We feel connected and "human" when interacting with friends because we often share similar stories and experiences that we relate to. We give feedback to the speaker through our statements and emotional reactions. We are aware of one another, and we are mentally and physically present during the social exchange. When we do not demonstrate these elements, we do not meet the subconscious expectations and schema of what a social interaction ought to be. Since no

reciprocity occurs, true social exchange does not take place.<sup>12</sup> Thus, we do not consider the relationship worthwhile because the cost of putting forth effort outweighs the benefit of receiving satisfactory interaction. Therefore, the individual may withdraw from the relationship or close him or herself off from said relationship. *Social de-penetration* is the name given to this concept.<sup>13</sup>

This is often the case when care providers are unable to exchange information or communicate in meaningful ways with severely injured, impaired or comatose patients. When only one party is engaging in communicative efforts, eventually, through continual negative emotional, verbal and physical feedback, the active party becomes disengaged in communication, and social de-penetration occurs.<sup>12</sup> The individual who is unable to communicate will often lose his or her personhood status, due to his or her inability to emulate the elements of social interaction previously described, thus making it more difficult to motivate care providers to continue quality social interactions, and may even effect the quality of care that an individual may receive.<sup>8</sup> Care and social interactions may degrade from more intimate relationships to distant or strained relationships, where the only objective is maintenance of care, and “custodial-like” duties.<sup>14,15</sup> The need for positive social interactions to sustain good health, well-being, and ultimately, self-actualization,<sup>4,16</sup> is why having the ability to re-establish some form of communication between patients and care providers could prove beneficial in quality of life and care outcomes.

### **1.3 Communication Barriers**

Since a multitude of communication barriers exist, this review defines communication barriers as any barrier to traditional communication that prevents an individual from experiencing co-presence and reciprocity in a social interaction, and thus denying an individual the bequeathal of "personhood". Examples of potential affected patient populations that could benefit from biomusic include: comatose patients, autism spectrum disorder, traumatic brain injuries or other traumatic injuries leaving a patient unable to communicate, as well as any severe intellectual or cognitive disability whether congenital or acquired. Blain-Moraes et al<sup>4</sup> chose the term "profound multiple disabilities" or PMD as a term that engendered the above examples. PMD will be the term referred to most frequently in this article.

#### **1.4 The Utility of Biomusic**

Currently, no effective and uncomplicated way of communication exists for those with PMD. Many of the current therapies and tools instituted require a base functionality such as the ability to push a button/choose a picture of the needed object (such as VOCA<sup>17</sup>), to follow simple commands, or to be cognizant enough to operate the tools necessary for standard communication.<sup>18</sup> Current communication practices with those that have PMD is mostly guesswork at what they are trying to communicate by trying to read into facial expressions, indiscriminate grunting or yelling, and gestures or muscle movements. These individuals may suffer from lesser quality of care and quality of life largely because of their inability to communicate their needs<sup>19</sup>. They may also suffer inadvertently due to their inability to establish personhood through social interactions, engendering a form of unintentional social isolation.

Biomusic, developed by Blaine-Moraes et al<sup>4</sup>, is a noninvasive and simple process that capitalizes on the body's functions as music. Biomusic is a computer program that interfaces with a person's autonomic nervous system (ANS) output data to create music that reflects the current emotional state the person is in. A care provider can listen to the computer rendered music in an attempt to understand and communicate with that person. Biomusic needs only four ANS outputs. (1) respiration, (2) fingertip skin temperature, (3) blood volume pulse (BVP)—a depiction the rate of change in blood flow and the amplitude of flow throughout the body, (4) electrodermal activity (EDA)—a measurement of skin sweat present, which can change in mere seconds in response to a stimulus.<sup>4,18</sup> There is no need for a basic level of motor functionality, cognition, or mental ability to operate this technology because the sole basis of Biomusic is on sensor detection of ANS output data.

Biomusic offers a new medium for communication between patients and care providers, and perhaps a new way to re-establish personhood. Music has long existed as a way to communicate information, stories, symbols in ceremonies and rites, politics, and history. Ancient texts, such as the Chinese *Yue Ji* and *Yue Shu*, as well as the Greek philosopher Plato's text, *The Republic*, tell of the importance of music upon the soul as well as in education, temperament, learning, and behavior.<sup>20</sup> These texts hint at some deeper ability of music to communicate information to others; tangibly shaping the elusive and intangible form our thoughts take. Thoughts and ideas are fleeting, lacking permanence, but by giving concretion to our thoughts by converting them to a different medium we can then experience and share thoughts, emotions, and ideas with our



physical senses; whether written, visual, or auditory, we take thoughts—something that is abstract and difficult for outsiders to understand or comprehend—and make it understandable by giving it a concrete and permanent form. Biomusic offers an opportunity to create a new tangible form of communication.

