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# THE ROLE OF SELF-INJURY IN THE ORGANIZATION OF BEHAVIOUR

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## Abstract

**Background—**Self-injuring acts are among the most dramatic behaviours exhibited by human beings. There is no known single cause and there is no universally agreed upon treatment. Sophisticated sequential and temporal analysis of behaviour has provided alternative descriptions of self-injury that provide new insights into its initiation and maintenance.

**Method—**Forty hours of observations for each of 32 participants were collected in a contiguous two-week period. Twenty categories of behavioural and environmental events were recorded electronically that captured the precise time each observation occurred. Temporal behavioural/environmental patterns associated with self-injurious events were revealed with a method (t-patterns; THEME) for detecting non-linear, real-time patterns.

**Results—**Results indicated that acts of self-injury contributed both to more patterns and to more complex patterns. Moreover, self-injury left its imprint on the organization of behaviour even when counts of self-injury were expelled from the continuous record.

**Conclusions—**Behaviour of participants was organized in a more diverse array of patterns with SIB was present. Self-injuring acts may function as singular points, increasing coherence within self-organizing patterns of behaviour.

### Keywords

Self-injurious behaviour; Non-linear analysis; Temporal pattern analysis; autism

## INTRODUCTION

Intentional acts of harm to self are mysterious behaviours exhibited by many species. In humans, self injurious behaviours (SIBs) are associated with numerous clinical manifestations, including genetic syndromes, chronic pain, psychological, personality and developmental disorders including autism (Sandman, 2009a). Individuals expressing SIB employ an assortment of methods of self-harm that include cutting, hitting or biting themselves, ingesting foreign objects, hurling themselves to the ground and banging their head against solid objects resulting in broken bones, disfigurement, blindness and even loss of life (Claes & Vandereycken, 2007; Sandman, et al., 1993; Sandman & Touchette, 2001; Thompson, Hackenberg, Cerutti, Baker, & Axtell, 1994). This broad spectrum of self-harm phenotypes, the range of methods used to commit these acts and the various motives proposed to explain them has militated against a unifying mechanism and against the development of a universally effective intervention.

Nevertheless, there are two dominant views about the mechanisms motivating this bizarre behaviour. The behavioural view is that SIB is a response to environmental or social stressors. This view asserts that individuals intentionally injure themselves to receive attention, alleviate anxiety (Nixon Cloutier, & Aggarwal, 2002 or to escape demands (Durand & Carr, 1987). Behavioural interventions are based on this belief and there is evidence that these strategies can be effective in some cases and some contexts (Hanley, Iwata, & McCord, 2003; Iwata, Roscoe, Zarcone, & Richman, 2002). A second view is that SIB is motivated by an underlying biological disturbance either in the pain and pleasure system (Bohus, et al., 2000; Sandman & Touchette, 2001; Sandman, Touchette, Lenjavi, Marion, & Chicz-DeMet, 2003) or in the dissipation or generation of arousal (Nixon, et al, 2002). Treatments that block pleasure, decrease pain thresholds, diminish aggression or reduce arousal are effective in some cases for various periods of time (Sandman, 2009b; Symons, Thompson, & Rodriguez, 2004). There are other plausible reasons that individuals self-injure, including attempts to mitigate chronic pain (Theodoulou, Harriss, Hawton, & Bass, 2005), self-punishment for guilt or shame (Klonsky, 2007), or because it is a vital component of a stereotypic ritual or a compulsive act (King, 1993).

The use of increasingly sophisticated sequential and temporal analysis of *in vivo* observations of behaviour provided alternative descriptions of SIB that may be important for understanding its initiation and maintenance (Emerson, et al., 1996; Hall, Oliver, & Murphy, 2001; Sackett, 1979; Symons, et al., 2001). We reported unique sequential dependencies among behavioural and environmental events in individuals exhibiting SIB (Kroeker, Touchette, Engleman, & Sandman, 2004; Marion, Touchette, & Sandman, 2003) and concluded that self-injury in a large majority of participants was predicted only by its own recent history and not by social or environmental contingencies. Similarly, findings in 2 to 4 year-old children who were observed over two years indicated that for eleven of twelve participants, SIB was not maintained by environmental or social consequences (Richman, Lindauer, & MacLean Jr., 2005). These findings suggested that SIB was a self-sustaining contagious act or collection of acts that may serve some role in the organization or disorganization of behaviour.

