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Exploring Relationships between Level of Mental Retardation and Features of Music Therapy Improvisations: A Computational Approach

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Abstract

The present study sought to identify relationships between musical features of music therapy improvisations and clients' level of mental retardation, using a computationally-based method of analysis. 216 improvisations, contributed by 50 clients, were collected in MIDI format. Clients were divided into four groups according to their level of diagnosed mental retardation: 1 = none, 2 = mild, 3 = moderate, 4 = severe or profound. 43 client-related musical features were automatically extracted from their improvisations in the MATLAB computer environment and entered into a series of linear regression analyses as predictors of clients' level of mental retardation. The final model, which contained nine significant musical variables, accounted for 67% of the variation in clients' level of mental retardation. Specifically, level of mental retardation was best predicted by temporal elements of the music relating to note duration, note density, articulation, and amount of silence.

***Keywords**: improvisation, computational analysis, mental retardation*

Introduction

General Introduction

Improvisation-based therapy is a widely-used form of music therapy, and has been utilised with a wide range of clinical populations, including individuals with intellectual disabilities (Bruscia, 1987). A variety of improvisational music therapy methods are currently in use (see Wigram, 2004, for a discussion), all of which aim to enhance the level of communication between the client and the therapist. It might be supposed that the level of communication a client is able to achieve is related to their clinical condition. It follows that at least some aspects of a client's clinical condition might be revealed directly in the music they produce.

A limited amount of research has been carried out into the relationship between clients' improvised material and their clinical condition, and even less specifically examining the relationships between features of improvised material and level of mental retardation. As regards this latter work, most of it is based on the recording, transcription, and subjective interpretation of the improvised material (e.g., Bruscia, 1982), traditionally created using acoustic instruments and the human voice. However, questionnaires have also been used to examine relationships between client characteristics and the improvisations they produce (e.g., DiGiammarino, 1990). Moreover, growth in the availability and sophistication of electronic instruments has prompted some researchers to turn their attention to other analysis methods. For example, the implementation of sequencer and notation software in the analysis process has been described in recent years (e.g., Orsmond & Miller, 1995; Lee, 2000; Wentz, 2000).

The results of this research suggests that certain features of an individual's musical performance might be related to that individual's particular level of retardation. In other words, an individual's level of retardation impacts upon the features contained in their musical performances. The methodologies used to analyse the musical material in these studies are varied, but fall into three broad categories: 1) questionnaire-based research, 2) anecdotal data with or without aural analysis, and 3) visualization or aural analysis of MIDI (Musical Instrument Digital Interface) data.

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In the following section, the main findings from this body of research are described.

Previous Music Therapy Research

One of the advantages of using questionnaires is that they allow large samples to be investigated. For instance, DiGiammarino (1990) conducted an impressive survey study concerning the musical skills of 120 adult and elderly individuals with mental retardation. Participants were grouped into those with profound or severe retardation, moderate retardation, or mild retardation. DiGiammarino found that, whilst individuals with profound or severe mental retardation were rated as the least able in terms of instrumental skills (as might be expected), it was the moderately retarded group who were rated as the most capable overall, as opposed to those with mild levels of retardation.

In terms of specific skills, 15% of individuals with profound or severe mental retardation were able to play recognizable rhythm patterns, 27% were able to change tempo at will, 32% could play percussion instruments in time to live or recorded music, and 4% could play a song in unison with others. None of the participants with severe mental retardation could play a song in harmony with others. As regards individuals with moderate mental retardation, 36% could play recognizable rhythm patterns, 28% could deliberately modulate tempo, 23% could play a song in unison, and 13% in harmony, with others. With regards to individuals with mild levels of mental retardation, 23% could play recognizable rhythm patterns, 20% were able to make deliberate tempo changes, and 32% could play percussion instruments in rhythm to live or recorded music. Of the individuals with mild mental retardation, only 10% were able to play a song in unison or in harmony with others. These results suggest that variation of tempo, and perhaps other features, might be negatively related to level of mental retardation, since only a minority of individuals with mental retardation were able to change tempo, or vary other aspects of their playing to match that of the therapist. Note that the original aim of DiGiammarino's (1990) study was to assess clients' musical skills; information about how skills may relate to level of mental retardation was a by-product.

One possible reason for DiGiammarino's (1990) finding, that individuals with mild mental retardation were rated as being less capable than individuals with moderate mental retardation in all but one of the listed instrument-related music skills, is that questionnaires concerning individuals with mental retardation are often completed by parents or teachers. This indirect nature of data collection may lead to inaccurate data being gathered. In particular, field-specific terminology, such as that used in musicology, may lead to questions being misunderstood, and incorrectly answered, by those who complete them. Thus, a more direct method of data collection is desirable.

Anecdotal reports, such as case studies, typically utilize rather more direct subjective observations than questionnaire-based research. In anecdotal reports, the analysis methodology is rarely specified, but qualitative analysis of audio or video recordings is commonly used since it is very challenging for a music therapist to both lead a session and try to observe musical details at the same time.

Anecdotal client histories have been reported in relation to clients with various levels of mental retardation. Wheeler (1999), for example, noted that a profoundly retarded music therapy client played or scratched a percussion instrument occasionally. Wolpow (1976) reported that musical responses relating to pitch and temporality of a profoundly retarded individual increased during therapy. Holck (2004) used video analysis to examine what contact occurred musically, non-verbally, and in terms of gesture, and included the description of a severely retarded individual's ability to produce a small rhythmic motif. Bruscia's (1982) case study gave details of a client with severe mental retardation, and no capability to imitate, whose mean length of musical response was five units. Meanwhile, Ingber (2003) described the cluster-playing behaviour of some adults with mental retardation: "Certain clients banged on the keyboard...thereby making more than one note sound at a time."

