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Hierarchical Organization of Segmentation in Non-Functional Action Sequences

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Abstract

Both folk and scientific taxonomies of behavior distinguish between instrumental and ritual behavior. Recent studies indicate that behaviors dominated by ritual features tend to increase cognitive load by focusing attentional and working memory resources on low-level perceptual details and psycho-physics. In contrast to the general consensus on ritual in anthropology and the study of religion, one study did not find any modulation effect of expectations (e.g., cultural information or priors) on cognitive load. It has, therefore, been suggested that the increase reflects a perceptual mechanism that drives categorization of ritual behavior. The present study investigated how an increase in cognitive load elicited by ritual behavior can influence hierarchically-related representations of actions and if expectation can modulate such hierarchical action representations. The study found that hierarchical alignment during segmentation of actions with ritual features was reduced in comparison to instrumental actions but that expectations only vaguely modulate this reduction. It is argued that these results lend support to the resource depletion model ritual behavior.

Keywords
ritual behavior, action perception, hierarchical alignment,
expectation modulation, resource depletion

Introduction

In the context of religious belief and practice, there is one type of action that is both frequently encountered and of central importance to religious practitioners, as well as scholars of religion, namely, ritual action. Although ritual studies offers numerous and diverse theoretical models of ritual action, for instance symbolic (e.g., Turner 1969) or performative models (e.g., Tambiah 1990), theories of ritual rarely approach ritual cognition as *action*, that is, as a temporally specified dynamic object that is accessible through its perceptual features. The present study investigated the cognitive effect of particular formal aspects of ritual actions. More precisely, we investigated how the fact that actions are ritualized influences the cognitive processing of these actions and whether, and to what extent, prior knowledge of the ritual modulates this influence. We claim that (1) rituals have systematic effects on cognitive processing due to features of the action processing system; (2) prior cultural knowledge and expectations can modulate these effects; and (3) particular cognitive effects of rituals explain why rituals are categorized as distinct on a folk-taxonomic level. This investigation is important because it contributes to the increasing knowledge of ritual and ritualization in general and how these relate to such phenomena as memory formation, categorization of actions and the formation and transmission of religious ideas. We review these implications in our discussion.

Actions fall into sets and subsets comparable to object categories; just as there are types of objects (e.g., pens, hats, and temples) there are also types of actions (e.g., conferences, prayers, and bar mitzvahs). Actions, however, unfold in time and as a result their parts are temporally specified in comparison to the spatially specified parts of static objects. For this reason the concept of "dynamic objects" is sometimes used to refer to the entire set of actions and events (Zacks and Tversky 2001).[1] Humans typically classify dynamic objects by means of elaborate taxonomies that supply a range of conceptual information concerning the specific features of the action and their relation to other actions (Zacks and Tversky 2001). While such taxonomies depend on cultural information, certain fundamental action categories seem to be nearly universal and are, therefore, likely to be dependent upon recurrent perceptual features of the dynamic object and receive their organizing structures from biological endowment (e.g., Rappaport 1977; Boyer and Liénard 2006; Liénard and Boyer 2006).

There is a systematic separation between instrumental and ritual actions in

1. Technically "event" covers both agentive (i.e. actions) and non-agentive dynamic objects and is often synonymous with dynamic objects. Since the present article focuses on actions, "event" is only applied when it refers specifically to a construct in Event Segmentation Theory (Zacks, Speer, Swallow, Braver and Reynolds 2007).

folk taxonomy,[2] that is, cross-culturally, we typically find a conceptual distinction between instrumental actions that are causally determined (i.e., actions that implement their goals through direct physical causality) and ritual actions that are causally under-determined (i.e., actions that do *not* implement their goals through direct physical causality, but, typically, through convention-based efficacy) (c.f., Malinowski 2008). Though instrumental actions depend critically on a tight coupling between action sequence and goal structure, this coupling is secondary in ritual action (Sørensen 2007). The goal of the Christian Eucharist, for instance, cannot be inferred on the basis of perceptually accessible causal links between the ritual's sub-actions and the purported goal—having bread before wine has no direct causal impact on attaining a state of grace. By contrast, the sub-actions of coffee-making are all causally linked to the goal of having freshly made coffee – grinding of coffee beans must necessarily precede brewing of coffee. Ritual actions are non-functional because, in a proximate and causal sense, their sub-actions are not functionally related to the purported goal (Boyer and Liénard 2006; Zor, Keren, Szechtman, Mort and Eilam 2009; Zor, Hermesh, Szechtman and Eilam 2009; Nielbo and Sørensen 2011).

