Computational Music Therapy

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Abstract. Free improvisation is a common technique in music therapy, used to express one's ideas or feelings in the non-verbal language of music. More broadly, music therapy is used to induce therapeutic and psychosocial effects; i.e., to help alleviate symptoms in serious and chronic diseases, and to empower the wellbeing and quality of life for healthy individuals and for patients. However, much research is required in order to learn how music therapy operates and to enhance its effectivity. Here we utilize our broad computational paradigm, which enables the rigorous and quantitative tracking, analyzing and documenting of the underlying dynamic expressive processes. We adapt the method, which we developed for the art and music modalities, to music therapy and apply it in a real-world experimentation. We study expressive emergent behaviors of clients directed by a therapist in a succession of sessions aimed at developing and increasing their expressivity through free improvisations. We describe our empirical insights, and discuss their implications in therapy and in scientific research arenas.

Keywords: Computational paradigm · Computer modeling · Music making · Arts therapies · Music therapy

1 Introduction

Music therapy is used in diverse populations and age groups to help alleviate symptoms and induce therapeutic and psychosocial effects in a wide variety of serious and chronic conditions, illnesses, mental disorders, disabilities, etc. [1–16]. For a patient or a healthy individual, the engagement with music also enhances one's well-being and quality of life, and is useful for research and practice in the social sciences, aimed at understanding and empowering individuals, groups and society [17–19]. Nevertheless, much research is required to reveal the underlying expressive behavioral mechanisms, by which music interventions work, and to enhance their effectivity [20–22].

The clinical setting, which consists of the musical work, the therapist and the patient, constitutes a rich dynamic environment of occurrences that is difficult to capture, driven by complex, simultaneous, and interwoven expressive behavioral processes, often considered intractable to human observers. Consequently, they are perceived and interpreted subjectively, and most often described verbally, thus

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affecting the subsequent analyses and understanding. Our broad computational paradigm (CP), developed and utilized for the art and music modalities [23, 24], allows substantial barriers in the arts-based fields to be overcome, by enabling the rigorous and quantitative tracking, analyzing and documenting of the underlying dynamic processes, and allowing one to carry out exploratory, hypotheses-testing and – generating, and knowledge discovery investigations, which are empirically based. Our empirical infrastructure enables intra-/local-/micro- analysis, where the focus is on specific moments within the dynamics of an arts-based session, and inter-/global-/macro-analysis with reference to wider perspectives, across sessions, individuals and collectives; e.g., the discovery of demographic variation factors in artistic making [23, 24]. Past attempts to use computation to analyze music making were found to be limited ad-hoc implementations: recording of some particular parameters that were based on predetermined hypotheses was carried out in [25], some featured tools were demonstrated on two single test cases [26], and in [27] extracted musical features of improvisations were used to predict the type of mental disorder of music therapy clients.

Musical improvisation is a common technique in music therapy used to express one's feelings or ideas in the non-verbal language of music. Directing patients or clients to improvise freely enables them to develop their creativity and expressivity, which is the basis of the study reported here. We adapt the CP and apply it to music therapy in a real-world experimentation aimed at improving one's expressiveness, yielding novel empirical insights to aid music therapists and researchers.

The CP captures emergent behaviors; i.e., arising properties and patterns of the behavioral processes, and it includes: *(1)* measuring and calculating exact time durations of occurrences within the music session; e.g., net idle time, in which the patient/client is not engaged in musical activity or pressing a key, total playing time and concurrent playing time, obtained from notes (keys) pressed in parallel; *(2)* tracking note use per time and per presses; e.g., net number of notes used, total number of notes pressed, their time durations and density, and their cluster formations, as well as note color preference (say, black and white keys on a piano keyboard); *(3)* capturing and analyzing preference profile of octave use and note intensity in the music making process; e.g., whether it is carried out in confined pitch (registers) and intensity levels (musical dynamics); *(4)* calculating transitions; e.g., crescendo, diminuendo, accelerando, ritardando and note color (for example, black to white, white to white, etc.); *(5)* profiling pitch classes; that is, the note use distribution collapsed onto an octave (C, C#, D,…, A#, B pitch); *(6)* pedal use; i.e., number of presses and time durations.

As described next, our setup involved human subjects participating in an experimental study that consisted of a series of sessions with a music therapist. We analyzed the dynamics of the emergent behaviors in their free improvisation playing, according to the parameters discussed above.