This latter finding might be related to the fact that, although a preference for consonance over dissonance is developed in the first few months of life (Trainor & Heinmiller, 1998; Trainor, Tsang & Cheung, 2002), there tends to be a negative relationship between level of mental retardation and sensorimotor functioning (APA, 1994). This can manifest itself in a client's propensity to play clusters of notes in spite of properly developed preference for consonance over dissonance. Moreover, these sensorimotor deficits may also affect a client's ability to control the volume of their playing.

Compared to the skills of profoundly or severely mentally retarded individuals noted above, moderately retarded individuals have been reported to have greater functionality in the musical domain. For example, Wheeler (1999) noted that a Trainably Mentally Retarded (TMR) child was able to play a percussion instrument. There are also anecdotal reports that individuals with mild mental retardation can express themselves symbolically through improvisation and lyrics (e.g., Heal & O'Hara, 1993).

As with DiGiammarino's (1990) questionnaire study, however, none of the anecdotal studies described above had the specific aim of diagnosing the client's condition. The connections made between the skills demonstrated by clients with various types of mental retardation were unsystematic and occasional relationships noted by the authors. Nonetheless, anecdotal evidence, such as that based on qualitative analysis of audio or video recordings, is more direct, and thus perhaps more reliable than questionnaire-based data. However, it still lacks a degree of objectivity, being frequently based upon a single therapist's observations and conclusions. To be sure, some level of objectivity can be achieved if multiple observers are used by checking inter-rater reliability. Moreover, qualitative and quantitative approaches should also be seen as being complimentary to each other. Still, qualitative methods are generally regarded as being less objective than quantitative methods (see, for example, Kleinig & Witt, 2001).

The use of MIDI-based analysis has increased in recent years, both due to its increasing availability, and the fact that it permits efficiency, accuracy, and objectivity. MIDI is a protocol for changing musical information between digital devices such as keyboards, synthesizers, and computers. It describes music as a set of performance actions rather than as the sounded result. Such actions include, for instance, note-on, note-off, and key-velocity. These actions can be stored in the MIDI File Format, which is usually the starting point of MIDI-based analyses.

Moreover, MIDI data permits both detailed analysis and visualisation of a client's performance. An early example of the use of MIDI-based analysis is reported by Spitzer (1989), who used computer-based musical skill training in a therapy setting. In this study, data collection was partly carried out by using a MIDI keyboard to record the clients' performances. Spitzer noted that mildly retarded individuals tended to possess good rhythmic and tonal skills, but a less advanced understanding of music at a symbolic level. In one particular case, a mildly retarded client with good motor coordination demonstrated an excellent sense of rhythm and a well-developed tonal memory.

In some MIDI-based studies, the level of retardation of the clients has not been given. Nonetheless, the methods employed, and the results obtained, are worth mentioning. Miller & Orsmond (1994), for example, conducted a study in which a relatively heterogeneous sample population (including autistic and developmentally disabled individuals) improvised freely on a keyboard. An aural analysis of the recorded MIDI sequences revealed that melody and harmony were rarely simultaneously present. In other words, these clients were unable to attend to the production of both the melody *and* the harmony.

In a later study, Orsmond and Miller (1995) found that improvisations with more melodic fragments and harmonic intervals correlated positively with better behaviour ratings given to clients with mental retardation on four out of a total of five factors on the Aberrant Behaviour Checklist (Aman, Singh, Stewart, & Field, 1985); namely, Factor 1 (irritability, crying, and agitation), Factor 2 (lethargy and social withdrawal, Factor 3 (stereotyped behaviours), and Factor 4 (hyperactivity and non-compliance). In other words, greater prevalence of melodic and harmonic elements were associated with fewer interfering behaviours.

Related Research

In addition to previous work directly related to music therapy, research in the medical and social sciences, such as that relating to verbal communication, is also relevant to the present study.

For example, a cluster analysis of Bayley's California First Year Mental Scale test data by Cameron, Livson and Bayley (1967) indicated that vocalizations were related to mature intelligence in girls. Furthermore, spectrographic analysis of infant cries has shown that in particular chromosome abnormalities, such as trisomy 13-15 (Ostwald, Peltzman, Greenberg & Meyer, 1970), and cri du chat (e.g., Vuorenkoski et al., 1966), vocal productions can contain highly diagnosis-specific features.

In addition to diagnosis-related vocal expression studies conducted mainly in the domain of medical science, social scientists have presented very promising results concerning the use of a music-related feature in communication, namely, amount of silence. For example, Spitzberg and Dillard (2002) conducted a meta-analysis of behavioural predictors of social skills in adolescents and adults, and found that the amount of talk time (or absence of silence) was the most important predictor of social skills. Specifically, amount of talk time (silence) was positively (negatively) related to level of social skills. Given the parallels between music and language, the proportion of silence in music may also relate to social and communication skills, which are in turn related to level of mental retardation (APA, 1994). Thus, we might suggest that more severely retarded individuals would exhibit more silence in their playing, compared to individuals with lower levels of mental retardation.

Summary

In summary, the results of previous work suggest the possibility of a relationship between features of musical or verbal communication and an individual's level of mental retardation. The music therapy-related work is largely based on questionnaires or subjective aural analysis, and the results of these studies suggest that level of mental retardation may be negatively related to level of musical functioning. However, the indirect or subjective nature of the data collection and analysis methods employed in these studies makes it hard to identify reliable relationships between specific musical skills and level of mental retardation. Whilst the adoption of a more objective MIDI-based data collection and analysis method has begun to clarify the picture, little work has been carried out to date.

In particular, one of the key strengths of a MIDI-based approach has yet to be exploited, namely the possibility to carry out an *automated analysis* of a client's improvisation. Such an automated analysis might, for example, be based upon the computational extraction of a set of musical features from the improvised material. These features, and their relationship to certain characteristics of the client(s), could then be examined using a variety of statistical techniques.