### **1.5 Purpose of this study**

The purpose of this study is to evaluate the effectiveness of biomusic as a communication tool for individuals with communication barriers.

## **2. METHODS**

### **2.1 Search Criteria**

The author conducted an exhaustive literature search using MEDLINE-Ovid, Evidence-Based Medicine Multifile, Proquest, MEDLINE-PubMed, NCBI, Google Scholar, Health and Wellness Resource Center, CINAHL, Web of Science, and Cochrane using the following search terms: biomusic, children, anxiety, autism, communication disorders, communication barriers, developmental disorders, disabled persons, personhood, affective technology design, NOT music therapy.

The author employed the following search strategies: “Biomusic”, “Children AND Biomusic AND Anxiety”, “Biomusic NOT music therapy”, “biomusic NOT (music therapy) AND (communication disorders)”, “(biomusic) AND (communication barriers) AND (affective technology design) NOT (music therapy)”, and lastly, search terms were blown up to yield the following search strategy: “\*Communication Barriers/ or \*Personhood/

or Child Development Disorders, Pervasive/ or exp \*Child, Preschool/ or Adolescent/ or Disabled Persons/ or biomusic.mp. or \*Communication Disorders/ :”.

## **2.2 Eligibility Criteria**

All studies that evaluated the effectiveness of biomusic in the context of any communication barrier in any human populations were included. The focus of this study was on the communicative effects of biomusic as defined by interfacing sensor detection of ANS output with the Biomusic computer program to create a musical sonification.<sup>4</sup> Exclusion criteria were the use of music therapy, and any articles related to music therapy. Also excluded were any studies on “biomusic” related to animal, plant, ecological, or environmental made music. Similarly, further exclusions included “biomusic” as a result of artistic expression or obscure experimental modernistic music. Examples include interfacing one’s EEG data or biological/physiological characteristics with musical components for the explicit purpose of artistic creativity/expression or performance.

## **2.3 Quality Assessment**

Studies were evaluated for quality using GRADE criteria<sup>21</sup>, see Table 1.

## **3. SEARCH RESULTS**

The author initially searched the Proquest database using all 12 inherent databases and the term “biomusic” which yielded 195 results. Removal of duplicates revealed just 3 articles that met criteria. Only 1 of the 3 articles found was a study<sup>4</sup>, the

other 2 consisted of an interview and a call for more research.<sup>18,22</sup> Refinement of the Proquest database search included the following databases: biology, health and medical collection, health management database, nursing and allied health database, psychology database, public health database, science database, and sociology database in an effort to find relevant articles based on physiological biomusic for medical purposes instead of the artistic biomusic found in music, fine arts, or humanities centered databases. Employed were the following search schemes: “biomusic NOT music therapy”, and “biomusic NOT (music therapy) AND (communication disorders)”, which yielded 12 results, although none were relevant or met criteria. Extensive searches of Evidence Based Medicine Multifile, Health and Wellness Resource Center, Web of Science, CINAHL, and Cochrane also yielded no results with the search term “biomusic”.

A search of PubMed with the term “biomusic” yielded 4 results. Three of which met the inclusion criteria for this study.<sup>1,4,18</sup> A similar search of Google Scholar only afforded 1 additional article meeting the inclusion criteria and not previously found in other databases.<sup>23</sup>

## **4. RESULTS**

### **4.1 “Biomusic: A Novel Technology for Revealing the Personhood of People with Profound Multiple Disabilities”**

This was the first pioneered study in biomusic done by Blain-Moraes et al<sup>4</sup>, who developed the concept of biomusic, and published the study in 2013. This was a

qualitative pilot study providing proof-of-concept of the use of biomedicine and its potential benefits for patients with PMD and their care givers and family members. The study chose subjects from the Complex Continuing Care Unit of a pediatric rehabilitation hospital located in urbanized Canada. To find comprehensive inclusion criteria for the child participants as well as eligibility criteria for the care providers please reference the original Blain-Moraes et al study. Blain-Moraes et al chose 3 participants to study along with up to 3-4 members of their care team (deemed “clusters” in the article). Outlined in the original study are inclusion and exclusion criteria for the child participants and eligibility criteria for the care providers. Researchers obtained written consent from each child’s parent or primary caregiver on behalf of their child. All other care provider participants gave their written consent to participate in the study. The Research Ethics Board as well as the hospital where the participants resided granted ethical approval for this study.<sup>24</sup> Researchers assigned pseudonyms to child participants and numbers to care-givers for confidentiality. Pseudonym assignments to the child participant and are as follows: Thomas, Fred, and Joanne. Researchers documented extensive histories concerning the individual’s condition, their current status, and responsiveness to care during the study.<sup>4</sup>