2 The Computational Paradigm and Its Use

The study reported upon in this paper is an application of our CP to understanding the effects of therapy in enhancing one's musical expression.

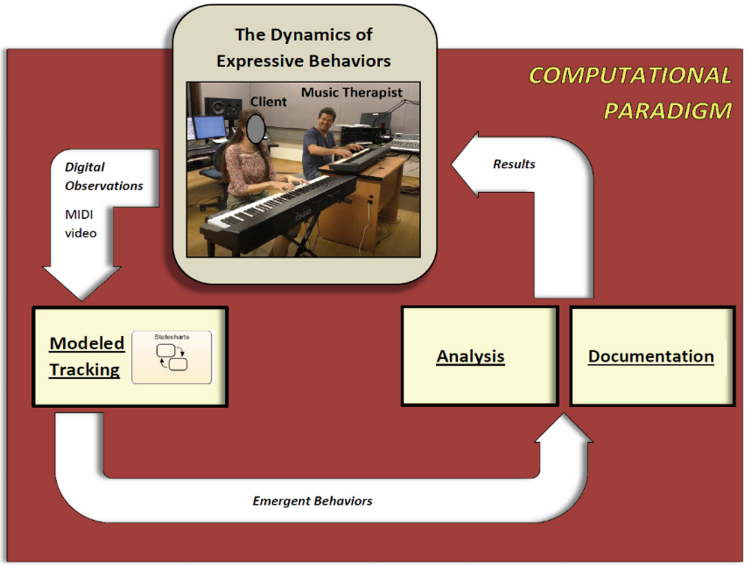

Fig. 1. The computational paradigm and its constituting components.

2.1 Music Room Modeling

Here we provide a brief description of the adaptation of the method for music therapy. We refer the reader to [23, 24] for a more detailed description of the methodology's architecture and modeling considerations for the various arts modalities. As seen in Fig. 1, digital observations of the system under study, i.e., musical work, are fed into the **Modeled Tracking** module, which captures the occurring events to yield emergent expressive behaviors. These are input to the **Analysis** and **Documentation** modules, the first of which outputs empirical insights into the field of study – music therapy, and the second transforms the behavioral dynamics to amenable descriptions therein. The **Modeled Tracking** module hosts the music room model, which is Statecharts-based [28]. Statecharts is a visual formalism [29], which enriches the basic state/event modeling approach with means for describing hierarchy (nested states) and multi-level transitions, as well as orthogonality (concurrent states), and more. We base our modeling on Statecharts, and use its underlying execution and analysis tools [30–32] to track and analyze the musical work system and the parameters therein. Three major entities comprise the music room: the musical work, the patient and the music therapist (see Fig. 2). The musical work (e.g., free improvisations), which is the center of attention here, is driven by events that transfer the system from state to state. For example, starting to play a musical note, and stopping it, pressing the piano pedal, entering an 'idle' state, etc. As such, and as seen in Fig. 2, the **Music_Work** subsystem state is decomposed into its exclusive substates, **Idle**, **Selecting**, and **Playing**, with the latter state further including the complex and rich dynamics therein; e.g., the orthogonal states **Timbre**, **Duration, Tempo, Cluster_size, Key_n, Max_metrics** and **Min_metrics** (see these in [24], where each of them is also further described by its substates).