This dual folk taxonomy of ritual and instrumental actions maps onto a similar scientific taxonomy of behavior, which has been applied in the scientific disciplines of anthropology, the study of religion, and ethology for more than a century (e.g., Huxley 1914; Smith 1972; Frazer 2000). Within these disciplines behavioral categories are often characterized by their opposing features, such that ritual actions are redundant, stereotypical, iterative, invariable, and goal-demoted, while instrumental actions are necessary, variable, typically non-repetitive, and goal-directed (e.g., Staal 1990; Tambiah 1990; Humphrey and Laidlaw 1994; Rappaport 1999; Watanabe and Smuts 1999; Boyer and Liénard 2006; Sørensen 2007). Although the transition between ritual and instrumental behavioral types and their related domains is probably best understood as graded and continuous, the folk categories make scientific sense in so far as the characteristic features of folk categories have specific perceptual and cognitive effects. These effects, then, can explain the widespread dual folk taxonomy.

Ritual studies

Ritual behavior has been theorized to express, stand for, or enact almost everything from erroneous causal knowledge or primary mental structures, to col-

2. "Folk taxonomy" designates systemic vernacular conceptualizations of, for instance, dynamic objects based on context dependent social information. Folk taxonomies are opposed to scientific taxonomies, that is, systemic conceptualizations based on objective criteria.

lective narratives and basic social structure.[3] The diversity of theories and conceptual models is quite astonishing and might indicate the heterogeneity of the subject matter.[4] But it is still suggestive that most theories seem to converge on the presence of certain formal[5] features of ritual behavior. Few ritual theorists would, therefore, disagree that ritual behavior tends to be characterized by the following formal behavioral features: rigidity, redundancy, stereotypy, and adherence to script (Staal 1990; Rappaport 1999; Boyer and Liénard 2006).

When, as in ritual, these *formal* behavioral features tend to co-occur, the features undermine the causal determination and intentional specification of an action sequence (Humphrey and Laidlaw, 1994; Boyer and Liénard 2006; Sørensen 2007). The process of ritualization (i.e., the transformation of an instrumental behavior into a ritual behavior) can, therefore, be modeled as a progressive decoupling of an action sequence's causal structure from its goal through the introduction of specific formal behavioral features (i.e., rigidity and redundancy, stereotypy, and adherence to script).

Perceptual causality and event perception

In cultural practices, causal under-determination, i.e. the *inability* to causally determine the purported goal of an action based on the structure of its sub-actions, is very interesting since studies of perceptual causality have repeatedly shown that humans automatically extract causal models from observed actions, and use these models to categorize and understand past, present, and future actions (Heider 1944; Heider and Simmel 1944; Michotte 1963; Leslie and Keeble 1987; Cheng and Novick 1992; Guthrie 1993; Dittrich and Lea 1994; Cheng 1997; Scholl and Tremoulet 2000; Blakemore and Decety 2001; Scholl and Nakayama 2002; Kushnir, Gopnik, Schulz, and Danks 2003; Gopnik, Glymour, Sobel, Schulz, Kushnir, and Danks 2004; Gopnik and Schulz 2004; Gopnik and Tenenbaum 2007; McClelland and Thompson 2007). Collectively, these studies indicate that the human perceptual system processes movement dynamics quickly and automatically in terms of causal structure, that this perceptual process is driven by dynamical features of the stimulus and, finally, that the process is a cornerstone in action understanding.

3. See Catherine Bell's *Ritual: Perspective and Dimensions* for one of the few historical presentations of ritual theories (Bell 1998).

4. An example of this heterogeneity can be found by comparing the many different contributions in *Theorizing Ritual: Issues, Topics, Approaches, Concepts,* in Kreinath, Snoek and Stausberg 2008.

5. Here "formal" means pertaining to the physical form of the action as opposed to its semantic content or pragmatic function.

According to a prediction-based account of action perception, we understand an action by constantly matching our predictions of the action's dynamic development with its actual development (Wolpert and Flanagan 2001; Zacks et al. 2007). If there is little difference between our predictions and the actual development, we rely on our predictions and do not need to use considerable perceptual resources processing the action. If on the other hand, our predictions are wrong, this results in a "prediction error," and we need to update our action representation by attending to the perceptual environment. The causal structure of an action supports predictability of the action's sequential dynamics (Nielbo and Sørensen *in press*). If predictability of an action is decreased and the associated prediction error increases, then humans tend to segment the action sequence into smaller units[6] using more event boundaries (Newtson 1973; Wilder 1978a, 1978b; c.f., Hanson and Hirst 1989). Event boundaries are points of change in an action sequence that specify the sequence's perceived unit size and internal structure.[7] These boundaries are processed actively by the perceptual system and are pivotal to action understanding (Newtson, Engquist and Bois 1977). At the perceptual level, the causal structure of an action facilitates representational coherence. Event boundaries are therefore, at least partly, dictated by the causal structure. If a change in the sequence is not predicted by the causal structure, it is likely that the system responsible for action perception has to update or change its causal expectations.