The MIDI-based approach would allow one to examine the relationship between a client's level of cognitive functioning and the musical performances they produce. More specifically, one could investigate the relationship between a client's diagnosed level of mental retardation, and the features which characterise their improvised material. With this in mind, we turn now to the literature relevant to the computational extraction of musical features.

Computational Extraction of Musical Features

Algorithms for the computational extraction of musical features have been developed for both audio and MIDI representations of music (e.g., Downie, 2003; Leman, 2002). These algorithms are usually based on methods of signal processing, music processing, machine learning, cognitive modelling, and visualization. Typical application areas of these algorithms include computational music analysis (e.g., Lartillot, 2004, in press; Cambouropoulos, in press), automatic classification (e.g., Toiviainen

& Eerola, 2006; Pampalk, Flexer, & Widmer, 2005), organization (e.g., Rauber, Pampalk, & Merkl, 2003) and transcription (e.g., Klapuri, 2004) of music, as well as content-based retrieval (Lesaffre et al., 2003).

Whilst the use of computer technology in recording and notation of music therapy improvisations has been an emerging trend, this new technology has not been used in the automatic analysis of collected improvisation data. The computational modelling of musical processes and cognitive musicology can offer more objective and accurate methods for the analysis of clinical improvisations. Several models can be directly applied to the algorithmic analysis of music. The present authors (Luck et al., submitted) utilized computational extraction of musical features and statistical modelling to predict listeners' dynamic ratings of activity, pleasantness, and strength of music therapy improvisations. It was found that regression models of computationally extracted features were able to predict the listeners' ratings with a relatively high accuracy, the proportion of variance accounted for by the models varying between 59% and 79%.

The Present Study

There is a compelling need for the development of objective, applicable models of improvisation analysis methods. Firstly, it seems increasingly likely that only evidence-based forms of treatment will be acceptable in the future. Music therapy improvisations are widely believed to reflect the physical, cognitive, emotional, and social functioning of a client. If this assumption could be confirmed, it would be a step towards much needed evidence-based models of improvisational music therapy. Such models would allow changes in a client's functional capacity over time (i.e., during an extended therapy process) to be examined more objectively than is currently possible. Secondly, explicit knowledge concerning relationships between musical features and diagnostic populations would allow therapists to generate realistic expectations regarding their clients' progress. This is essential both in the therapist's initial assessment of a client, as well as throughout a therapy process. Finally, there is the issue of the therapist's involvement in a client's diagnostic process (see Wigram, 1995, for a discussion). Clients often receive different diagnoses from different doctors, and this can be confusing for a therapist. If a therapist had some knowledge regarding the relationship between different diagnoses and musical features, he or she could interpret these various diagnoses more meaningfully. At the very least, the therapist could offer their opinion as to the accuracy of the various diagnoses.

The present study is the first computationally-driven investigation of the relationship between musical features of music therapy clients' improvisations and their level of mental retardation. Such a relationship has been studied in the past mainly by administering questionnaires to therapists, or through therapists' somewhat subjective aural analyses of their clients' improvisations. The aim of the present study is to examine whether the way in which a client expresses themselves musically is related to their diagnosed level of mental retardation.[1] Moreover, since music therapy aims to enhance communication, we are interested not only in the client's musical productions, but also in the musical communication, i.e., integrative or synchronous aspects, between the therapist and the client.

We will examine how our real-world data relates to the results of, and theory that has emerged from, previous work which has employed the methods noted above. Furthermore, the computational extraction of musical features from a series of MIDI files will allow us to examine various aspects of the clients' improvisations in more detail than has previously been possible. For example, the fine-grained quantitative nature of the musical features will allow us to examine

[1] Throughout this paper, higher levels of mental retardation are synonymous with lower levels of cognitive functioning, i.e., more handicapped clients.

Group	N of clients	N of improvisations	N of improvisations of individual clients			
			Min	Max	Average	Standard deviation
1	9 (9)	52 (52)	1 (1)	29 (29)	5.78 (5.78)	8.94 (8.94)
2	18 (17)	50 (49)	1 (1)	8 (8)	2.78 (2.88)	2.24 (2.26)
3	9 (8)	47 (41)	1 (1)	18 (15)	5.22 (5.13)	6.57 (5.67)
4	14 (14)	67 (60)	1 (1)	29 (29)	4.79 (4.29)	7.27 (7.25)
Total	50 (48)	216 (202)	1 (1)	29 (29)	4.32 (4.21)	6.11 (5.99)

***Table 1**. The number of improvisations contributed by each clinical group, and the range of improvisations contributed by individual members of each group. Numbers in parentheses refer to the data actually selected for analysis (see Results section).*

finer nuances in the range of dynamics (i.e., variations in volume) employed by the clients.

Method I: Data Collection

Participating Institutions and Therapists

In order to collect a large, representative sample of music therapy improvisations, the researchers sought collaboration with all districts of services for the intellectually disabled in Finland. A total of four leading institutions for the intellectually disabled[2] agreed to participate in this study, each of which provided the researchers with the human and material resources necessary for the completion of the project. Five music therapists came from these institutions. In addition, two clinically experienced private music therapists were enlisted in order to increase the number of improvisations the researchers were able to collect. Thus, a total of seven qualified music therapists participated in the present study.

Client Participants

A total of 50 individuals with varying levels of mental retardation participated in this study. Participants were classified into four groups according to their diagnosed level of mental retardation, and these respective numerical values were used in the subsequent analysis to investigate the direction of relationships between musical features and level of mental retardation. Group 1 ($n = 9$) was comprised of individuals with no mental retardation, but with some other medical diagnosis.[3] Group 2 ($n = 18$) was comprised of individuals with mild mental retardation (ICD code F70). Group 3 ($n = 9$) was comprised of individuals with moderate mental retardation (ICD-10 code F71). Group 4 ($n = 14$) was comprised of individuals with severe or profound mental retardation, or unspecified mental retardation (ICD codes F72, F73, and F79, respectively). Table 1 shows the number of improvisations contributed by each clinical group, and the range of improvisations contributed by individual members of each group.

