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Detection of temporal patterns in dog–human interaction

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Abstract

A new time structure model and pattern detection procedures developed by (Magnusson, M.S., 1996. Hidden real-time patterns in intra- and inter-individual behaviour description and detection. Eur. J. Psychol. Assess. 12, 112–123; Magnusson, M.S., 2000. Discovering hidden time patterns in behaviour: T-patterns and their detection. Behav. Res. Methods, Instrum. Comput. 32, 93–110) enables us to detect complex temporal patterns in behaviour. This method has been used successfully in studying human and neuronal interactions (Anolli, L., Duncan, S. Magnusson, M.S., Riva G. (Eds.), 2005. The Hidden Structure of Interaction, IOS Press, Amsterdam). We assume that similarly to interactions between humans, cooperative and communicative interaction between dogs and humans also consist of patterns in time. We coded and analyzed a cooperative situation when the owner instructs the dog to help build a tower and complete the task. In this situation, a cooperative interaction developed spontaneously, and occurrences of hidden time patterns in behaviour can be expected. We have found such complex temporal patterns (T-patterns) in each pair during the task that cannot be detected by "standard" behaviour analysis. During cooperative interactions the dogs' and humans' behaviour becomes organized into interactive temporal patterns and that dog–human interaction is much more regular than yet has been thought. We have found that communicative behaviour units and action units can be detected in the same T-pattern during cooperative interactions. Comparing the T-patterns detected in the dog–human dyads, we have found a typical sequence emerging during the task, which was the outline of the successfully completed task. Such temporal patterns were conspicuously missing from the "randomized data" that gives additional support to the claim that interactive T-patterns do not occur by chance or arbitrarily but play a functional role during the task.

Keywords: Temporal patterns; Dog–human interaction; Cooperative interactions

1. Introduction

It has been often claimed that the ability to understand human gestural and verbal communicative signs

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allowed humans to share their social life with the dog (Miklósi et al., 2004) In everyday life man interacts with dogs through various forms of communicative and cooperative interactions that are based on the interchange of various behavioural cues, mostly in the forms of visual (e.g. Miklósi et al., 1998, 2000; Soproni et al., 2002; McKinley and Sambrook, 2000; Virányi et al., 2004) and acoustic signals, like behavioural commands and names of objects (Warden and Warner, 1928; Young, 1991; Kaminski et al., 2004; Pongrácz et al., 2001).

The interaction between humans and their dog can occur in many contexts. Most often humans walk their dog (without a leash), dogs for the blind navigate their owner (Naderi et al., 2001), or humans of various ages can be seen to play with their pet (Millot and Filiâtre, 1986; Rooney et al., 2001). The common feature for all these interactions lies in the extended duration in time, and the continuous and uninterrupted expression of behavioural sequences, much of which occur seemingly in a response to an action, displayed by the partner. Although dog–human interaction is an important part of our life, until now, the temporal structure of this interaction has received little attention. To our knowledge only three studies investigated the temporal aspects of human–dog interactions (Millot and Filiâtre, 1986; Filiâtre et al., 1986; Millot et al., 1988; Mitchell and Thompson, 1993).

These studies have focused on the synchronisation of dog and human actions, but the time window was very short taking into account only actions that have followed directly one another. Looking at the literature this corresponds to the traditional approach of temporal analysis of behaviour based on first order contingency tables ("transition matrix"), Markov chain analysis or lag sequential analysis (Fagen and Young, 1978; Bakeman and Gottman, 1997, see also McLeod, 1996). Although all these methods have their merits but they are able to detect only some aspects of the temporal structure in behaviour.

For the analysis of complex social interactions the preferred method should be highly flexible in detecting temporal patterns. However, as mathematically possible types of temporal structure and patterns are infinite, it must focus on relevant types of such structure in behaviour and interactions. To this end, Magnusson (1996, 2000) has proposed new a time structure model called T-pattern and developed special algorithms for their detection implemented in a software package called THEME (Magnusson, 2000; Anolli et al. 2005; www.hbl.hi.is; www.patternvision.com; www.noldus.com).