During the study, a researcher would attach a series of non-invasive Velcro sensors to the left hand and chest of each child. Table 2 summarizes the location of these receptors and the programmed sound produced from the sensor detected changes, which were standardized.<sup>4</sup>

Each caregiver participant was to perform a total of 4 biomusic sessions, wherein the caregiver would turn the biomusic on and allow it to play quietly in the background as they performed their care tasks and functions. The first 2 sessions required the presence of biomusic, and the last 2 sessions allowed for care-providers to choose if the biomusic were to remain on or off while they performed their functions. Skilled researchers with interviewing expertise and experience performed a series of interviews with the care-providers, for a total of 3 interviews per caregiver. Researchers conducted a pre-biomusic interview to obtain baseline information about the quality of the patient and care-provider relationship. Another interview occurred after fulfillment of the first 2 biomusic sessions. Completion of a final interview occurred after the conclusion of the last biomusic session. Questions were semi-structured and open-ended to allow care providers to articulate their thoughts and feelings about their relationships and interactions with the patient, their perceptions and thoughts about biomusic and whether they believed it helped improve their interactions, if it was enjoyable, and their reasons for continuing/discontinuing the biomusic during their sessions. Included in the original article are verbatim transcriptions of portions of the interviews with caregivers. Each transcript received heavy analysis via the constant comparative method to evaluate for themes in transcripts.<sup>25,26</sup> The original Blain-Moraes et al study contains further details about the method of analysis, a list of questions, and portions of the interview.<sup>4</sup>

Of note, researchers discarded data from the second interview set due to inconsistencies with some of the sensor placements. They had found that some sensors

were not staying in place as participants moved. Only 1 care provider from Fred's cluster was able to complete all 4 sessions of biomusic-accompanied care before Fred died. Therefore, researchers did not include data from interviews with Fred's other caregivers as they were unable to complete the remainder of their sessions after Fred's death.

At the final interview, and after accounting for the inability of Fred's cluster to complete their interviews, 8 participants remained. Majority of them (7 of the 8) agreed upon the positive influence that biomusic had on their interactions. Participants subdivided into 2 categories based on their beliefs about biomusic. Three of the 7 believed that biomusic acted as a manifestation of co-presence for the individual with PMD. Four of the 7 felt that the individual's biomusic was a reaction to the care providers actions. Further analysis revealed that the perception of biomusic as a reaction to caregiver actions seemed connected to previously established pathways of communication with the PMD patients. These established communication pathways consisted of things like gesturing, laughing, coughing etc. Care providers had attached meaning to these types of behaviors and treated them as a form of communication. Researchers noted that biomusic seemed to act as a reinforcement of the perceived communication pathways if changes were concurrent with each other, e.g. if the patient smiled or gestured during a certain exercise and there was a notable change in biomusic, then care givers perceived that as a reinforcement of what the laughing meant. Researchers also noted that this relationship showed a positive correlation with the amount of previously established pathways. The more consistent or predictable a PMD patient's responses were to certain things, the more the care providers

contributed biomusic to that individual. Likewise, the less predictable the individual's responses were to stimulus, the less the care providers perceived a link between biomusic and the individual.

To summarize, biomusic is a feasible technology that can re-establish co-presence and help individual's with PMD regain personhood through more meaningful interactions. Integrating biomusic into interactions also seemed to remind the care providers that the person still exists and creates a new way to connect with him or her.<sup>4</sup>

#### **4.2 "Biomusic: An Auditory Interface for Detecting Physiological Indicators of Anxiety in Children"**

This study was done by Cheung et al<sup>1</sup> in 2016 and served as a follow up study to the pilot study done by Blaine et al in 2013. The Blaine et al study<sup>4</sup> proved the feasibility of biomusic, but also raised more questions from parents and caregivers. Those individuals wanted to know what the biomusic songs meant, if there was a way that it could be interpreted, or if emotions could be told apart with different biomusic characteristics. Cheung et al designed this diagnostic study to determine if it were possible to use biomusic to detect anxious and relaxed states in individuals. Children with Autism Spectrum Disorder participated, with the hope that if the study was successful, biomusic could then be used on those with more severe disabilities.<sup>1</sup>