Our previous studies (Kroeker, et al., 2004; Marion, et al., 2003; Sandman, Touchette, Marion, & Chicz-DeMet, 2008) and conclusions about this bizarre behaviour were limited by the assumptions inherent in the types of lag sequential analysis applied, that is, either the real-time relations among behaviours were specified a priori, or ordinal time (event counts, event-time) was used instead of real-time when considering distances between events. The consequence of these limitations or assumptions was that behavioural patterns were dismissed if either, (i) events did not immediately follow each other in sequential patterns or, (ii) if the order of the events was indifferent as long as they shared some arbitrary but specified temporal order. The separation of temporal from contiguous events and the analysis of person-environment patterns of behaviour required a fundamentally different method of analysis.

Non-linear temporal behavioural patterns related to self-injurious events were examined with a method for detecting a particular but very broad class of complex real-time patterns, called t-patterns. T-patterns often are hidden to the observer and traditional multivariate and sequential analytical methods are generally inadequate for their detection. The t-pattern type definition along with the specially developed detection algorithms have been described elsewhere (Magnusson, 1996, 2000) and have been applied in a number of studies of phenomena ranging from neuronal interactions to human interactions (Anolli, Duncan, Magnusson, & Riva, 2005; Cassarrubea, Sorbera, Magnusson, & Cresciminno, 2010). In essence, t-patterns are defined in terms of the recurrence of sets of event-types characterized by a fixed order (and/or concurrence) of the elements with significantly invariant distances between them, defined in terms of a critical interval relationship (Magnusson, 2000). The purpose of the current investigation was to determine if SIB was nested in complex behavioural networks and to determine the influence of its occurrence on the organization of behavioural-environmental interactions.

# METHODS

## Participants

Participants were residents of a 900-bed residential facility for individuals with a wide range of neurodevelopmental disabilities. Study candidates were referred by primary care or residential staff because they exhibited self-injury. Selection of the final participants (18 male, 14 female; mean age = 40±13 years) was based upon a thorough review of records by the research staff of charted behavioural counts over a six month period to ensure that all participants currently were exhibiting self-injury. The method of participant consent/assent and the protocol were reviewed and approved by ethics oversight committees of the University of California, Irvine (UCI Institutional Review Board) and the State of California (Committee for the Protection of Human Participants). All participants were over 16 years of age, and did not have a diagnosed medical condition that could have been responsible for their maladaptive behaviour (e.g. diabetes, hypertension, neuroendocrine disorders, sensory loss, etc). The prevalence of DSM-IV Axis I disorders was: Autistic Disorder, 21%; Mood Disorders, 15%; Stereotypic Movement Disorder, 12%; Impulse-Control Disorder, 12%; PICA, 9%; Pervasive Developmental Disorder NOS, 9%; Psychotic Disorder NOS, 6%; and Anxiety Disorders, 3%. The distribution of Axis II disorders was: Profound Mental Retardation, 70%; Severe Mental Retardation, 18%; and Mild Mental Retardation, 12%. All individuals previously had been exposed to repeated behavioural and pharmacological interventions with either limited or no success.

## Procedures

Individual participants were observed by research staff throughout their regular daily routines, in situ, with minimal intrusion. Forty hours of direct observations were collected in two, two and half hour sessions each day [9:30 AM to 12:00 PM, and 1:00 PM to 3:30 PM] for each participant in a contiguous two week period. Twenty broad and atheoretical categories of behavioural and environmental events were recorded with a palm-top computer-assisted observational system (The Observer® Noldus Information Technology) that captured the precise time each observation occurred as described in detail previously (Sandman, Touchette, Ly, Marion, & Bruinsma, 2000). As described elsewhere (Marion, et al., 2003; Sandman, Touchette, Marion, Lenjavi, & Chicz-Demet, 2002), staff interactions, peer interactions, stereotypies, staff proximity, agitation and restraint were clearly defined and recorded as discrete events. Self-injury consisted of the following phenotypes: hits self with open hand or fist (57% ±37 of the total number of SIB events), bangs head with or against an object (18% ±29), bites self (8% ±21), any other self-inflicted harmful behaviour (e.g., picking lesions; 17% ±30).