Looking for temporal patterns during courtship dance in humans Grammer et al. (1998) showed that synchrony could be described as a complex T-pattern time structure detected through the use of Theme. These patterns were usually very complex and highly idiosyncratic. Similarly, analysing complex cooperative behaviour in humans (football) Borrie et al. (2001) have detected a multitude of T-patterns in interactive behaviour, and showed that teams with a more patterned play structure are also perceived as "playing better" by the coach. The application of T-pattern detection also proved to be useful in analysis of the time structure of pecking behaviour in chicks, as Martaresche et al. (2000) found that feeding is composed of both synchronised and unsynchronised acts.

We assume that cooperative interactions provide a natural context for the emergence of temporal patterns. In this exploratory study, our aim was to describe temporal pattern in the behaviour of interacting dog–human dyads observed in a cooperative task. This paper was designed to study the questions: (I) whether there are any temporal patterns in the cooperative behaviour of dog–human pairs: and if yes (II) whether communicative behaviour units and action units can be detected in the same T-pattern during cooperative interactions.

2. General method

2.1. Subjects

Seven owners (3 men and 4 women) and 10 adult pet dogs (4 males and 6 females, mean age: 3.6 ± 2.7 years; 7 Belgian Tervuerens, 2 Vizslas and 1 collie) participated in the test (Table 1).

2.2. Procedure

The test was carried out in 1997 at the owners' home in a familiar room of, approximately, $3\,m \times 4\,m$. The task was to get the building blocks from a starting point to the target point with the goal of building a tower. We used 24 plastic cubic building blocks (a children's toy)

Table 1
Summary table of dogs participating in the test

Dog				Owner's sex	Housing conditions	Time spent with the dog (no. of hours per day)	Age of the dog when acquired by the owner
Name	Age (years)	Sex	Breed				
Dicky	3.5	Male	Vizsla	Male	Flat	5	7 weeks
Atma	8	Female	Vizsla	Male	Flat	3	8 weeks
Liu	7	Female	Tervueren	Female	Flat and garden	6	7 weeks
Vuk	3	Female	Tervueren	Female	Flat and garden	6	7 weeks
Rozsdi	10	Male	Tervueren	Female	Flat and garden	6	7 weeks
Robin	1.5	Male	Collie	Male	Flat	4	8 weeks
Vau	1	Female	Tervueren	Female	Flat and garden	9	1 year
Stanley	4	Male	Tervueren	Female	Flat and garden	9	7 weeks
Füles	3.5	Female	Tervueren	Female	Flat	4	8 months
Varázs	1.5	Female	Tervueren	Female	Flat	4	8 months

in eight different sizes (length at edges was 2, 4, 6, 8, 10, 12, 14, 16 cm, respectively, and three items for each size) and of different colour. In each case the experimenter determined the starting point (the location of the building blocks on the floor) and the target point (the location for the tower to-be-built) in the room 4 m apart. The test consisted of three 5-min episodes. The behaviour of the owner and their dog was recorded on video.

In the first episode only the owner carried the building blocks from one location to the other without any help from the dog. The owner could once call the dog's attention verbally at the beginning of the episode, but after this she/he must not talk to the dog. At the end of the episode the owner took back the building blocks to the starting point.

In the second episode both the dog and the owner could carry building blocks to the target point. The owner was allowed to talk to the dog, but only the use of less familiar verbal utterances were permitted, which were not regarded as commands by the dog ('please help me' or 'come on', etc.). At the end of the episode the owner took back the building blocks to the starting point; however, 5 building blocks were left on the target point.

In the third episode the owner sat on the floor at the target point with five building blocks in front of her/him and was not allowed to leave this position. In order to build the tower she/he had to rely on the help of the dog, so she/he could instruct the dog to carry the building blocks to her/him. The owner was allowed to talk to the dog but only less familiar verbal utterances were permitted (e.g. 'please help me' or 'come on', etc.) and direct commands for retrieving were prohibited. No restrictions have been placed on gestural communication.

2.3. *Theme software*

We have coded and analyzed only the third episode of this cooperative task with the Theme software package (www.patternvision.com, www.noldus.com). The Theme software allows the analyst to detect complex repeated temporal patterns even when a multitude of unrelated events occur in between components of the patterns, which typically makes them invisible to the naked eye and (to our knowledge) to currently available statistical methods and software (for theoretical foundation and explanation of the model and method see Magnusson (1996, 2000) and www.hbl.hi.is).