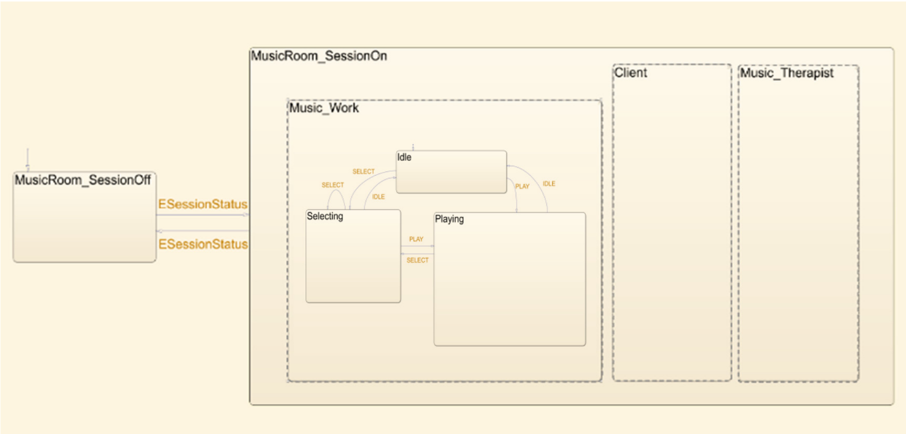

Fig. 2. Statecharts [28] modeling of the high-level state of the music room, with three concurrent/orthogonal states (dashed lines) specifying the entities therein: the **Music_work**, **Client** (patient) and **MusicTherapist**. The figure also shows the events that trigger the beginning of the therapy session and its termination, specified as mutually exclusive states, **MusicRoom_SessionOn** and **MusicRoom_SessionOff**, respectively (solid lines). Further details as to the nested states can be found in the text and in [23, 24].

2.2 Experimental Design

The study included a music therapist and four participants, or subjects, A, B, C, and D[1]. Each subject participated in six 50 min sessions, each of which began with a free improvisation and ended with one. That is, a total of 12 free improvisations for each subject. In between, the subjects were given exercises and tasks by the therapist, to execute either alone or accompanied by him. The participants were healthy/normal subjects, 22–35 years old, having had college-level musical education with several years of piano training (mostly during childhood) and modest experience in improvisations. The sessions were intended to develop the participants' expressive abilities.

The musical instrument used by the participants was a Casio MIDI piano keyboard controller (PX-160) and a pedal (sp-3). We employed the MIDI protocol [33, 34] for digital data collection. The improvisation data was recorded using Cubase9 [35] and was transformed by Max/MSP [36] to output script files. These were subsequently "read into" our Statecharts model and analyzed by the CP methodology.

[1] The research protocol was reviewed and approved by Bar-Ilan University's Ethics Committee. All participants signed a written informed consent.

For each of the subjects, the first and last improvisations (nos. 1 and 12) were extracted from the MIDI recordings, and were analyzed. The improvement of expressiveness should to be apparent in the sound (e.g., intensity, pedal use), physical (e.g., key color, octave range) and temporal (e.g., improvisation time) attributes of piano playing. Here we report on the results of Subject-B and then of Subject–A (additional results will be reported elsewhere).

3 Results

The results obtained from analyzing the first and last improvisations of Subject-B and Subject-A manifest enhanced musical expressiveness, whereas the empirical values of the musical parameters enable the rigorous comparison of the performances and the expressiveness change.

As seen in the top panel of Fig. 3A, the range of Subject-B's octave use grew, that is, the minimum octave used was no. 2 (marked by a green square) and the maximum octave value of 4 (in red) changed to the higher value of 5. The black square marks the most used octave in playing time, that is, from octave 4 to 3 in this case, whereas the exact distribution of the octave number use per the percentage of the playing time is depicted in the histogram appearing in the top left panel of Fig. 3B. The range of intensity values (dynamics) also grew. See the bottom panel in Fig. 3A, and the accompanying histogram showing the exact percentage of playing time for each intensity value (Fig. 3B top right panel). Interesting also to note is the increased use of the black keys (see Fig. 3C two bottom right panels for key color distribution of presses and their transitions, respectively). In addition, the pitch classes preference is shown in the bottom left panel of Fig. 3B; adding the notes E and F# to the repertoire of the last improvisation, "letting go" of the C note, and tending to more chromaticity overall. A meaningful change is also seen in the total time duration of the improvisation length, from 0.6 min of the first to more than four times in length, that is, to 2.7 min (Fig. 3C top left panel). In fact, all subjects increased the durations of their improvisations – feeling more comfortable in expressing themselves. Subject-B placed her foot statically on the pedal in the first improvisation (even before it started), whereas in the last one the pedal was freely used; 19 presses with 8.5 s average press throughout 91.6% of the improvisation time. Notable also is the concurrent playing time[2] (Fig. 3C top right panel), which grew from 214% to 264%, mostly owing to the larger cluster of keys pressed together (Fig. 3B bottom right panel) and almost 'doubling' the percentage of keys used doing so, from 29% to 50% (Fig. 3C top right 2nd panel). It is interesting to compare our detailed and precise approach with the therapist's written summary. The therapist described the first improvisation merely as "a short improvisation" and did not document the last one at all.

