G-autonomy of EEG recordings of psychotic patients undergoing the primitive expression form of dance therapy

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Abstract. Primitive expression (PE) is a form of dance therapy (DT) that involves an interaction of ethologically and socially based forms which are supplied for re-enactment. Brain connectivity has been measured in electroencephalographic (EEG) data of patients with schizophrenia undergoing PE DT, using the correlation coefficient and mutual information. These parameters do not measure the existence or absence of directionality in the connectivity. The present study investigates the use of the G-autonomy measure of EEG electrode voltages of the same group of schizophrenic patients. G-autonomy is a measure of the “autonomy” of a system. It indicates the degree by which prediction of the system’s future evolution is enhanced by taking into account its own past states, in comparison to predictions based on past states of a set of external variables. In the present research, “own” past states refer to voltage values in the time series recorded at a specific electrode and “external” variables refer to the voltage values recorded at other electrodes. Indication is provided for an acute effect of early-stage PE DT expressed by the augmentation of G-autonomy in the delta rhythm and an acute effect of late-stage PE DT expressed by the reduction of G-autonomy in the theta and alpha rhythms.

1. Introduction
Dancing belongs to a time-honoured form of therapeutic experience and practice. Dance therapy (DT) is the psychotherapeutic use of movement and dance through which the individual participates creatively in a process that furthers his cognitive, emotional, physical and social integration [1,2]. In the present work a specific form of DT called Primitive Expression (PE) is investigated. In PE DT, with the use of percussion, roles are played and figures of myth are enacted providing opportunities related to expression of feelings, use of unfamiliar stances and behaviours, which might lead to therapeutic experiences [2].

DT, when applied to patients undergoing treatment is usually evaluated by assessing psychological and behavioural modifications that are potentially connected with the DT process. The scope of the studies and their assessment horizon can be expanded if the research protocol includes also neurophysiological changes. In [3] stress hormone levels were measured in fibromyalgia patients undergoing DT. In [1] hormonal and neurotransmitter levels were measured in depressed non-medicated adolescents. In [2] a PE DT-based protocol was applied to a small group of medicated psychiatric patients with psychotic, obsessive compulsive and depressive disorders. Electroencephalographic (EEG) recordings were acquired in a subset of the patients suffering from...
psychotic disorders. PE DT treatment led to quantifiable modifications in psychological state, behaviour and to brain physiology as expressed by EEG recordings. It was found that the patients experienced an increase in their happiness level and expressed a positive attitude to the PE DT process. For the group of patients that had EEG recordings, there was an increase in the alpha EEG frequency activity (8–12 Hz).

A further step in the investigation of neurophysiological parameters has been made in a recent study [4], as an expansion of the study initiated in [2]. Correlation coefficient (ρ), mutual information (MI) and a set of novel measures extracted from ρ and MI were computed from the EEG of schizophrenic patients that underwent PE DT. Those parameters were computed with the aim of providing insights about brain connectivity changes that could have resulted from the PE DT process. Indication was provided for an acute potentiation effect, at late-stage PE DT, on the inter-hemispheric connectivity in frontal areas, as well as for attenuation of the inter-hemispheric connectivity of left frontal and right central areas. In the transition from early to late-stage PE DT, indication was provided for potentiation of the intra-hemispheric connectivity of frontal and central areas, bilaterally. ρ and MI are concerned with undirected functional connectivity, while, most likely, a more in-depth understanding of neural processes might require investigation of directed functional connectivity. In the framework of linear regression modelling, directed connectivity might be investigated using the notion of Granger causality or G-causality [5,6]. Causality between two processes X1 and X2, expressed through two time series, can be substantiated, for example, if the inclusion of past observations of X2 reduces the prediction error of X1 in a linear regression model of X1 and X2, as compared to a model which includes only previous observations of X1. It might then be conjectured that X2 “causes” X1. The G-causality analytical framework can be used to measure the G-autonomy of a process [7]. In this perspective, autonomy is not thought as a simple reflection of lack of connectivity, which might have been indicated by low values of ρ and MI. Autonomy is related to the self-determination or ‘self-causation’ of the process investigated and the G-autonomy is augmented when the prediction error of X1 is reduced by including its own past observations, given a set of external variables X2 . . . Xn. In the present work, the EEGs of the same set of patients used in [4] were investigated for modifications in the level of G-autonomy of electrode recordings.