[2] Pääjärvi Federation of Municipalities, Rinnekoti-Foundation, Satakunta District of Services for Intellectually Disabled, and Suojarinne Federation of Municipalities.

[3] These diagnoses were: disturbance of activity and attention ($n = 3$), childhood autism ($n = 2$), atypical autism ($n = 1$), Asperger's syndrome ($n = 1$), psychological stress ($n = 1$), and mixed specific developmental disorders ($n = 1$).

Procedure

The therapists improvised with each client using a pair of identical 88 key weighted-action MIDI keyboards (Fatar Studiologic 880-PRO master keyboard). These keyboards contained no internal amplification, so each keyboard was connected to an external amplifier. A range of different amplifiers was used between the therapists, but in each case maximum dBA levels were calibrated to 85 dBA with an audio test instrument (Minilyzer ML1) for each room in which the improvisations were collected. Neither the length nor the content of the improvisation was constrained by the researchers. Timbre, however, was limited to the standard grand piano voice of the sound module to which the keyboard was connected. Cubase MIDI sequencer software was used to record the improvisations as it permitted the simultaneous recording of two separate MIDI tracks without merging them into a single track. At the end of each improvisation, the therapist exported it in MIDI format as two separate MIDI tracks, the therapist's performance on track 1, the client's on track 2. These MIDI files were then delivered to the researchers using the World Wide Web.

Material

A total of 216 improvisations were collected. The combined duration of these improvisations was 26 hours and 40 minutes, and a total of 779,803 notes were recorded. Of these, the therapists played 359,967 notes, and the clients 419,836. The average length of the improvisations was 7 min 24 sec, with a standard deviation of 4 min 45 sec.

Method II: Musical Features, and Musical Variable Extraction

Having collected the improvisations, the next step was to extract the musical features from which a set of variables would be derived to be used in the statistical analysis. Note that throughout the method section, the term 'feature' refers to the descriptors extracted directly from the MIDI files, while the term 'variable' refers to the musical variables derived from these features, and subsequently used as predictors of level of mental retardation.

The musical stimuli were subjected to a computational analysis to obtain a set of quantitative descriptors representing a variety of musical features. The analysis was carried out on the MIDI representation, which offers a detailed description of performances recorded on digital musical instruments. Each note is described with four main parameters. *Onset* and *offset* times give the precise dates of the attack and the release of each note. *Pitches* are indicated independently of any tonal context, as the position of the corresponding key on the keyboard. Finally, *velocity* indicates the strength of the attack of the note, and gives a detailed account of dynamic levels.

The analysis was carried out with algorithms implemented for the purpose of this study in MATLAB using the MIDI Toolbox (Eerola & Toiviainen, 2004). Different musical features were computed from MIDI files following a two-step methodology. Firstly, the temporal evolution of selected musical features was computed by moving a sliding window along the musical sequence, and by analysing the contents of each successive window. Preliminary tests led to the choice of a 6-sec-length sliding window, moving at successive intervals of 1000 ms. In a second step, simpler variables were deduced through a statistical description of the resulting windowed features, and it was these variables that were used in subsequent statistical analyses.

The musical features to be extracted were chosen on the basis of the following criteria. First, the features had to be extractable from the information available in the MIDI file format, i.e., from note onset and offset times, pitches and key velocity. Second, they had to comprise several musical dimensions in order to provide a comprehensive representation of the musical content. Finally, they had to encompass differing levels of complexity, ranging from psychophysical properties, such as note density and dynamics, to more context-dependent properties, such as pulse clarity and tonality. In what follows, each of the musical features is listed, and, where appropriate, explained in more detail.

Musical Features

A. Temporal surface features. These features were based on the MIDI note onset and offset positions, and were computed for each position of the sliding window (except feature 4).

1. Note density. Number of notes in the window divided by the length of the window.

2. Average note duration in the window.

3. Articulation. Proportion of short silences in the window. Short silences were defined as intervals no larger than two seconds during which no note was played. These short silences are not included in the silence factor, as they are generally not perceived as real silence, but rather as intermediate pauses characterising the performance style. Values close to zero indicate *legato* playing, while values close to one indicate *staccato* playing.

4. Silence factor. Proportion of long silences *within the whole improvisation*. Long silences were defined as time intervals larger than two seconds during which no note was played. The silence factor is given by the sum of all these silence intervals divided by the total length of the musical excerpt. Note that, unlike the other features which are time-series in nature, this is a scalar feature. It is included here because it relates to the temporal surface of the improvisations.

B. Register-related features. These features were based on the MIDI pitch values of notes, and were computed for each position of the sliding window.

5. Mean pitch.

6. Standard deviation of pitch.

C. Dynamic-related feature. This feature was based on the MIDI velocity parameter, and was computed for each position of the sliding window.

7. Mean velocity.

D. Tonality-related features. These features, based on the Krumhansl-Schmuckler key-finding algorithm (Krumhansl, 1990), give a statistical assessment of the tonal dimension of the improvisations, and were computed for each position of the sliding window.

8. Tonal clarity. To calculate the value of this feature, the pitch-class distribution within the window was correlated with the 24 key profiles representing each key (12 major keys and 12 minor keys). The maximal correlation value was taken to represent tonal clarity.