## Interobserver Agreement

Research staff was trained to observe behaviour and utilize the software and hardware by viewing video samples of behaviour until they achieved 100% agreement with a master observer. Training continued in vivo until the accuracy of their data recording achieved an acceptable (above 85%) level of agreement with expert observers. Inter-observer reliability during data collection was established by comparing records of two observers simultaneously but independently recording the behaviour of individuals during 117, 20-minute sessions. Pearson product-moment correlations between observer records were highly statistically significant for all categories of recorded events (r’s from .83 to .97).

## THEME Procedures (t-patterns)

T-patterns are defined in terms of the *detection* of recurrent sets of event-types characterized by a fixed order (and/or concurrence) of the elements with significantly invariant distances between them defined as a *critical interval relationship* (Magnusson, 2000).

A t-pattern Q of length m that occurs n times may thus be noted as

$$Q = X_{i1}\, dt_{i1}\, X_{i2}\, dt_{i2} \ldots X_{ij}\, dt_{ij}\, X_{i(j+1)} \ldots X_{i(m-1)}\, dt_{i(m-1)}\, X_{im}$$

Where the $X_{ij}$ terms represent the m elements (event-types) of the pattern and the $dt_{ij}$ terms represent the distance from element $X_{ij}$ to element $X_{i(j+1)}$ at the i'th occurrence of the pattern. The range of values (a critical interval, $[d_1, d_2]_j$) of each of the distance terms $dt_{ij}$ i=1, 2, ..n is smaller than expected assuming the null hypothesis that all the elements (event-types), X, are independently and randomly distributed over the observation period of length = T with a fixed probability per basic discrete time unit given by $N_X/T$. The parameter m is also called the length of the pattern.

Replacing the dt terms with their variation intervals (the *detected* critical intervals), Q can be written as:

$$Q = X_1\, [d_1, d_2]_1\, X_2\, [d_1, d_2]_2 \ldots X_j\, [d_1, d_2]_j\, X_{(j+1)} \ldots X_{(m-1)}\, [d_1, d_2]_{(m-1)}\, X_m$$

Where the values for $d_1$ and $d_2$ in $[d_1, d_2]_j$ may be very different for different values of j and the general term $X_j\, [d_1, d_2]_j\, X_{(j+1)}$ means that during occurrences of the pattern, its j'th element occurring at t, is followed by the next, within the interval $[t + d_1, t + d_2]_j$.

T-patterns are binary hierarchical trees of *detected* critical interval relationships between components and thus often represent complex conditional (multi-ordinal) relationships among their parts. The same underlying t-pattern, Q, of length 5 could be detected as a t-pattern of simpler t-patterns in various ways, for example, (((A B) (C D)) E) or (((A B) C) (D E)). Each of the sub-patterns may occur in various numbers independently of occurrences of Q. Note also that the event-types in the pattern may involve different behaviours and events. To detect t-patterns we used the specially developed software THEME version 5 (see Magnusson, 1996, 2000; www.patternvision.com; www.noldus.com). The main algorithm detects critical interval relations using a special algorithm and gradually detects patterns bottom-up, that is, by first detecting the simpler patterns and then the more complex patterns always on the basis of detection of critical interval relations between their occurrences. All but the simplest (first level) t-patterns are composed of two kinds of components: event-types and t-patterns. To avoid redundant detection of the same underlying patterns an evolution algorithm is used retaining only the most complete versions of patterns by eliminating redundant and partial detections. Thus, when the occurrences of a new pattern refer to the same instances of the implicated event-types as an earlier detected pattern the new one is discarded. A particular strength of this algorithm is that it is undisturbed by other behaviours occurring between the terms of a t-pattern. In technical terms, the procedure is robust to departures from stationarity (i.e., shifts to the underlying probability structure generating sequential events) and $N - 1$ serial dependence (e.g., compared to Markov Chains), and it is better equipped than other symbolic dynamics procedures to handle various types and sources of error (e.g., Orbital Decomposition; c.f., Guastello, 2010).

The criteria for a pattern in the behavioural records of individual participants were: (i) a pattern *must have occurred a minimum of three times within the session* (2 ½ hours) (ii) *the probability that a given pattern would occur under the null hypothesis was < .001* assuming a random Poisson distribution of the data and (iii) the transitional probability had to achieve 99% for two components to be lumped into a larger pattern while excluding the two components from the pattern search (i.e., if component A follows component B at least 99% of the time within the critical interval, then pattern AB is retained while components A and B are removed from the analysis). The behavioural record for each participant was sorted into sessions with and without SIB.