2. Materials and Methods

2.1. Subjects, EEG recordings and EEG pre-processing
The subjects’ group, the EEG recording procedure and EEG pre-processing have been described in detail in [4]. The EEG recording of 8 medicated schizophrenic patients were used. 12 PE DT sessions took place. An EEG recording session, in the awake resting state with eyes closed, with recording electrodes located at F3, F4, C3, C4, O1 and O2, lasting for about 3 min, took place before the 5th DT session (s1), after the 5th DT session (s2), as well as before (s3) and after (s4) the 11th DT session. In the following, by “session” it will be meant “EEG recording session”. For each patient and each session, an EEG data segment lasting 32 sec was selected for further analysis. If there were electrode recordings with unacceptably high level of artifacts in the duration of the selected segment, those electrodes were excluded from further analysis. The recorded data were filtered, with low-frequency and high-frequency cut-offs set at 0.4 Hz and 3.5 Hz, respectively, for the delta EEG rhythm, at 4 Hz and 7 Hz for the theta rhythm and at 8 Hz and 12 Hz for the alpha rhythm.

2.2. G-autonomy computation
The G-autonomy (ga) value for subject i (i=1,...,8), for electrode j (j=F4,C4,O2,F3,C3,O1), for session s_k (k=1,...,4) and for EEG rhythm r_m (m=D,T,A, corresponding to the delta, theta and alpha rhythm data, respectively) is denoted as ga_{i,j}^{s_k,r_m}. ga values and related parameters were computed using the “Granger causal connectivity analysis” (GCCA) freely available toolbox [8].
The time separation between EEG recording sessions \( s_2 \) and \( s_1 \) and between EEG recording sessions \( s_4 \) and \( s_3 \) was much smaller compared to the time separation between \( s_3 \) and \( s_1 \) and between \( s_4 \) and \( s_2 \). Therefore, it could be tentatively conjectured that the difference values

\[
\Delta( g_{i,j}^{s_2-s_1;\text{r}_m} ) \equiv g_{i,j}^{s_2;\text{r}_m} - g_{i,j}^{s_1;\text{r}_m} , \quad \forall \ i,j,m
\]

might reflect an “acute” effect on the G-autonomy value occurring at the (“middle-stage”) 5th DT session, and that the difference values

\[
\Delta( g_{i,j}^{s_4-s_3;\text{r}_m} ) \equiv g_{i,j}^{s_4;\text{r}_m} - g_{i,j}^{s_3;\text{r}_m} , \quad \forall \ i,j,m
\]

might reflect an “acute” effect on the G-autonomy value occurring at the (“late-stage”) 11th DT session.

For example, if a specific value of \( \Delta( g_{i,j}^{s_2-s_1;\text{r}_m} ) \) was positive, this might indicate that for that specific subject, electrode and EEG rhythm, the “autonomy” of the processes reflected in the voltage time series, as far as it might be related to G-autonomy values, increased “just” after the completion of the 5th DT session, compared to the situation “just” before the 5th DT session.

Furthermore, it could be tentatively hypothesized that the difference values

\[
\Delta( g_{i,j}^{s_2-s_1;\text{r}_m} ) \equiv g_{i,j}^{s_3;\text{r}_m} - g_{i,j}^{s_1;\text{r}_m} , \quad \forall \ i,j,m
\]

might reflect a “long-term” effect on brain connectivity, that occurred between just before the 5th and just before the 11th DT sessions. The difference values

\[
\Delta( g_{i,j}^{s_4-s_3;\text{r}_m} ) \equiv g_{i,j}^{s_4;\text{r}_m} - g_{i,j}^{s_2;\text{r}_m} , \quad \forall \ i,j,m
\]

might reflect a “long-term” effect on brain connectivity, that took place between just after the 5th and just before the 11th DT sessions, and an “acute” effect on brain connectivity resulting from the (“late-stage”) 11th DT session.