9. Majorness. Calculated as tonal clarity, but only the 12 major key profiles were considered.

10. Minorness. Calculated as tonal clarity, but only the 12 minor key profiles were considered.

E. Dissonance-related features.

11. Sensory dissonance. Musical dissonance is partly founded on cultural knowledge and normative expectations, and is more suitable for the analysis of improvisation by expert rather than by non-expert musicians. More universal is the concept of *sensory dissonance* (Helmholtz, 1877/1954), which is related to the presence of beating phenomena caused by frequency proximity of harmonic components. Sensory dissonance caused by a couple of sinusoids can be easily predicted. The global sensory dissonance generated by a cluster of harmonic sounds is then computed by adding the elementary dissonances between all the possible pairs of harmonics (Plomp & Levelt, 1965; Kameoka & Kuriyagawa, 1969). In the present study, the dissonance measure is based on the instrumental sound (MIDI default piano sound) used during all the improvisations. Since successive notes may also appear dissonant, even when not played simultaneously, we also took into consideration the beating effect between notes currently played and notes remaining in a short-term memory (fixed in our model to 1000 ms). Sensory dissonance was calculated every 1000 ms.

F. Pulse-related features. A method was developed which enabled the automatic detection of rhythmic pulsations in MIDI files. More precisely, a temporal function was first constructed by summing Gaussian kernels, that is, narrow bell curves, centred at the onset point of each note. The height of each Gaussian kernel was proportional to the duration of the respective note; the standard deviation (i.e., the width of the bell curve) was set to 50 ms (see Toiviainen & Snyder, 2003). Subsequently, the obtained function was subjected to autocorrelation using temporal lags between 250 ms and 1500 ms, corresponding to commonly presented estimates for the lower and upper bounds of perceived pulse sensation (Westergaard, 1975; Warren, 1993). In accordance with findings in the music perception literature, the values of the autocorrelation function were weighted with a resonance curve having its maximal value at a period of 500 ms (Toiviainen, 2001; see also Van Noorden & Moelants, 1999). The obtained function will subsequently be referred to as the pulsation function.

Like all the other musical parameters, the pulsation function was computed for each successive position of the sliding window. The analysis of a complete improvisation results in a two-dimensional diagram called a pulsation diagram. Figure 1 a) and b) shows examples of such pulsation diagrams. The x-axis indicates the temporal progression of the improvisation, whereas the y-axis indicates the tempos of the pulsations. Tempos are expressed as pulse periods, which correspond to the inverse of tempo. On the y-axis, the periods range from 250 ms (corresponding to a tempo of 240 bpm) to 1500 ms (corresponding to a tempo of 40). Each black area in the diagrams indicates a local pulsation at a specific instant of the improvisation (indicated by the x-coordinate) and at a particular period (indicated by the y-coordinate). From the pulsation diagrams, two musical features were deduced:

12. Individual pulse clarity. The evolution of client's and therapist's pulse clarity is obtained by collecting the maximal values of each successive column in the respective pulsation diagram.

13. Individual tempo. The evolution of client's and therapist's tempo is obtained by collecting the tempo values associated with the maximum values of each successive column in the respective pulsation diagram.

Based on the features described thus far, we derived 24 variables that were based on the clients' improvisations only. These were the following:

For features 1 – 3, and 5 – 13, we calculated mean and variance for the client.

In addition, feature 4 (silence factor) was extracted for the client.

Quantifying the Client - Therapist Interaction

In order to quantify the client-therapist interaction we calculated a number of variables that were based upon the musical features derived from both the clients' and the therapists' playing.

Firstly, for features 5 and 7 we calculated the average difference between client and therapist.The decision to calculate only these two differences, and not differences between client and therapist for other features, was based on clinical work. Music therapists often tend to take 'bass-line position' (see DeBacker, 2004), i.e., to play in the lower register, in order to give the role of soloist (the higher register) to the client. If the client has the capacity to understand and employ such roles, this should be seen as a difference in average mean pitch. Average mean velocity is another variable where the nature of basic expression and communication can be seen. In the conscious role of a soloist, one probably tends to play louder than the accompanist, while the accompanist tends to play softer, thus giving room for the soloist. If the client has the capacity to understand and employ such roles, this should be seen as a difference in average mean velocity.

In order to assess the common pulsation developed in synchrony by both players, a new diagram called a synchronised pulsation diagram was produced by multiplying each individual player's values at respective points of their related pulsation diagrams. Figure 1c shows the common pulsation diagram derived from the individual pulsation diagrams displayed in Figures 1a and 1b. Two features were derived from the common pulsation diagram:

14. Common pulse clarity. Similarly to individual pulse clarity, the evolution of common pulse clarity is given by the maximal pulsation values in the synchronised pulsation diagram.