Initially the number of different patterns, the total number of their occurrences, pattern lengths (m) and pattern levels (number of hierarchical levels in the binary pattern tree) for each individual were compared during sessions with and without SIB. This within participant approach allows testing of the influence of SIB on behavioural/environmental patterns with each participant as its own control. Next, to determine the “fingerprint” of SIB on the number and complexity of patterns, an analysis was performed on sessions during which participants exhibited SIB, after removing all SIB occurrences from the data to avoid the obvious bias in pattern number and complexity because an extra class of behaviour may result in greater opportunity to detect patterns. Thus the influence of SIB on patterns (with SIB removed) was compared with patterns during sessions without SIB. Finally, because there were sessions without any patterns (~10%) and others with as many as 40 patterns (~10%), we tested the probability that these two outcomes were equally distributed during SIB and non-SIB sessions.

Two examples of patterns are presented in Figures 1 and 2. The temporal pattern in Figure 1 is initiated by self-injury (bite) and has eight elements or events (pattern length) that reflect both patient behaviour and staff interactions. This complex pattern has four hierarchical levels (smaller patterns connected to form larger patterns). In this pattern, self injury initiates a long constellation of events that are ultimately linked to the patient receiving attention. The frequency and temporal ordering of the events evolving into patterns is illustrated in the right panel of Figure 1. There are frequent bouts of stereotypy and of staff being close and making demands. The entire complex pattern is not apparent until halfway through the observation and then it occurs again two times about three-quarters of the way through the observation.

Figure 2 is presented to illustrate that self-injury may be nested within a larger pattern. In this case a staff member is close and makes a demand. The patient exhibits self-injury as the staff retreats. This subpattern precipitates a cycle of agitation. It is clear in this example that the smaller pattern of demand/self injury is most prevalent but ultimately links up with the larger constellation of events.

## RESULTS

### T-Patterns when SIB was included

Sessions that included SIB as a behavioural class produced significantly more distinct temporal patterns ($t_{31}$=2.33, p<.03; Figure 3A), more temporal pattern occurrences ($t_{31}$=2.14, p<.04; Figure 3B), longer patterns ($t_{31}$=2.19, p<.04; Figure 3C), and more complex patterns ($t_{31}$=2.37, p<.03; Figure 3D) compared with sessions in the same participants without SIB. This result may be expected because there are significantly more recorded observations ($t_{31}$=4.19, p<.001) during sessions when SIB was included. After controlling for “opportunity,” (dividing by total data points) both pattern complexity and level remained significant. This finding supported the conclusion that the inclusion of SIB in the behavioural record contributed both to the two pattern complexity measures, length and hierarchical levels, even after opportunity was controlled.

### T-Patterns when SIB was excluded

In this analysis, we determined if sessions during which individuals exhibited SIB generated different t-patterns than sessions without SIB. However, in contrast to the previous analysis, we removed SIB from the data record as another control for “opportunity.” Once again, sessions that included SIB (despite removing all SIB codes) produced significantly more distinct temporal patterns ($t_{31}=1.99$, $p<.05$; Figure 4A), more temporal pattern occurrences ($t_{31}=2.37$, $p<.03$; Figure 4B), longer patterns ($t_{31}=1.99$, $p<.05$; Figure 4C), and more complex patterns ($t_{31}=2.08$, $p<.05$; Figure 4D) compared with sessions in the same participants without any recorded SIB. After controlling for the number of data points, pattern length ($t_{31}=2.08$, $p<.05$; Figure 4C) and complexity ($t_{31}=1.99$, $p<.05$; 4D), remained significantly longer and greater respectively in the SIB sessions. These findings indicate that even when SIB events are excluded from the analysis, a significant influence of SIB remains on the organization of temporal patterns.