The study was broken into 2 separate experiments. The first experiment (Experiment 1) served to ensure the feasibility of utilizing biomusic to tell anxious states from relaxed states only in typically developing children with biomusic alone. It also served as a control for the rest of the experiment. The second experiment (Experiment

2) was similar to the first in method and design, with the exception that samples of anxious and relaxed biometric were taken from children with autism spectrum disorder (ASD) and included with anxious and relaxed biometric samples from 2 different sets of typically developing children.<sup>1</sup>

The Holland Bloorview Children's Rehabilitation Hospital had their science and ethics review board approve all aspects of the study. Only typically developing children ages 8-13 were included in the initial experiment (Experiment 1). Twelve child participants were originally included in Experiment 1, however due to interference on the sensors from the excessive fidgeting as well as the inability to meet the validity criteria, only 5 children remained qualified for the experiment and their data was used.

Samples of biometric for each experiment were collected in a similar manner: Children were asked to watch a 20-minute nature video as biometric samples were generated and collected during the relaxing phase of the experiment. Afterward, children were asked to report their feelings during these tasks. Self-reports were collected from children using the child version of Spielberger's State Trait Anxiety Inventory (STAI) at baseline and following each relaxing or anxious trial.<sup>27</sup> The STAI is considered gold standard for evaluating anxiety. Validity of data was established if the child's STAI reports matched the test condition (anxious or relaxed).

For the anxiety inducing portion of Experiment 1, children were asked to solve anagram puzzles in a series of 3 individual 2-minute sessions, which was then immediately followed up by a 5-minute break, wherein each child would watch another



relaxing nature-based video. Afterward, the child would again self-report their feelings, using the STAI, during the anxiety inducing task.

Experiment 2 utilized the same relaxation and anxiety inducing task method, using the STAI after each task to obtain self-reports, in the same way as Experiment 1. Albeit, Experiment 2 differed from Experiment 1 in the anxiety inducing portion. Three total groups were used to collect anxious and relaxed biomusic in Experiment 2: typically developing Stroop test, typically developing Anagram test, and ASD. For Experiment 2, 10 biomusic samples from Experiment 1 from the typically developing children who performed the anagram task as their anxiety inducing task were used. Another set of 10 biomusic samples was obtained in Experiment 2 from a different group of typically developing children who performed the Stroop test as their anxiety inducing task, which did not require as much hand movement as the anagram test. Researchers considered the Stroop test, a deviation from the Anagram test used in Experiment 1, a “methodological strength”, ensuring that the anxiety evoked biomusic was not specific to the Anagram test, but could be consistently duplicated through other anxiety-inducing tests. A final set of 10 biomusic samples was obtained from a third group comprised of ASD children. In summation, Biomusic samples from both the typically developing anagram and the typically developing Stroop group were included in Experiment 2 along with the samples from children with ASD, for a total of 30 songs to be listened to by adult participants.

Biomusic from anxiety and relaxed states was only used if the results of the STAI corresponded in a predictable fashion with the intended scenarios to create a baseline

for testing. Sections of each biomusic session were then taken at random and placed into a randomized set of anxious and relaxed biomusic sections. Methods for sample collection can be reviewed in depth in the Cheung et al study.<sup>1</sup>

In both experiments, college age adults, who were representative of a typical Bloorview Hospital pediatric volunteer listened to samples of anxious or relaxed biomusic. In each experiment, anxious and relaxed samples from included groups were randomized into one group and college age participants were asked if they could classify their initial impression of the music clip (whether it was an anxious state or a relaxed state). Each participant was given a short training (less than 10 minutes for Experiment 1, and less than 5 minutes for Experiment 2) that explained the different components of biomusic that could be heard. Training examples consisted of new samples of anxious and relaxed states of biomusic that were not included in Experiment 1 or Experiment 2. Participants who interpreted the music were blinded to the samples they were listening to as well as the results. However, researchers could not be blinded in order to administer the experiment.