The basic assumption of this methodological approach is that the temporal structure of a complex behavioural system is largely unknown, but may involve a set of particular type of repeated temporal patterns (T-patterns) composed of simpler directly distinguishable event-types, which are coded in terms of their beginning and end points (such as "dog begins walking" or "dog ends running"). The kind of behaviour record (as set of time point series or occurrence times series) that results from such coding of behaviour within a particular observation period (here called T-data) constitutes the input to the T-pattern definition and detection algorithms.

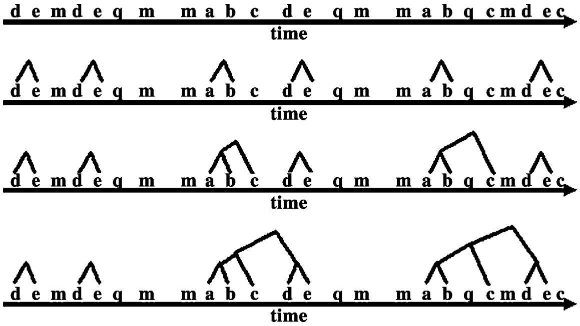

Fig. 1. Formation of a T-pattern from simple T-pattern of ab pairs to more complex T-patterns. From the behaviour sequence depicted on the top, Theme detects T-pattern from simple (like T-patterns of ab in the second row) to more complex ones, as the T-pattern on the bottom).

Essentially, within a given observation period, two actions, a and b, occurring repeatedly in that order or concurrently, are said to form a minimal T-pattern (ab) if more often than expected by chance assuming as h0 independent distributions for a and b, there is, approximately, the same time distance between them. Instances of a and b related by that approximate distance then constitute occurrence of the (ab). T-pattern and its occurrence times are added to the original data. More complex T-patterns are consequently gradually detected as patterns of simpler already detected patterns through a hierarchical bottom-up detection procedure. Pairs (patterns) of pairs may, thus, be detected, for example (((ab)c)(de)), etc. (see also Fig. 1.) Special algorithms deal with potential combinatorial explosions due to redundant and partial detection of the same patterns using an evolution algorithm (completeness competition), which compares all detected patterns and lets only the most complete patterns survive. As any basic time unit may be used, T-patterns are in principle scale-independent, while only a limited range of basic unit size is relevant in each concrete study.

2.4. Data analysis

In our samples, we have coded 38 behaviour units in dogs, and 32 gestural behaviour units and 8 verbal behaviour units in humans. The present analysis is limited to 21 behaviour units that occurred most frequently in the behaviour of the partners. Nine of the 21 behaviour units were displayed by the dogs, 8 of them can be regarded as human gestural behaviours and 4 of them were verbal utterances (Appendix A).

From the point of view of the successful fulfilment of the task, one of the most important behaviour elements is the ‘*dog picks up the building block*’.

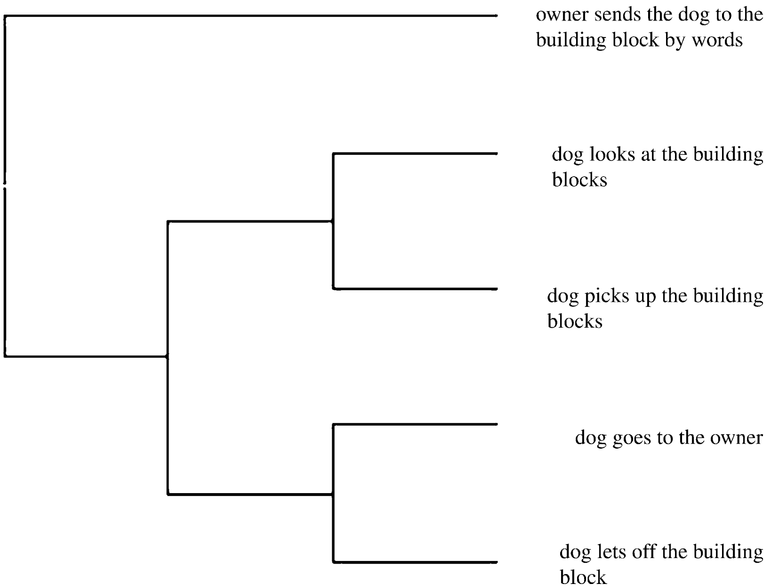

Fig. 2. A typical T-pattern found in a dog–owner pair. Time is running from top to bottom as the behavioural sequence is happening. Note that there could be any number of intervening behavioural actions between behaviour units in this T-pattern.