### T-Patterns when SIB and staff behaviour were excluded

Staff interactions, including proximity, making demands, etc, contributed to the t-patterns, but it is possible that these classes of events are not causally linked to the participants’ behaviour and therefore may contribute irrelevant variance to the outcome. A third analysis was conducted that removed both SIB and staff codes from the data record. Again, the findings were identical to those identified in the previous analyses. Specifically, sessions that included SIB (despite removing all SIB and staff codes) produced significantly more distinct temporal patterns ($t_{31}=2.02$, $p<.05$; Figure 5A), more temporal pattern occurrences ($t_{31}=2.80$, $p<.01$; Figure 5B), longer patterns ($t_{31}=2.07$, $p<.05$; Figure 5C), and more complex patterns ($t_{31}=2.85$, $p<.01$; Figure 5D) compared with sessions in the same participants without any recorded SIB. Both pattern level ($t_{31}=2.78$, $p< .01$; Figure 5C) and complexity ($t_{31}= 2.24$, $p< .03$; Figure 5D) remained longer and greater during the SIB sessions. In addition, pattern occurrences were significantly greater during SIB sessions after controlling for opportunity ($t_{31}=2.17$, $p<.03$; Figure 5B). The influence of self-inflicted pain on the organization of patterns remained after the contributions to the patterns by SIB and staff were eliminated.

### Comparison of extreme sessions

In the 506, two and a half hour sessions containing all of the data, there were 34 sessions during which no patterns were detected. These sessions were compared with a group of sessions (N=37) in which there were more than 40 patterns displayed. Of the 34 sessions without detectable patterns, only 7 were during sessions when SIB was exhibited ($X^2_{df=1}= 11.77$, $p< .001$). Conversely, of the 37 high pattern sessions, 29 were during sessions when self-injury was expressed ($X^2_{df=1} = 11.92$, $p<.001$).

## DISCUSSION

Previous attempts from our laboratory with lag sequential analysis and conditional probabilities, have failed to discover behavioural and environmental antecedents for SIB. Instead, we described a unique structure of SIB that was sequentially patterned as determined by real-time relations among behaviours that were specified a priori or by the order of events (Kroeker, et al., 2004; Marion, et al., 2003; Sandman, et al., 2008). The conclusion of these studies was that the single best and significant predictor of SIB in a large majority of participants was a previous self-injuring event. The current approach abandoned the limiting assumption of a linear analytical strategy and permitted an opportunity to examine a far more complex organization of behaviour (Magnusson, 1996, 2000). With this approach we discovered that there are non-linear networks emerging during sessions in which individuals exhibited self-injurious behaviours. These dynamical patterns often were unique from session to session and from participant to participant. The probability increased of observing environmental-behavioural patterns during sessions with self-injury, however, the probability was low that these patterns repeated within and between participants. These results suggest that SIB serves a general structuring function on behavioural patterns, rather than influencing the contents of any particular type of pattern. This represents an alternative to conventional approaches based on simple antecedents and consequences of this profoundly maladaptive behaviour. Instead of the traditional strategy to examine how events (environmental and behavioural) influence (or predict) target behaviour, these findings suggest that the focus should be to examine how a target behaviour (SIB) influences the emergence of more global patterns of events and behaviours over longer periods of time.

The influence of SIB was observed on the temporal organization of behaviour without the restriction of a priori limits. The behavioural episodes of SIB either initiates a cascade of consequences that may not be completed for many minutes or hours and even longer or, more often, may be nested deeply within a complex behavioural pattern. The finding that temporal patterns of behaviour are more complex and more numerous during sessions when SIB was exhibited, even when SIB counts were expelled from the record, suggests that it is not just a behaviour in response to avoidance or escape. Instead, SIB contributes to complex organized behavioural/environmental patterns that differ widely in their length and level. These possibilities may explain why SIB is notoriously difficult to modify. If the assumptions are wrong that SIB is a response to specifiable antecedents or that it is member of a linear cause and effect sequence (Kroeker, et al., 2004; Marion, et al., 2003; Sandman, et al., 2008), then interventions based on these assumptions will fail. Alternatively, if the behaviour appears to be random to observers armed only with traditional analytical tools, then effective interventions cannot be developed. The current results may pave the way for interventions that are directed at tuning the global structure of an individual's environment, rather than simply increasing or decreasing specific antecedents or consequences surrounding SIB.