Subject-A's results are presented in Table 1. Notable is the use of the black keys in the last improvisation as compared to the first (almost all white), in terms of the

[2] Concurrent playing metric, quantifies the percentage of concurrent playing time per net improvisation playing time, yielded by keys pressed in parallel (e.g., three keys pressed throughout the session play time yield 300%).

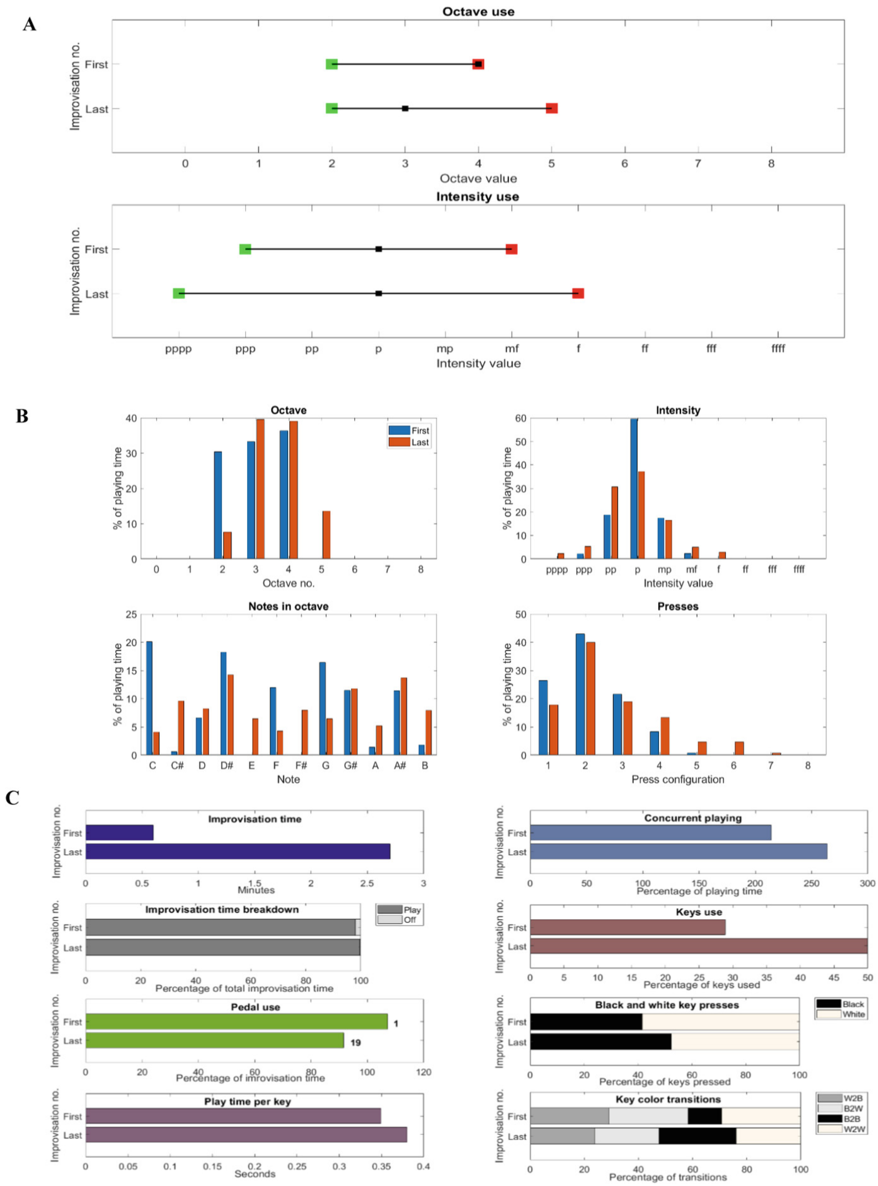

Fig. 3. Comparable empirical depiction of the first and last improvisations of Subject-B (extracted from the 1st and 6th sessions, respectively). Explanations are in the text. (Color figure online)

percentage of presses, the transitions (see '% black to black'), and the percentage of playing time distribution into pitch classes. This adds a more accurate aspect to the therapist's summary, including the use of the 'white' A note that was not captured by

Table 1. Parameter comparison of first and last improvisations of Subject-A.