Experiment 1 contained 16 college aged participants who were interpreting the biomusic results from normally developed children. Experiment 2 retained the same group of college aged participants, however only 12 of the 16 original participants were able to participate due to graduation from the university. College participants listened to the entirety of the music clip and were asked to state their impression of the music and to rate their confidence in the choice they made.<sup>1</sup>

Researchers then took the children's self-reported anxiety scores based on the STAI results and looked at how the adult research participants rated the children's corresponding biomusic. This was done to determine how well one could identify anxiety from biomusic samples compared to the STAI.<sup>1</sup>

Accuracy, specificity and sensitivity was calculated for both experiments and were comparable. In Experiment 1 the accuracy, specificity, and sensitivity were: 84.8% (SE=2.9), 80.0% (SE=4.5), and 89.7% (SE=4.1), respectively. In Experiment 2 the accuracy, specificity, and sensitivity for all groups (typically developing Stroop, ASD, and the typically developing anagram groups) were: 83.9% (SE=2.9), 80.6% (SE=3.4), and 87.1% (SE=3.4). Positive and negative likelihood ratios have been calculated from this data and have been included in Table 3a and Table 3b. Furthermore, researchers determined that it took adult participants 11.3 seconds on average to be able to classify the music, with the melody component being the most influential in decision making. Further analyses were conducted to determine if specific songs were repeatedly mislabeled by listeners. The analysis showed that the initial misclassification was most likely due to the child erroneously self-reporting their anxiety state.<sup>1</sup>

To summarize, researchers determined that biomusic can in fact be used to determine anxious vs. relaxed states in children with ASD, and that with minimal training, individuals could identify anxious states quickly and with relative confidence, and with little background information on the patient or situational context.<sup>1</sup>

## **5. DISCUSSION**

### **5.1 Effectiveness of Biomusic**

Due to the subjective nature of the data, it is hard to evaluate just how effective biomusic is as a communication tool. Further questions arose as to what makes an effective communication tool, and whether there are gold standards. Deeper research revealed that “gold standards” for efficacy of communication tools don’t currently exist due to the very personal and subjective nature of communication. Each communication interaction between individuals can vary widely, and multiple factors are involved to produce the concept that we consider effective communication. Each study presented in this review evaluated different aspects of biomusic as a communication tool, therefore each study can’t be compared to one another to determine effectiveness, and different criteria for effectiveness must be met for each study individually. For the purposes of the Blain-Moraes et al study,<sup>4</sup> the ability to re-establish personhood, co-presence and reciprocity have been used as more objective measures of efficacy. Blaine-Moraes et al<sup>4</sup> concluded that biomusic can re-establish co-presence and help to re-affirm an individual with PMD’s personhood. Majority of care providers felt that it changed the quality of their interactions with the individual with PMD, and that the patient was present again in some way. This study<sup>4</sup> proved that biomusic was a viable concept and also determined that biomusic could at least take the first steps towards being an effective communication tool where none had previously existed.

The Cheung et al<sup>1</sup> study proved effective as a communication tool in a different capacity. Anxiety and relaxed states could be determined from an individual’s biomusic.

Furthermore, individuals with ASD often have difficulty expressing or identifying their emotional states, which can lead to frustration and distress in the effected individual and their families. Biomusic could be employed as a tool to assist outsiders in understanding a person with ASD's emotions. An existing gold standard anxiety rating tool was used (the STAI) and data from the biomusic experiments was compared to the STAI results. Researchers found the results comparable and consistent, thus concluding that biomusic can be an effective communication tool for determining anxiety states from relaxed states in typically-developing children and those with ASD. More research will need to be conducted to determine if more emotional states can be identified by individuals listening to biomusic, and whether it can be done for individuals with more severe disabilities. Moreover, in an interview with Stephanie Blain-Moraes published by The Canadian Press, she discussed the possibility of using biomusic as a biofeedback device for individuals with ASD so that they may be aware of their emotions and how to interact socially.<sup>28</sup>

While no objective parameters exist to measure the efficacy of communication tools, there are a few subjective considerations about what makes an effective communication tool. It is important to note that in most cases of patients with PMD, the standard communication practices consisted of deciphering bodily gestures, yelling, screaming, and a variety of other similar factors in an attempt to communicate and understand those with PMD. Other modes of communication exist, however, many of these tools and devices require dexterity, a level of controlled movement and cognition in order to perform certain tasks like point or press a button.<sup>17</sup> These tools automatically

exclude those that lack this capacity, and barriers still remain in communicating with these individuals. Biomusic offers a new way of communication that doesn't exclude this group of individuals. Due to its ease of use and its non-invasive administration, it can be considered a potentially superior tool to the current methods of establishing communication with these individuals. Furthermore, it requires no extensive or elaborate training, heavy maintenance, or life-threatening procedures. The musical components were chosen to be non-intrusive and to mirror the normal physiological "sounds" the body makes as much as possible. Further studies will need to be done to determine the abilities and limitations of biomusic and whether or not it can reliably mirror communication patterns to become a viable substitute for those that can't verbally communicate or physically gesture.