The dynamical process underlying transitions between periods of relative calm and SIB may reflect a system that is in a critical state at the edge of chaos (Kitzbichler et al, 2009), or some other process of self-organization (for a review see Guastello & Liebovitch, 2009). Future research may attempt to extend the current results by investigating the specific mechanisms underlying the emergence of order that appears in the proximity of SIB (e.g., fractal patterns; Pincus, Ortega, & Metten, 2010). Regardless of the specific mechanism, transitions were observed between relatively disorganized behavioural states with few behavioural/environmental patterns to a relatively organized state characterized by significantly more patterns of greater complexity. It was surprising that the transition to an organized state was observed when SIB was exhibited because increased complexity and system integrity typically are associated with adaptive states (Pezard and Nandrino, 2001) and biopsychosocial resilience (Pincus & Metten, 2010). It is possible that the movement from behavioural calm to periods of self-inflicted injury confers an adaptive advantage or gain for the individual. Perhaps SIB produces a movement toward equilibrium that is associated with changes in arousal (Nixon et al, 2002) or in pleasure (Sandman et al, 2008). Previous findings from our studies indicated that there was a strong association between the number of behavioural patterns that included SIB and the plasma levels of POMC peptides (B-endorphin and ACTH) associated with stress, pleasure and pain (Kemp et al, 2008).

Exactly how or why the transitions to self-organization occur when participants self-injure is unknown, but it does suggest that SIB is acting as a driver or singular point within a highly interactive and complex biopsychosocial system. Such systems tend to naturally and spontaneously "self-organize" (Guastello & Liebovitch; 2009; van Geert, 2009)) into highly structured patterns, often invisible to even trained observers, as we described here for the various patterns of temporal relations among events.

In summary, these findings indicate (i) that the behaviour of the participants observed is organized in a more diverse array of patterns when SIB is present, (ii) that these patterns are more "complex" with regard to the number of events they encompass and the hierarchical levels of association among them, and (iii) that these patterns are primarily related to increased rates of non-injurious behaviours such as peer interaction, agitation, and stereotypy. Self-injury may function as a singularity around which a complex configuration of behavioural patterns becomes organized. It is possible that the temporal patterning of behaviours associated with SIB reflects the dynamical influence of an internal regulatory mechanism that drives the surrounding environment toward greater behavioural coherence and complex structural integrity.

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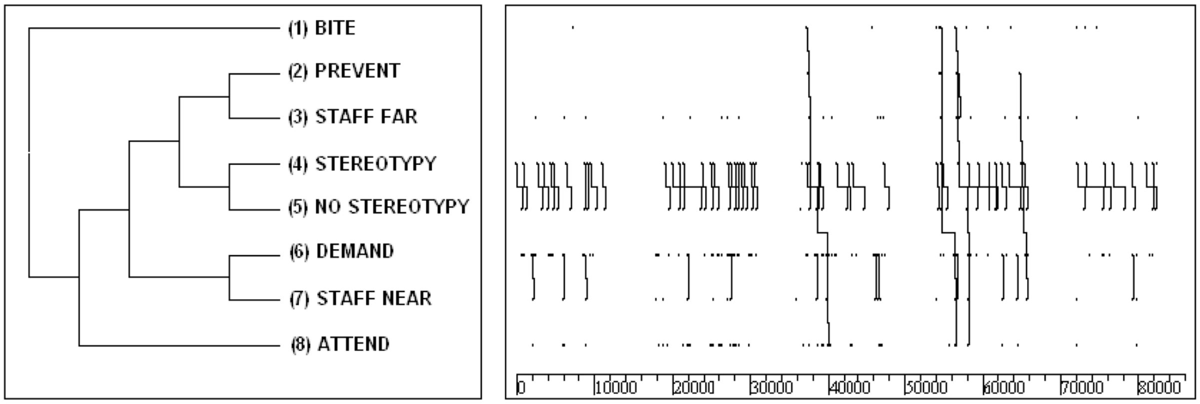

**Figure 1.**

A representative temporal pattern (T-pattern) of related events. Such T-patterns are only detected if they occur repeatedly within the same observational record with approximately the same temporal distribution among the constituent events and have a relatively low probability of occurring in a random distribution. Note that this T-pattern contains 8 constituent events (“length”) and 4 levels of hierarchical connection (“level”). Both length and level are considered measures of T-pattern complexity.