15. Common tempo. Similarly to individual tempo, the evolution of common tempo is given

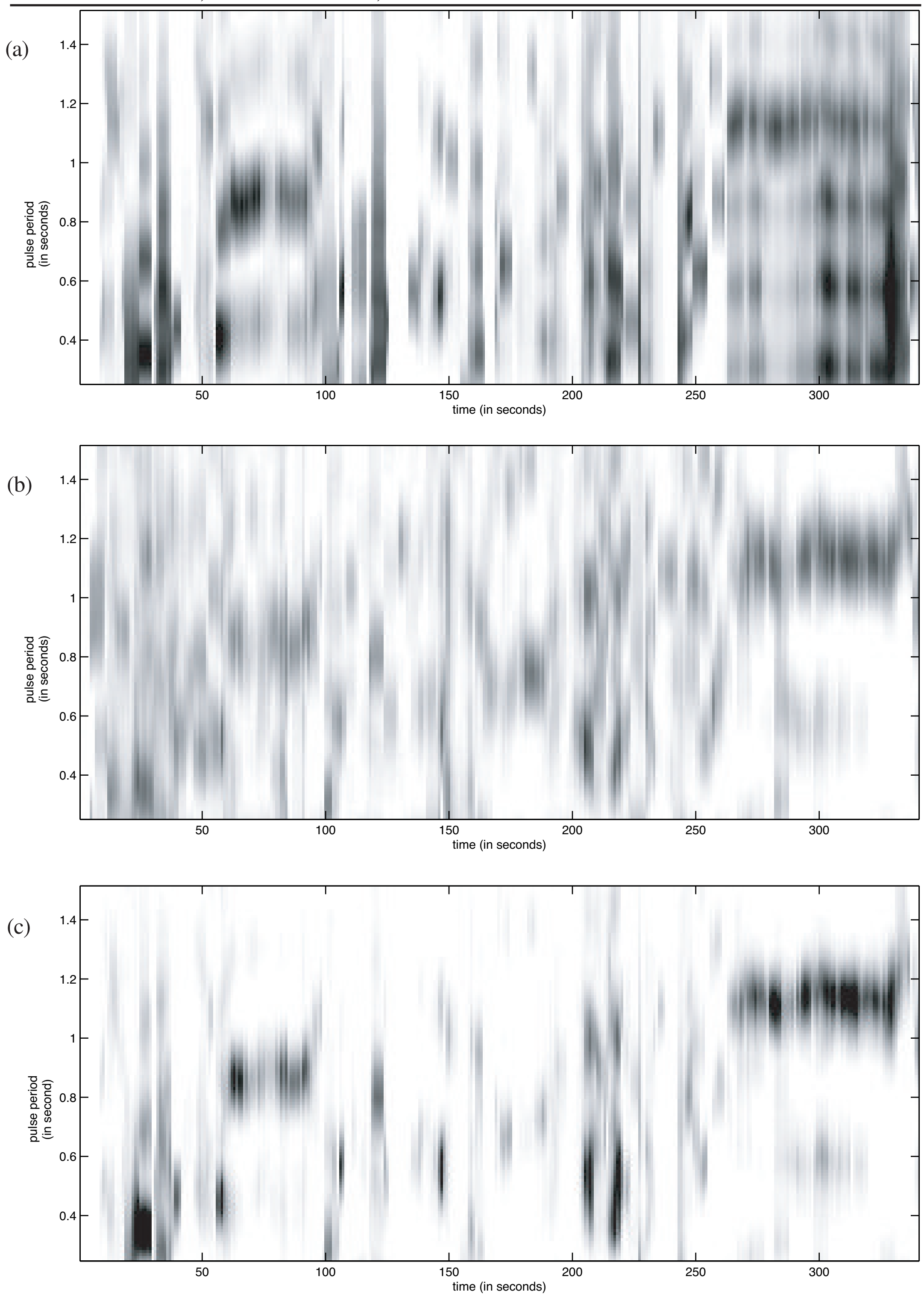

***Figure 1**: Pulsation diagrams describing the rhythmic clarity of the therapist (a), the client (b), and the rhythmic synchronicity of both (c).*

by the tempos related to the maximal pulsation values in the synchronised pulsation diagram.

Another important dimension of musical expression that is of particular interest in music therapy is the degree of communication between the therapist and the client. In particular, when communication takes place, players imitate one another or jointly elaborate same gestures. The musical dialog may therefore be assessed by observing the degree of local similarity between the temporal evolutions of both improvisations, along the different features presented in the previous section. These local integrations are represented graphically in what we call an integration diagram.

Figure 2 shows four examples of the relationship between the temporal evolution of a musical variable and its respective integration diagram. Each line of Figure 2 is dedicated to a different musical feature: from top to bottom – note density, mean duration, standard deviation of pitch, and mean velocity. On the left side is displayed the temporal evolution of the corresponding feature with respect to each player, the therapist in black and the client in grey. On the right side is the associated integration diagram, where the horizontal axis also corresponds to the temporal evolution of the improvisation. Lines in the integration diagram indicate local integrations. The darkness of the lines is associated with strength of integration: light-grey corresponds to slight and coarse similarities, while black corresponds to distinct and close imitations. When the line is vertically centred, the integration between both players is synchronous. When the line is in the upper half of the diagram, the client imitates the therapist after a certain delay, displayed by the vertical axis, in seconds. Similarly, when the line is in the lower half of the diagram, the therapist imitates the client. Finally, the length of the line indicates the duration of the integration.

From each integration diagram, a variable called integration was obtained by collecting the maximum imitation values along the vertical axis, for each successive horizontal position in the diagram, and by averaging the obtained series.

To quantify the degree of client-therapist interaction on different musical dimensions, we derived the following 18 musical variables:

For features 5 and 7, we calculated the average difference between client and therapist.

For features 1 – 3, and 5 – 13, we calculated the integration between the client and the therapist.

For features 14 and 15, we calculated the mean and variance.

In total we had 25 client-only variables, and 18 client-therapist variables, and these are summarised in table 2.

Results

The analysis followed a four-stage approach, in which four separate linear regression analyses were carried out. The aim of this approach was to reduce the number of significant predictors (musical variables) in the final model through the logical selection of variables in multiple analyses, as opposed to relying on statistically-dependent methods of variable entry (e.g., stepwise methods) in a single analysis.

Prior to any analysis, the data were screened for outliers, and for signs of heteroscedasticity. While there were no major issues relating to heteroscedasticity, non-normal values of some of the musical variables were found in a number of improvisations. Consequently, fourteen improvisations were excluded from further analyses, leaving a total 202 improvisations to be analysed.[4] See figures in parentheses in Table 1 for the number of improvisations contributed by each clinical group, and the range of improvisations contributed by individual members of each group, for this selected data.

[4] The selected improvisations were contributed by 48 clients. The combined duration of these improvisations was 25 hours and 17 minutes, and a total of 735,287 notes were recorded. Of these, the therapists played 342,273 notes, and the clients 393,014. The average length of the improvisations was 7 min 30 sec and the standard deviation 4 min 45 sec.