While this is not a systematic review about music therapy and its benefits, it is important to note the role that music plays upon communicating emotion, desires, and thoughts.<sup>29</sup> Often times, music is much more profound and evocative than other forms of art or communication can be, not just for the musician but for the listener.<sup>29</sup> Music has the unique ability to soothe the soul and communicate levels of human emotion that cannot be conveyed through words alone. Listening to and understanding music can change one's understanding of other aspects in life as well as their temperament. The *Yue Ji* and *Yue Shu* also state how music may be a proper facsimile of the harmony that lies within nature.<sup>20</sup> The balance between the heavens and the earth create a harmonious relationship in which we live and listen to each day.<sup>30</sup> Music's ability to create harmony, mimic sounds from nature, change in pitch, timbre, melody, tempo and

rhythm reflect the endless ability of nature to blend together symbiotically, to separate violently, to become peaceful like a babbling brook, or to crash into the tumultuousness of a thunderstorm, but in the end, to create balance. Vivaldi's *The Four Seasons* violin concertos are a famous example of a musical attempt to capture the harmonious change and balance that nature communicates with us.<sup>31</sup> It would then make sense that the body, with all of its delicate chemical interactions, intricate cellular processes, and ability to balance itself is also a facsimile of the harmonious balance that exists between the heavens and earth, and likewise, the harmonious melodies enveloped within music could course from the body, to act as a path of communication.

With the history of music, and just how personal and intimate it can be, It is logical then to assume that the effect of music upon a listener can evoke a much stronger connection and understanding than some other forms of communication can. Biomusic aims to create this type of bond between patient and listener. Among the various unexplored utilities of biomusic is the fundamental fact that, at its core, it is still music, and it has the potential capacity to elicit stronger bonds between individuals than other forms of communication were previously incapable of doing. There is a possibility that while the sociological qualities of co-presence and reciprocity may not be attainable through more traditional verbal and nonverbal communication for those with severe disabilities, biomusic could overcome these aspects and create an entirely new way of communicating and bonding. At the very least, it would create a better way to understand those that lack the necessary communication skills to achieve proper care and better quality of life. By being able to re-establish a way of communicating with

those that can't, we could re-establish personhood, and therefore increase the ability of care providers to feel connected to these patients and hopefully be able to provide better care.<sup>15</sup>

## **5.2 Limitations of the study**

The Grading of Recommendations Assessment, Development and Evaluation (GRADE) method was used to determine the quality of each study.<sup>21</sup> Table 1 provides a summary. The pilot study done by Blaine-Moraes et al was a qualitative study, which initially classified it as “low quality evidence” according to GRADE criteria. There were no limitations of bias in this study. No publication bias was present. All inclusion and exclusion criteria were met according to what was outlined in the study. The clusters that were chosen shared similar circumstances in an attempt to control any confounding variables. All participant information was gathered after the second and fourth biomusic sessions. While one of the participants did die before all care-providers were able to finish the 4 sessions of biomusic, one care provider was still able to complete the experiment before Fred's death. Researchers only included this care-provider's interview data for the conclusion of Fred's cluster. Researchers also accounted for technical complications that occurred during the second biomusic session due to issues with sensors staying in place, and therefore did not include data from any of the second sessions due to possible inaccuracies in the projected biomusic and the effects that could be perceived by care-providers. In regard to inconsistency, the methodology for sensor placement was standardized, as was the data collection points. The study was unable to produce confidence intervals for data collected, which merited



the study a downgrade to “very low” as per GRADE criteria for imprecision; nevertheless, the researchers did use the constant comparative method as a way to analyze data from each interview.<sup>25</sup> The study proved that no indirect measures were used to measure outcomes. Current communication methods were compared to biomusic as a communication method and the outcomes were self-reported during the post-biomusic interviews. Overall, based on the type of study and the lack of confidence intervals, the Blain-Moraes et al study was awarded a “very low quality” status according to GRADE criteria.