Therefore, we have focused our analysis on the (interactive) T-patterns involving this goal-oriented behaviour. We have searched for T-patterns that occurred so often as the dog picked up the building block during the task minus one (test for CI: $p = 0.001$) We have analyzed the characteristics of T-patterns detected by investigating their length (the number of behaviour units in the sequence), duration (the number of frames between the first and the last behaviour unit in a T-pattern), number of actors in a T-pattern and their composition of behaviour units. T-patterns containing both dog and human behaviour units are called interactive T-patterns. We have also analyzed the first and the last behaviour units of T-patterns containing '*dog picks up the building block*' unit to see if there is any behaviour unit which starts or terminates a T-pattern more frequently than others. We have also looked for common T-patterns present in all dog–owner pairs. As an example, see Fig. 2 presenting an interactive T-pattern of six behaviour units.

In order to analyze whether temporal patterns in the behaviour of dog–human dyads emerged more frequently than it was expected by chance, we have compared the frequency of occurrence of all and interactive T-patterns separately in "real data" and "randomized data" (the randomization and searching for T-patterns was made by the program in each dog–owner pairs separately using the same parameters as for the real data)

3. Results

3.1. Total number of T-patterns and number of interactive T-patterns

In our sample, we have found on average 218 T-patterns (ranged between 10 and 681) in total and 181 (ranged between 7 and 604) of them were interactive (83%). We have compared these results with the number of T-patterns found in randomized data that contained on average four T-patterns in total and three of them were interactive (75%). This difference between the "real data" and "randomized data" was significant, both when comparing all T-patterns ($t_9 = 2.914$, $p = 0.017$) and in the case of interactive T-patterns ($t_9 = 2.727$, $p = 0.023$) (Fig. 3), suggesting that T-patterns, as well as interactive T-patterns in our sample are not the results of chance effects.

3.2. Length and duration of interactive T-patterns

The length of the T-patterns in the "real data" varied from 2 to 12 behaviour units with an average of 4.9, in contrast the length of T-patterns detected in "randomized data" was 2 or 3 behaviour units with an average of 2.1. Comparison showed that there were significantly more T-patterns with 2–8 units in the real data, no such difference was found in case of longer patterns (Fig. 4). If we take to the longest T-pattern containing the '*dog*

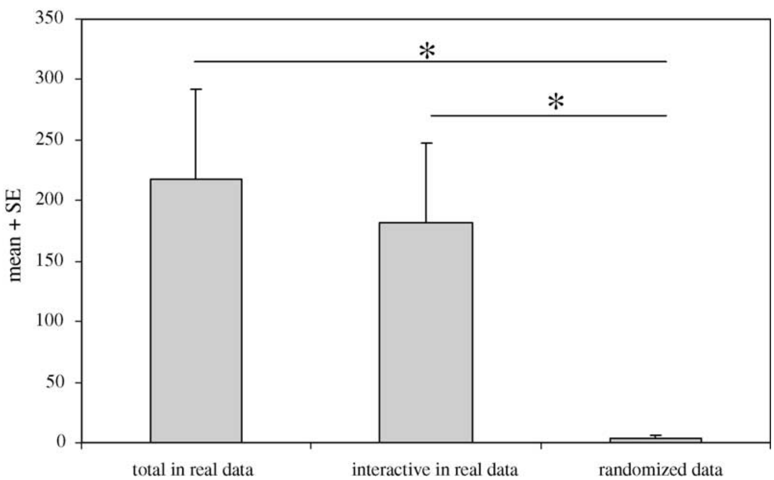

Fig. 3. Number of T-patterns in real dog–owner pairs and randomized data (due to program limitations the number of interactive T-patterns in randomized data cannot be calculated).