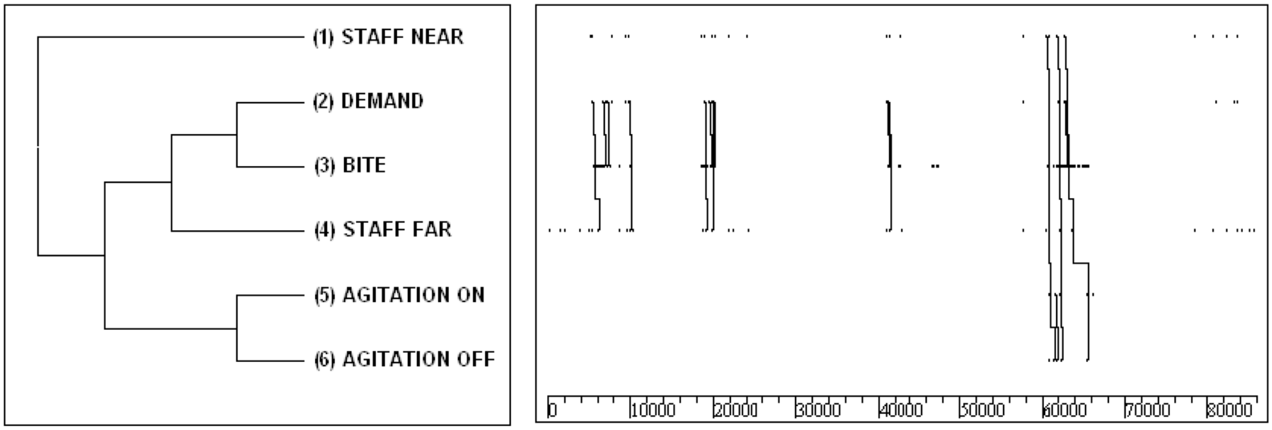

**Figure 2.**
A representative temporal pattern (T-pattern) of related events. Note that this T-pattern contains 6 constituent events (“length”) and 3 levels of hierarchical connection (“level”). Both length and level are considered measures of T-pattern complexity.

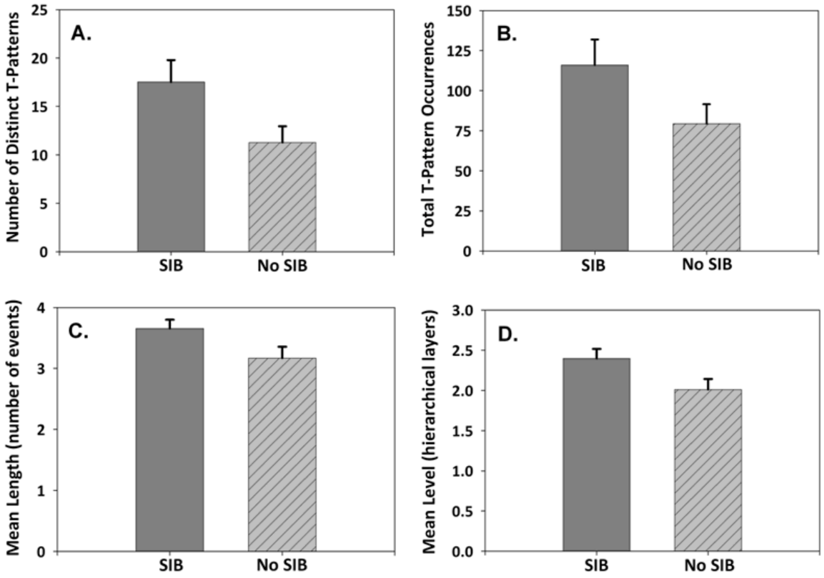

**Figure 3.**

Quantitative results of the temporal pattern (T-pattern) analyses on files with and without an observed episode of SIB. Panel A shows the mean number of distinct T-patterns detected, panel B shows the mean number of T-pattern occurrences, panel C shows the mean length (number of events comprising the T-patterns), and panel D shows the mean level (number of hierarchical levels of connectivity).