The Cheung et al study was a diagnostic study that qualified and was graded as an RCT, thus making the initial classification of this study a “high quality” study. No downgrading was awarded in the Limitations of Methodology/Risk of Bias category. A control group was identified, participants were blinded. However, based on the study design, it wasn’t feasible to perform allocation concealment. Although 4 participants were unable to participate in the second experiment due to graduating from college, data was still able to be collected without any major consequences. No selective outcome bias was determined, and no publication bias was present. While it is possible that recruitment bias did exist in the adult participants, researchers stated that this was representative of a typical volunteer group for the children’s hospital. It is possible that this group of college age participants could be quicker at understanding the components of biomusic, classifying, and interpreting songs based on their higher level of education. This sample size was small and may not be representative of other parents or outside care providers that didn’t receive the same type of institution level education, therefore

a downgrade was awarded in this category. This study did not demonstrate any inconsistencies, and the study was direct in measuring outcomes. A down grade was awarded for imprecision due to the lack of confidence intervals in this RCT based on GRADE criteria, however researchers did use a gold standard tool to measure data against, as well as a second anxiety-inducing test (Stroop) to ensure that results weren't specific to the anagram test performed in Experiment 1. Overall, the Cheung et al study was awarded "low quality" evidence as per the GRADE criteria.

## **5.2 Evaluating the effectiveness of biomusic as a communication tool**

The study populations were very small in number. Blaine-Moraes et al had an N=8 after accounting for the death of one of the patient's with PMD, resulting in the inability of majority of his care providers to complete the study. Moreover, it is also a qualitative study based on opinions and interviews from a small group of individuals, which could create a very narrow understanding of biomusic. Cheung et al recorded samples from 5 children for their first experiment after accounting for eligibility criteria and interference with the samples from excessive fidgeting. Their sample size was N=16 for actual adult participants that would be classifying the musical samples, however in the second experiment only 12 of the original 16 were still available to participate in the study. These studies had very small samples and more studies with larger samples need to be done. Furthermore, assessing quality of life is difficult due to the subjective nature of the concept, and is further complicated by the fact that we aren't able to clearly communicate with individuals with PMD to determine whether or not they feel that their quality of life is acceptable or not.

Researchers also had difficulty with sensors staying in place in the Blaine-Moraes et al study. Velcro sensors may not be as sensitive to changes in ANS output, and as demonstrated in this study, run the risk for being displaced which could erroneously change the biomusic output, and the care-provider's response to said music.

Another limitation of biomusic is the potential for cultural or musical bias. Major and minor keys were used in a western styled tonality of music; however, this may sound less familiar, inviting, and possibly be less welcomed by those accustomed to eastern styles of musical keys. Similarly, different elements may be more heavily emphasized in one culture over another. In Cheung et al,<sup>1</sup> it was noted that melody seemed to be the most decisive factor for determining anxious or relaxed states from the song clip. However, in cultures where rhythm or drum beats are the focus of music, the understanding and focus of the biomusic could change. Researchers did state that the musical components of biomusic could be programmed and there is a potential to change the elements to help accommodate different musical cultures. More research needs to be done on whether or not cultural differences can change perceptions of biomusic. Another consideration is that listening to music is as much a subjective and personal experience as communicating with someone is, and the possibility remains that individuals may project their own feelings onto what is being heard, therefore obscuring what is actually being presented.

It is also possible that biomusic could be used as a biofeedback tool, and that with enough practice, individuals could train themselves to influence their ANS output enough to evoke intended changes in their biomusic to communicate more effectively.

More research has yet to be done on the capabilities and limitations of biomusic. Researchers will need to determine baseline trends or patterns that can occur to establish what is “normal” and what is “abnormal” in biomusic. The identification of affective states may eventually be studied as well. The current studies do not identify multiple emotional states, nor do they identify transitions between states. More research will need to be done to determine if specific diseases or disability states effect ANS output to a degree which changes biomusic output and could convey erroneous results. Research will also need to be done on the use of biomusic as biofeedback. This list only represents a fraction of potential areas that can be researched in biomusic. As more research is done, more questions will need to be answered, and for each solution found, new problems may arise.

Ethical considerations should also be discussed and explored early on as biomusic technology continues to progress. A few considerations are discussed in this review. Biomusic may be considered by some as too personally invasive or revealing. Similar to a lie-detector test, individuals may not want their emotional state broadcasted for others to listen to, however, those that are likely to utilize biomusic may also not be able to verbalize that they feel this way. Controversy may arise about when to use biomusic, when not to use it, and who decides to use it. If its efficacy can be improved, would care-providers be denying a patient a “voice” if they chose not to utilize biomusic? Would a person be able to consent for themselves through biomusic? These questions and more need to be answered as we consider the ethical and moral implications of the technology we develop and the impact that it could have.