Attribute	*Parameter*	*First Impro*	*Last Impro*
Time	% playing time	95.8%	76.2%
	% idle time	4.2%	23.8%
	% concurrent	237.1%	159.7%
	total (minutes)	1.5	3.6
Notes/ Keys	# of presses	425	905
	% used	51.3%	47.4%
	presses per key	10.9	25.1
	play per key (sec)	0.209	0.184
	% black presses	5.2%	97.9%
	% white presses	94.8%	2.1%
Intensity†	average	5	5
	lowest (minimum)	1	2
	highest (maximum)	9	9
	most used	5	4
Octave	average	4	4
	lowest (minimum)	1	0
	highest (maximum)	6	7
	most used	4	5
Cluster of notes	# of instances	814	1522
	max pressed‡	6	4
	most pressed§	2	1
	% most played‖	36.5%	59.5%
Transitions	% diminuendo	49.9%	51.5%
	% crescendo	48.7%	45.3%
	% same intensity	1.4%	3.2%
	% accelerando	8.9%	2.3%
	% ritardando	91.1%	97.7%
	% white to black	5.2%	1.8%
	% black to white	5.2%	1.7%
	% black to black	0.0%	96.1%
	% white to white	89.6%	0.4%
Pitch Classes	% C	12.5%	0.0%
	% C#	0.7%	13.3%
	% D	16.8%	0.0%
	% D#	0.0%	35.2%
	% E	28.4%	0.0%
	% F	7.8%	0.0%
	% F#	0.0%	20.6%
	% G	5.4%	0.0%
	% G#	3.6%	15.7%
	% A	18.8%	1.5%
	% A #	0.0%	13.7%
	% B	6.1%	0.0%
Pedal	# of presses	23 (3.9sec)	47(4.6 sec)
	% of impro time	98.5%	97.4%

† 1-*pppp* ; 2-*ppp* ; 3-*pp* ; 4-*p* ; 5-*mp* ; 6-*mf* ; 7-*f* ; 8-*ff* ; 9-*fff* ; 10-*ffff*
‡ configuration of maximum number of keys pressed ;
§ most pressed configuration ;
‖ relative playing time of the most pressed configuration ;

the human observer, nor the durations of the improvisations and pedal use. The durations almost doubled from 1.5 min to 3.6 min, whereas pedal average duration grew from 3.9 s per press to 4.6 s.

We have found empirical evidence of change. For example: *(i)* enhanced octave use, which usually indicates that the patient has the ability to use more notes to express him/herself; *(ii)* enhanced range of intensity, which indicates the ability to express more varied emotional states; *(iii)* chromatic key transitions, which indicate more opportunities to express feelings and situations (at first, patients tend to “stick” to white keys or to black keys or to avoid chromaticity); *(iv)* frequent pedal use, which enables more shades of expression and thus indicates an improvement in expressive abilities; *(v)* enhanced concurrent notes use that requires playing with more than one finger at a time, which, again, enables broader expressive possibilities.

4 Discussion

Our CP tracks, analyses and documents the precise dynamics of emergent behaviors and change, and hence may: *(i)* complement the therapist's written subjective summary, adding empirical evidence and novel insights to missed and/or unreported occurrences; *(ii)* allow improvisation and session comparison, as well as retrieval, reproduction and sharing of information to be used in communication and understanding between specialists and communities of relevant fields; *(iii)* aid in the assessing and diagnosing of the patient/client and his or her progress, as well as the therapist's professional performance. Furthermore, the method facilitates comparison between clients, therapists, and collectives, differentiated by their performances and demographics [24], pathologies, etc.

Some of the future planned developments of the CP are: *(i)* to determine which of the parameters (as in Table 1) evaluate session progress and outcome; that is, to identify 'behavioral markers', such as those depicting change; *(ii)* to correlate the therapist's verbal description of the improvisation with the parameters/quantified occurrences obtained; e.g., "more freedom, more courageous, less fixation" could be correlated with octave and intensity range, and black and white key use; *(iii)* to track bodily and auditory dynamics narrating social interaction; e.g., facial expressions, body language, and therapist intervention (which can be done by modeling the patient and therapist entities; initial Statecharts-based models can be found in [23, 24]); *(iv)* to analyze the parameters for their musical syntax; e.g., harmony and structure (as here, we account for parameters that describe musical processes taking place in therapy amongst client populations for whom music-specific exposure in not common [37, 38]).

We believe that our approach has the potential of helping make significant progress in both scientific and clinical fields employing music, such as education, social work, psychology, healthcare and recreation.

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