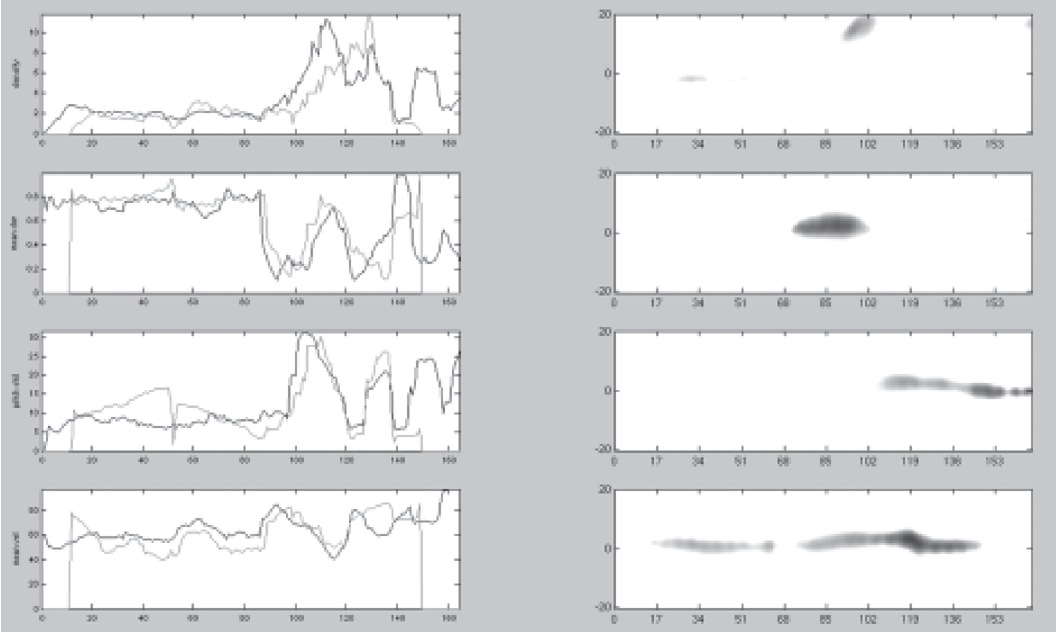

Figure 2: *Temporal evolution of musical variables (on the left) and their respective integration diagrams (on the right). Four features are shown as examples, namely (from top to bottom) note density, mean duration, standard deviation of pitch, and mean velocity.*

At stage 1, all client-only variables (a total of 25[5]) were simultaneously entered into a linear regression analysis, in which level of mental retardation was the dependent variable. A significant model emerged ($F(25, 176) = 16.499$, $p < .001$; $R^2 = .701$; adjusted $R^2 = .658$), in which nine variables were significant predictors of level of mental retardation.[6]

At stage 2, all client-therapist variables (a total of 18) were simultaneously entered into a linear regression analysis, in which level of mental retardation was the dependent variable. A significant model emerged ($F(18, 183) = 11.032$, $p < .001$; $R^2 = .520$; adjusted $R^2 = .473$), in which nine variables were significant predictors of level of mental retardation.

At stage 3, the significant variables from stages 1 and 2 (a combined total of 18) were simultaneously entered into a linear regression analysis, in which level of mental retardation was the dependent variable. A significant model emerged [$F(18, 183) = 24.211$, $p<.001$; $R^2 = .704$; adjusted $R^2 = .675$], in which nine variables were significant predictors of level of mental retardation.

Finally, at stage 4, the significant variables from stage 3 were simultaneously entered into a linear regression analysis, in which level of mental retardation was the dependent variable. A significant model emerged ($F(9, 192) = 43.587$, $p < .001$; $R^2 = .671$; adjusted $R^2 = .656$), in which all nine variables were significant predictors of level of mental retardation. Variables in the final model are shown in table 3.

It can be seen from table 3 that most of the features that predicted level of mental retardation related to temporal aspects of the clients' improvisations. With regards to these temporal

[5] While this number of variables was, given our sample size, slightly larger than the maximum number recommended by Green (1991, pp. 449-510), we considered this small violation to be acceptable in order to retain the logic in our selection of variables for each analysis.

[6] In order to conserve space, only variables in the final model (stage 4) will be described in detail.

Features	Variables					
	Client only		*Client and therapist*			
	Mean	*Variance*	*Integration*	*Average difference*	*Common mean*	*Common variance*
1. Note density	*	*	*			
2. Average note duration	*	*	*			
3. Articulation	*	*	*			
4. Silence factor	* (scalar)					
5. Mean pitch	*	*	*	*		
6. Standard deviation of pitch	*	*	*			
7. Mean velocity	*	*	*	*		
8. Tonal clarity	*	*	*			
9. Majorness	*	*	*			
10. Minorness	*	*	*			
11. Sensory dissonance	*	*	*		*	
12. Pulse clarity	*	*	*			
13. Tempo	*	*	*			
14. Common pulse clarity					*	*
15. Common tempo					*	*

Table 2: *A summary of the 43 variables used in the analyses.*

features, the amount of silence in clients' improvisations was positively related to level of mental retardation, and, based upon the beta value, was the best predictor of level of mental retardation. Clients' average note duration was also strongly positively related to level of mental retardation, while variation in clients' note duration was mildly positively related to level of mental retardation. Clients' average note density was moderately positively related to level of mental retardation, while variation of clients' note density was moderately negatively related to level of mental retardation. Moreover, clients' average articulation was strongly positively related to level of mental retardation, while integration of articulation between client and therapist was mildly negatively related to level of mental retardation.

In addition, integration of tempo between client and therapist was mildly positively related to level of mental retardation. Finally, as regards the significant dynamic-related variable, difference in mean velocity between client and therapist was mildly negatively related to level of mental retardation.