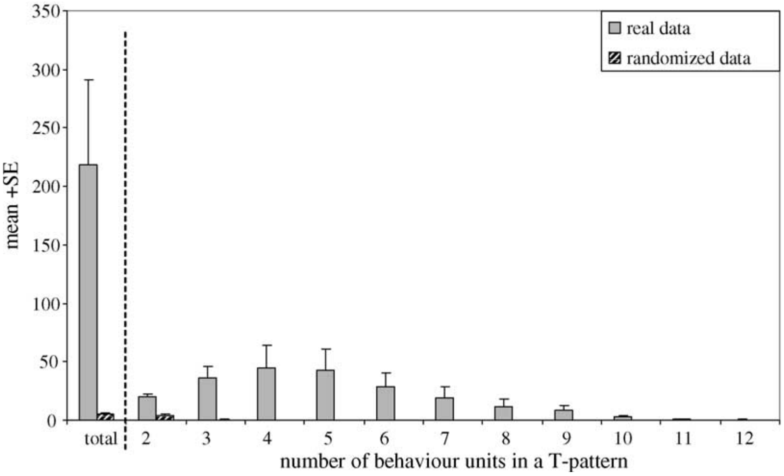

Fig. 4. Number of T-patterns in real dog–owner pairs and in randomized data.

picks up the building block' unit of each dog then we find an average duration of 8.1 s (S.E. = 1.5) compared to the longest T-pattern not containing this unit (7.4 s, S.E. = 1.4). This difference was not significant.

3.3. Common T-patterns containing the behaviour unit 'dog picks up the building block'

In the present analysis we have found on average 11.3 (ranged between 0 and 47) T-patterns that contained the behaviour unit 'dog picks up the building block'. The length of these T-patterns varied from 2 to 12 behaviour units (Fig. 5).

Interestingly, all but one occurrence of the behaviour unit '*dog picks up the building block*' was found to be part of a T-pattern (74 out of 75 in our sample of 10 dogs). In the one exceptional case the dog accidentally dropped the brick, and the second 'pickup' is not included in any T-pattern. This means that 98% of occurrences are parts of a pattern, which is more than for any other behaviour unit. Similar high levels of preference for being in pattern can be found for '*dog goes*

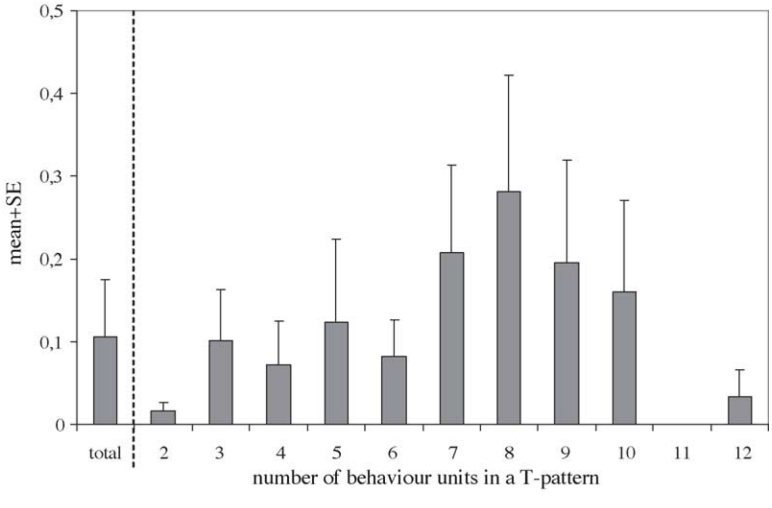

Fig. 5. Ratio of interactive T-patterns of different length containing the behaviour unit '*dog picks up the building blocks*'.