The same kind of difference values were also computed for the mean values \( g_{i,j}^{s_k;\text{r}_m} \) of sessions \( k = 1, \ldots, 4 \), of the distributions of \( g_{i,j}^{s_k;\text{r}_m} \).

3. Results and Discussion

In Table 1 the mean values \( g_{i,j}^{s_k;\text{r}_m} \), and the respective standard deviations, per EEG recording session \( k = 1, \ldots, 4 \) and rhythm (D,T,A) are given. Paired t-tests revealed that statistically significant differences existed for the differences \( \frac{g_{s_2;\text{r}_D} - g_{s_1;\text{r}_D}}{g_{s_4;\text{r}_T} - g_{s_3;\text{r}_T}} \approx 1.5 \) (p<0.001), \( \frac{g_{s_4;\text{r}_A} - g_{s_3;\text{r}_A}}{g_{s_4;\text{r}_T} - g_{s_3;\text{r}_T}} \approx 1.4 \) (p<0.001), \( g_{s_4;\text{r}_A} - g_{s_3;\text{r}_A} \approx 1.8 \) (p<0.001) and \( \frac{g_{s_4;\text{r}_D} - g_{s_3;\text{r}_D}}{g_{s_4;\text{r}_T} - g_{s_3;\text{r}_T}} \approx 1.2 \) (p=0.002). When the autonomy values per separate electrode recordings were investigated, no statistically significant differentiations emerged between sessions or between electrodes, per rhythm.

According to the rationale exposed in the previous section, it can be conjectured that indications are provided for an acute effect of early-stage PE DT expressed by the augmentation of G-autonomy in the delta rhythm, an acute effect of late-stage PE DT expressed by the reduction of G-autonomy in the theta and alpha rhythms and a long-term effect of PE DT expressed by the augmentation of G-autonomy in the delta rhythm that occurred just before the 5th and just before the 11th DT sessions.
Table 1. Mean values and standard deviation (s.d.) of $g_a$ for the various EEG rhythms and EEG recording sessions ($s_1$ to $s_4$). Asterisks denote the existence of statistically significant differences between the mean values having the same number of asterisks.

|        | Delta rhythm | Theta rhythm | Alpha rhythm |
|--------|--------------|--------------|--------------|
|        | mean | s.d. | mean | s.d. | mean | s.d. |
| $s_1$  | 25.8* | 1.7  | 26.0 | 1.0  | 25.9 | 1.1  |
| $s_2$  | 27.3* | 1.2  | 26.2 | 1.0  | 25.8 | 1.3  |
| $s_3$  | 27.0  | 0.9  | 25.8**| 0.7  | 25.9***| 0.6 |
| $s_4$  | 25.8  | 3.6  | 24.4**| 1.5  | 24.1***| 1.7 |

The above results should be examined in conjunction with the results that were presented in [4], although attention should be placed on the fact that in the present study the “autonomy” of the processes, probably reflected by the voltage recordings at each electrode, is measured in connection to all other available electrodes concurrently, making direct comparisons with electrode pair and regional connectivity indications not possible.

The present study has limitations concerning the relatively few electrodes used, the small number of subjects, and the lack of a control cohort [4]. Unless these limitations are addressed, any modifications in the EEG-derived measures cannot be solely attributed to the DT protocol used in the present study.

4. Conclusion
The present work enriches the set of EEG-based measures used for quantifying effects of DT, by examining the G-autonomy measure. Both acute and long-term effects of DT could tentatively be indicated, concerning modifications of the autonomy level of the brain processes that are responsible for producing the recorded scalp EEGs.

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