## **6. CONCLUSION**

Blain-Moraes et al proved the feasibility of the biomusic technology that she and her team developed. Their study proved that biomusic could be used to re-establish a more meaningful relationship with patients that suffer from PMD. Biomusic could also re-establish a sense of co-presence and reciprocity in social interactions which are needed to re-establish personhood. This new form of communication and new-found personhood could lead to more positive interactions and better health outcomes for patients and their families.

Cheung et al proved that biomusic could be used not only as a communication tool, but potentially as a diagnostic tool for those with ASD experiencing anxiety who can't communicate what they're feeling/experiencing. Cheung et al demonstrated that with minimal training (<10 min) individuals were able to determine anxious states from relaxed states in a matter of mere seconds (average of 11.3 seconds) and to do so accurately 83.9% of the time on average.

Overall, in order to validate biomusic as a reliable clinical tool for providers and care givers to use, more research is warranted on biomusic. It is a novel technology still in its infancy that has untapped potential. Many questions still remain that need to be answered, and improvements can always be made.

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**Table 1: Quality Assessment of Reviewed Articles**

Study	Design	Downgrade Criteria					Upgrade Criteria	Quality
		<i>Limitations</i>	<i>Indirectness</i>	<i>Inconsistency</i>	<i>Imprecision</i>	<i>Publication bias</i>		
Blain-Moraes et al <sup>4</sup>	Qualitative	Not Serious	Not Serious	Not Serious	Serious <sup>a</sup>	Unlikely	No upgrade criteria met	Very low
Cheung et al <sup>1</sup>	RCT	Serious <sup>b</sup>	Not Serious	Not Serious	Serious <sup>a</sup>	Unlikely	No upgrade criteria met	Low

<sup>a</sup>Small sample size

<sup>b</sup>Cheung et al used college-age participants recruited from a university. The education level of this population may not be representative of parents and outside caregivers, which could influence their ability to understand and classify biomusic.

Table 2: Sensor placements and programmed sound patterns

Sensor type	Placement	Programmed sound pattern
Electrodermal activity (EDA)	<ul style="list-style-type: none"> <li>• Middle phalanx, pointer finger</li> <li>• Middle phalanx, middle finger</li> </ul>	Melody (or pitch). Changes in pitch were determined by changes in EDA based on averages over 0.25 s. Multiple variations changed the pitch which resulted in a melody.
Skin temperature	<ul style="list-style-type: none"> <li>• Distal phalanx, ring finger</li> </ul>	Key. Changes in skin temp (higher or lower) resulted in corresponding transpositions of key based on a tonic chord (e.g. transposed down a key for a drop in temp).
Blood volume pulse (BVP)	<ul style="list-style-type: none"> <li>• Distal phalanx, little finger</li> </ul>	Tempo. A drumbeat sound was programmed to correlate with increases or decreases in BVP.
Respirations	<ul style="list-style-type: none"> <li>• One elastic chest strap, thorax</li> </ul>	Musical articulation. Respirations changed the dynamics of the melody and it's musical phrasing.

- The left hand was used for all sensors placed on fingers.
- All sensors measured changes in data points over a specified period of time measured in seconds.
- Refer to Blaine-Moraes et al<sup>2</sup> for more details and information.

*Table 3a. Experiment 1 Likelihood Ratios Calculated from the Cheung et al. study<sup>1</sup>*

<b>Experiment 1 Biomusic</b>	<b>Positive Likelihood Ratio</b>	<b>Negative Likelihood Ratio</b>
Typically-developing (anagram group)	4.465	0.12875
<ul style="list-style-type: none"> <li>• All data was calculated from the sensitivity and specificity data provided in the Cheung et al study<sup>1</sup></li> <li>• Please refer to Cheung et al for any additional information</li> <li>• This data reflects the ability to accurately predict anxious vs relaxed states in typically developing children.</li> </ul>		

*Table 3b. Experiment 2 Likelihood Ratios Calculated from the Cheung et al. study<sup>1</sup>*

<b>Experiment 2 Biomusic</b>	<b>Positive Likelihood Ratio</b>	<b>Negative Likelihood Ratio</b>
Typically-developing (Stroop group)	3.434	0.113
ASD	5.073	0.20095
Typically-developing (anagram group)	5.6667	0.17647
All	4.4896	0.1600
<ul style="list-style-type: none"> <li>• All data was calculated from the sensitivity and specificity data provided in the Cheung et al study<sup>1</sup></li> <li>• Please refer to Cheung et al<sup>1</sup> for any additional information</li> </ul>		

- *This data reflects the ability to accurately predict anxious vs relaxed states in typically developing and ASD children.*