Table 2
The frequency of different behaviour units in T-patterns containing '*dog picks up the building block*' or not

Coded behaviour units	T-patterns containing '*dog picks up the building block*'	T-patterns not containing '*dog picks up the building block*'	*t*-Value (paired sample *t*-test)	df	*p*-Value
Dog looks at the owner's face	0.940	0.060	16.633	9	<0.001
Dog looks at the owner's hand	0.876	0.024	8.706	9	<0.001
Dog looks at the building blocks	0.860	0.140	6.837	9	<0.001
Dog goes towards the building blocks	0.770	0.230	2.818	9	0.020
Dog walks around in the room	0.496	0.004	2.999	9	0.015
Dog goes towards the owner	0.709	0.291	2.129	9	0.062
Owner points towards the building blocks with his/her hand	0.915	0.085	12.226	9	<0.001
Owner directs the dog to the building blocks by words	0.784	0.016	5.889	9	<0.001
Owner sends the dog to the building block by words	0.651	0.049	4.244	9	0.002
Owner looks at the building block	0.498	0.002	2.999	9	0.015
Owner looks at the dog	0.484	0.016	2.963	9	0.016
Owner pets the dog	0.345	0.055	2.206	9	0.055
Owner praises the dog	0.278	0.222	0.311	9	0.763

to human' and '*dog goes to bricks*' (96% and 91%, respectively). In the case of the human '*directing words*' can be found most frequently in T-patterns (66%) that is followed by '*pointing*' with 59%.

To see whether some behaviour units occur relatively more often in T-patterns containing the '*dog picks up the building block*' unit we have compared the frequency of occurrence in T-patterns with and without this particular unit (Table 2). Results show that not only behavioural units naturally associated with the particular action are present at a higher frequency but also communicative behaviours like '*dog looks at the owner's face*' or '*owner looks at the dog*'.

In order to trying to account for the rigidity of these T-pattern we have analyzed all sequences together and calculated how often one behaviour unit is followed by different behaviours. Raw data show that for example in the case of Dicky (Table 3) there are five different behaviour units in the T-pattern, and four of them are always followed by the same behaviour unit whilst one behaviour unit is followed by two different units at different occasions. Looking at the table as a whole

Table 3
The number of different behaviour units that can follow a unit in T-patterns with the '*dog picks up the building blocks*'

Dogs	Maximum number of units in the sequence	Always the same	Two different	Three different	Four different	Five different	Six different	Seven different
Dicky	5	4	1	0	0	0	0	0
Atma	11	1	7	3	0	0	0	0
Liu	7	3	4	0	0	0	0	0
Vuk	14	12	1	1	0	0	0	0
Rozsdi	4	3	1	0	0	0	0	0
Robin	0	0	0	0	0	0	0	0
Vau	14	8	5	1	0	0	0	0
Stanley	8	4	4	0	0	0	0	0
Füles	14	3	3	3	3	0	1	1
Varázs	9	6	3	0	0	0	0	0
Mean	8.6	4.4	2.9	0.8	0.3	0	0.1	0.1
S.E.	1.507021	1.10755	0.690411	0.38873	0.3	0	0.1	0.1

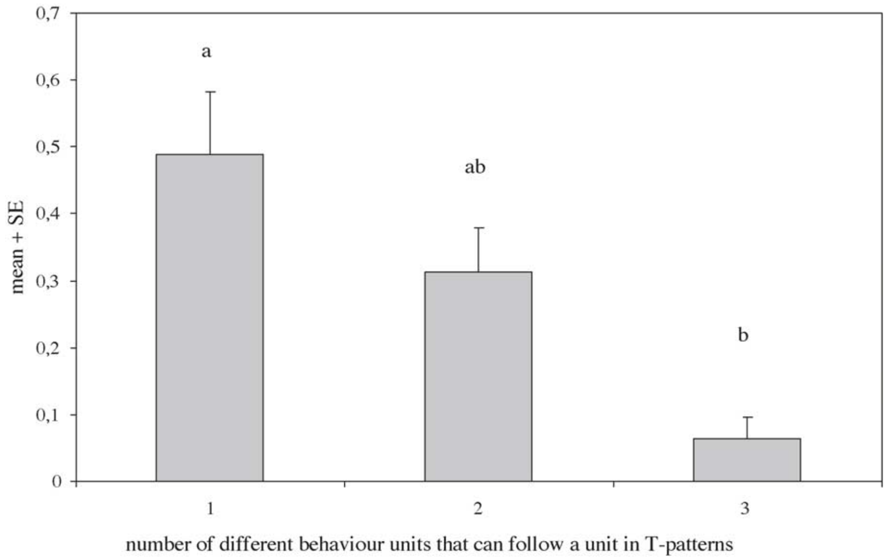

Fig. 6. The ratio of behaviour units that can be followed by a certain number of different behaviour units in T-patterns with the '*dog picks up the building blocks*'.

suggests that the T-patterns containing the '*dog picks up the building block*' unit are relatively stable within a dog, and also that they are characterized by a relatively constant sequences in most cases because any given behaviour unit is followed by the same or by two different behaviour units. This is supported by the finding that the number of units followed always by the same behaviour unit is larger than those followed by two or three different behavioural units on different occasions (Friedman ANOVA with Dunn' post-hoc test: $X_2 = 8.867$, $p = 0.012$ (Fig. 6).