Discussion

To summarise, improvisations produced by clients with higher levels of mental retardation (that is, with lower levels of cognitive functioning) were characterised by: longer periods of silence, longer average note durations, more variation in note duration, higher average note density, less variation in note density, more detached (staccato) playing, less integration of articulation with the therapist, better integration of tempo with the therapist, and less difference in volume compared to the therapist.

Given the lack of previous systematic research on the relationship between an individual's level of mental retardation and characteristics of their improvisations, it is hard to offer a meaningful interpretation of many of these findings. Nonetheless, several observations can be made, relating to the type of variables which were significant, and specifically about the relationships between level of mental retardation and both silence and integration.

Firstly, then, it is interesting to note that most of these variables are temporal in nature. Variables relating to tonality and register, for example, were not found to be significant using the four-stage linear regression approach used here. Several previous studies and clinical reports have noted the prominence of rhythmic/temporal elements, and the absence, exiguity, or accidental employment of tonal elements, in the music produced by individuals with mental retardation (DiGiammarino, 1990; Bruscia, 1982; Wheeler, 1999; Holck, 2004; Nordoff-Robbins, 1977; Miller & Osmond, 1994). Although these previous studies have not identified specific relationships between such elements and level of mental retardation, the present results are certainly in line with this previous work. Overall, these findings suggest that it might be easier to identify a client's level of mental retardation on the basis of temporal elements of their improvisations, as opposed to tonal- or register- related elements.

Secondly, with regards to the positive relationship between amount of silence and level of mental retardation found in the present study, this is line with Spitzberg and Dillard's (2002) finding that individuals with poorer social skills tend to talk less. We might suggest that these two types of spontaneous expression (talking freely, and free expression with a musical instrument) have much in common, especially from a social perspective. Moreover, our results suggest that earlier findings (Cameron et al., 1967; Ostwald et al., 1970; Vuorenkoski, et al., 1966) concerning the relationship between infant vocalization and crying, and mental retardation/abnormalities, might also be applicable to instrumental expression.

Thirdly, there were contradictory findings for the two significant integration-related variables. While individuals with higher levels of mental retardation showed poorer integration of articulation with the therapist, these same individuals demonstrated better integration of tempo with the therapist. The former relationship might be associated with an inability to adjust or modify one's role according to, or stimulated by, another party, and may also relate to more retarded clients' limited social and motor skills. In as much,

Predictor variable	Beta	Sig.
Temporal - non-periodic		
Amount of silence in client's improvisation	.784	***
Client's average note duration	.711	***
Variation in client's note duration	.152	**
Clients' average note density	.499	***
Variation of clients' note density	.675	***
Client's average articulation	-.344	***
Integration of articulation between client and therapist	-.112	*
Temporal - periodic		
Integration of tempo between client and therapist	.185	**
Dynamic		
Difference in average mean velocity between client and therapist	-.155	**

*significant at the .05 level **significant at the .01 level ***significant at the .001 level

Table 3: *The nine significant predictors of level of mental retardation, grouped into non-periodic temporal-, periodic temporal-, and dynamic-related features. The beta values indicate the strength and direction of the relationship between each predictor variable and level of mental retardation. Overall, these nine variables explained 67% of the variance in clients' level of mental retardation.*

this relationship might be expected. The latter relationship, on the other hand, runs contrary to this argument, as well as to findings reported by DiGiammarino (1990), who identified a possible (albeit rather tenuous) negative relationship between level of mental retardation and ability to change tempo at will. Rather than speculate as to who obtained the more accurate result, perhaps it is better here to note that the results of the present study run contrary to both common sense expectation and previous work, and propose that integration between client and therapist be examined in more detail in future work.

In addition, it is noteworthy that long note duration and high note density co-occurred in the improvisations analysed in the present study. This runs contrary to the common sense view that note duration and note density tend to be negatively related. This suggests that clients with higher levels of mental retardation played clusters with long durations, perhaps due to limited cognitive abilities and/or limited motor skills.

One limitation of the present study that should be noted, however, relates to statistical dependencies within the improvisation data. In the present study, most clients contributed several improvisations taken from sessions in which they interacted with the same therapist. Two or more improvisations produced by the same individual introduces statistical dependencies into the data, especially if produced with the same therapist. These dependencies violate one of the assumptions of linear regression, and can result in unstable model parameters. In other words, we cannot be certain that the model described in the present study is 100% accurate. On the other hand, given the size of the present data set, and the fact that it took one year to collect, the logistics (and therefore the likelihood) of gathering a collection of completely independent improvisations are hard to comprehend. The present model may not be perfect, but it represents an important first step towards evidence-based models of music therapy.

The present study suggests that there may be many indicators in an individual's musical expression as to that individual's level of mental retardation. The therapist's task, to identify the musical capabilities of the client as well as find the most appropriate musical interventions, is clearly a challenging one. Undoubtedly, the importance of a therapist's innate musicality, social sensitivity, clinical training, and experience, cannot be overrated.

That said, the present study supports many clinical assumptions, often based on aural analysis and individual case studies, made in the music therapy literature. It also shows that a combination of computational musical feature extraction and statistical modelling can be used to investigate various kinds of musical micro processes more efficiently, and certainly much more easily, than traditional analysis methods. The present method also shows promise in the analysis of integration between the client and therapist.

The main benefits of the present method are the speed and precision of the analysis. This makes it possible to analyse a large number of improvisations very quickly, and would thus be extremely useful for the therapist who wants to analyse a long therapy process comprised of tens, if not hundreds, of improvisations. In addition, the present method makes it possible to extract, and investigate on an individual basis, many overlapping processes exemplified in the music – a known shortcoming of traditional analysis methods (see Wigram, 2001).

However, there are still many musical phenomena that require human input in order to be revealed and interpreted. After all, a computer's understanding of concepts such as melody, phrase, pattern, etc., or of referential or motional meaning, within the musical complex, is currently at best extremely limited.

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