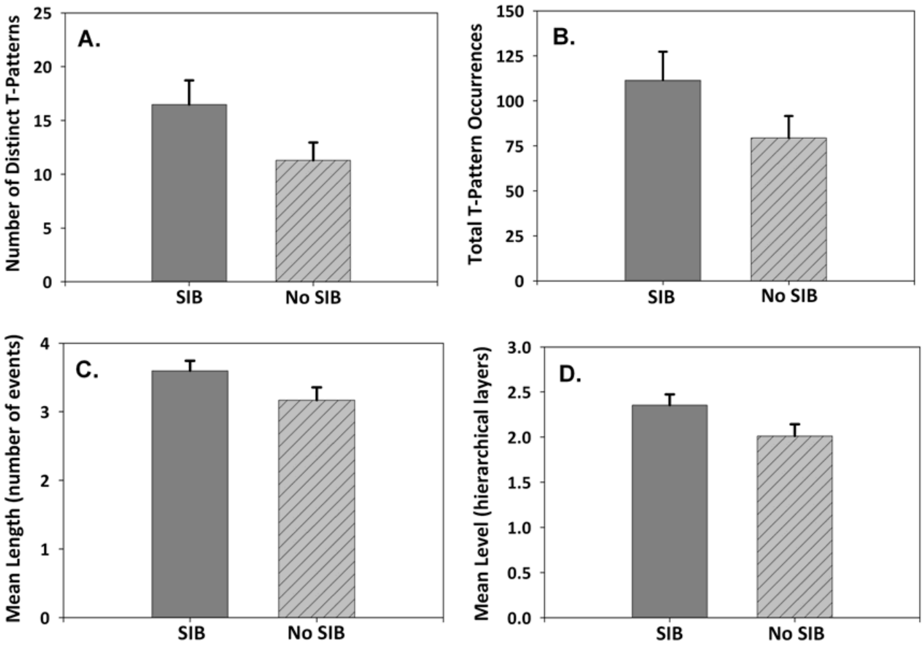

**Figure 4.**

Quantitative results of the temporal pattern analyses on files with and without an observed episode of SIB, after excluding all SIB event codes. Panel A shows the mean number of distinct T-patterns detected, panel B shows the mean number of T-pattern occurrences, panel C shows the mean length (number of events comprising the T-patterns), and panel D shows the mean level (number of hierarchical levels of connectivity).

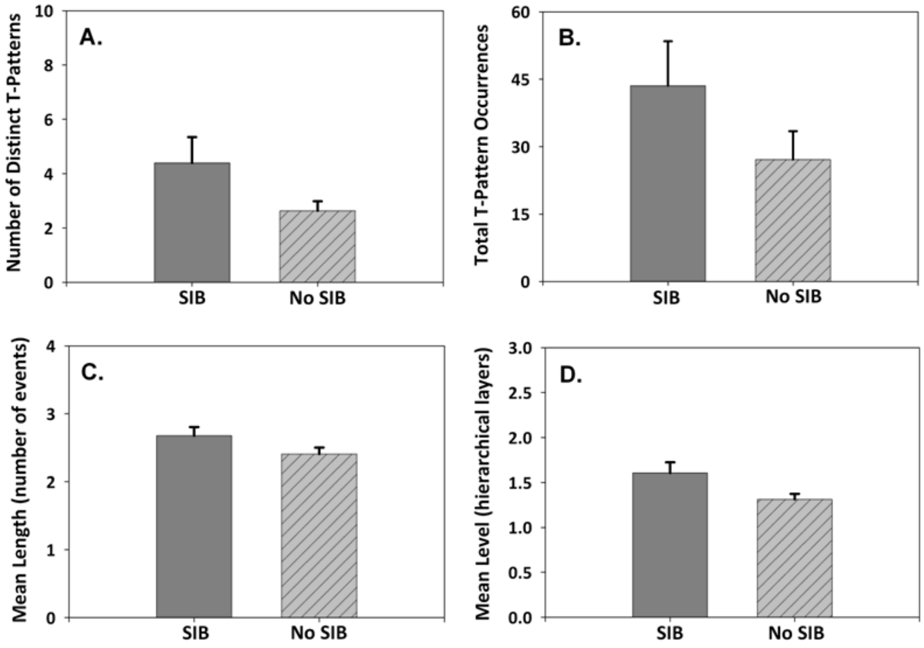

**Figure 5.**

Quantitative results of the temporal pattern analyses on files with and without an observed episode of SIB, after excluding all SIB and Staff event codes. Panel A shows the mean number of distinct T-patterns detected, panel B shows the mean number of T-pattern occurrences, panel C shows the mean length (number of events comprising the T-patterns), and panel D shows the mean level (number of hierarchical levels of connectivity).