In the 113 T-patterns containing the '*dog picks up the building block*' unit, we have found 26 different behaviour units of which only 11 occur as the starting unit of the pattern. In 41 of the 113 patterns the sequence starts with the '*dog looking at the building block*' unit, but, in general, neither of the 11 behavioural units start more frequently a pattern than the others (Friedman ANOVA $X_2 = 13.44$, $p = 0.055$). In similar vein, the last unit can be one of 19, and no domination of any behavioural unit was found for terminating the sequence (Friedman ANOVA $X_2 = 18.02$, $p = 0.896$). The '*dog picks up the building block*' unit can occupy starting or terminating positions in the pattern, but in most cases (48%) it was found to be in the second position (Friedman ANOVA $X_2 = 20.09$, $p = 0.005$).

Considering all T-patterns containing the '*dog picks up the building block*' unit together, we can construct a matrix that shows all possible transitions from one behaviour unit to the next. Note, however, that this is not a traditional transition matrix but one where all transitions have been previously verified statistically by THEME. If now we look for the most frequent transitions provided that the next frequent transition occurs by 25% less then we get a cycle shown on Fig. 7. The typical sequence emerging during the task was cyclic (the starting and the terminating behaviour unit was the same) and consisted of seven behaviour units. This sequence was the outline of the successfully completed task. The part of this cycle or even the whole cycle occurs in the majority of T-patterns containing the '*dog picks up the building blocks*' unit.

4. Discussion

The present analysis provides strong support for long-term temporal sequences in dog–human interaction. This is the first time that such temporal patterning has been shown by statistical methods, on the basis of analyzing sequential data of continuous behavioural interaction in dogs and humans. Although

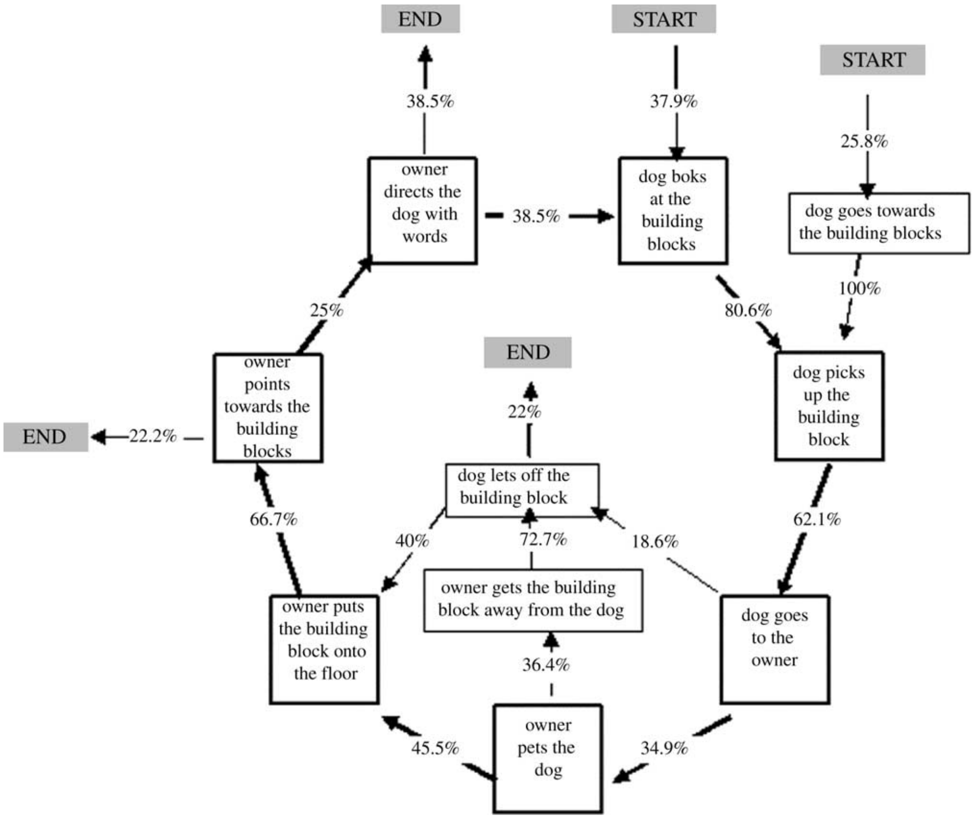

Fig. 7. The common form of T-pattern shown in cyclic form.

one can assume that cooperation or communication requires some regularity in behaviour of the partners, this notion has been often taken for granted without experimental or statistical verification. The present analysis has shown that during cooperative interactions there is a mutual dependency in dogs and humans, that is, their behaviour becomes organized into highly complex interactive temporal patterns. Such temporal patterns were conspicuously missing from recordings in which the two partners' behavioural data were randomized for comparative analysis. This gives additional support to the claim that interactive T-patterns do not occur by chance or arbitrarily, but play a functional role during the task.

This analysis suggests that in the course of the present cooperative task many task-related actions enacted by the partners became spontaneously organized into T-pattern. The repetition of the same sequence similar to the one shown in Fig. 7 allows the behaviour units to organize into a pattern that occurs every time when the dog picks up a building block. By its very nature the detected T-pattern does not only represent a sequential organisation but a temporal relationship among these units that is also relatively constant and gives a typical behavioural rhythm to the pattern. It is interesting to see how communicative units of behaviour get interrelated with behaviours of action in the sequence. This suggests that there is a two-way communication going on between the dog and the owner, and this exchange lasts over a series of action. This marked tendency for joint coordination between dog and owner suggest that the formation of T-pattern contributes to the successful completion of the task. The result that every occurrence of the '*dog picks up the building block*' unit is a part of a T-pattern also supports this hypothesis.

These findings also offer the possibility to ask whether such coordination is natural to cooperative interactions in either animals or humans. Based on human data collected in different context (e.g. courtship dance, Grammer et al. (1998)) we assume that humans show similar features when cooperating. In the case of animals this situation is less clear. By looking at the behaviour of dog–owner dyads during leading the blind we have found similarly strong tendency for behavioural coordination by using a different method of analysis (Naderi et al., 2001). It was our impression that blind leading would be impossible in practice if dogs and humans were not sensitive to each other actions and would not be able to interchange the initialisation of the actions that results in certain levels of behavioural coordination.

Interestingly this ability did not depend on the training of the dogs since most animals were able to interact with their owners in a similar way. On this basis one can suppose that dogs have a natural tendency to organize their behaviour in a way that is compatible with the behaviour of their human partners. It remains to be seen whether other animals (socialized similarly with humans) are able to display such level of coordination.

It is very likely that such connection over a long period of time could have not been detected by traditional methods of sequential analysis, where one is only looking for first order relationship between behaviour units. Therefore, our results show a clear advantage of using THEME in the analysis of the hidden behavioural structure of cooperative and communicative interactions.

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Appendix A. Behaviour units analyzed in during the cooperative interaction between owner and dog.

Dog's behaviour units
- dog goes towards the building blocks
- dog goes towards the owner
- dog lets off the building block
- dog looks at the building blocks
- dog looks at the owner's face
- dog looks at the owner's hand
- dog looks out of the camera's sight
- dog picks up the building blocks
- dog smells the building block
- dog walks around in the room, and does not go towards the building blocks or the owner

Human's gestural behaviour units
- owner builds the tower
- owner calls the dog using a gestural signal
- owner gets the building block away from the dog
- owner holds a building block in his/her hand and shows it to the dog
- owner looks at the building block
- owner looks at the dog
- owner pets the dog
- owner points towards the building blocks with his/her hand
- owner puts the building block onto the floor

Human's verbal behaviour units
- owner calls the dog by its name
- owner directs the dog to the building blocks by words
- owner praises the dog
- owner sends the dog to the building block by words

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