The concept of event boundaries has been developed within Event Segmentation Theory (EST), which is one of the leading perceptual and cognitive accounts of action perception, or what is more generally known as event perception and understanding (Zacks and Tversky 2001; Zacks, Speer, Swallow, Braver, and Reynolds 2007; Kurby and Zacks 2008; Zacks and Sargent 2010). According to EST, humans are equipped with a composite event segmentation system that mediates perception and cognition of actions. Basically, the system drives action understanding by predicting and classifying an action's sequential structure on several hierarchically related levels. The system utilizes bottom-up sensory and top-down schema-based information to construct an event model, that is, an online working memory representation of the action and its immediate context. An error monitoring sub-system, which capitalizes on the difference between actual and expected dynamic input (i.e., a prediction error signal), regulates the event segmentation system's sensory update and stability. If the error signal is small, the current event model is accurate in predicting the structure of the

6. An action unit is the segment of an action that occurs between two event boundaries.

7. Assuming that an action sequence is finite, an increase in the amount of event boundaries placed in an action sequence is equivalent to a decrease in unit size. Event boundaries and unit size are, in other words, inversely correlated.

observed action. If, on the other hand, the error signal is high, the current event model models the action structure inadequately. In the low error case, the system is stable because it can rely on its current event model to classify and predict the development of the observed action. However, when prediction error is high, the system is unstable and the current event model needs to be updated or replaced. To make model modifications, the system has to search for new action cues by allocating resources to the sensory environment. The error signal is, therefore, positively associated with externally allocated attentional resources.

Event boundaries are directly related to prediction error because when prediction error is high, the event segmentation system will perceive a large event boundary (e.g. a boundary between two different action sequences) and when prediction error is low the system will perceive a small event boundary (e.g. a boundary within an action sequence) (Reynolds, Zacks and Braver 2007; Zacks, Speer, Swallow, Braver, and Reynolds 2007; Kurby and Zacks 2008). Finally, in EST the organization of the event segmentation system is modeled as a two-level hierarchy (Zacks, Tversky, and Iyer 2001; Hard, Tversky, and Lang 2006). Low-level segmentation is sensory-driven and primarily relies on the bottom-up information with limited biasing from stored schematic structures. Internal schemas, however, are more influential on high-level event segmentation. In normal event segmentation, these levels are hierarchically aligned in such a way that the low-level boundaries constitute a subset of high-level boundaries (Zacks, Tversky, and Iyer 2001; Hard, Tversky, and Lang 2006; Kurby and Zacks 2008).

Because ritual actions are causally under-determined, that is, as their constituent sub-actions are not specified by a purported goal, they elicit an increase in prediction error, which results in an extensive allocation of the agents' limited attentional resources to low-level perceptual information. Since high-level representations of the ritual action lack concrete goal-directed information, it is reasonable of us to predict that the hierarchical organization of ritual action representations is reduced. It is furthermore interesting to ask whether the increase in prediction error elicited by ritual actions is independent of familiarity and cultural information. Children have been observed to establish novel action schemas from repeated exposure to a given action (Bauer and Mandler 1990; Mandler 1992). These novel action schemas define specific causal expectations relevant for understanding the newly learned action. Thus, given that action schemas can be *learned*, it is plausible to hypothesize that in the case of cultural rituals, associated cultural information that induces action specific expectations will modulate event perception by reducing the prediction error signal, thereby countering the effects of causal under-determination.

In the event segmentation system, expectations are embedded event schemas stored in long-term memory that bias event perception in a top-down fashion. Though plausible, the evidence in support of this perceptual expectation modulation hypothesis is quite limited (Zacks, Tversky, and Iyer 2001; Hard, Tversky, and Lang 2006). Nielbo and Sørensen have argued that abstract cultural expectations (e.g. the belief that the Christian Eucharist causes a state of grace) can modulate prediction error during ritual behavior (Nielbo and Sørensen 2011, *in press*), but this effect has yet to be demonstrated experimentally. For instance, if expectations reduce prediction error then an increase in hierarchical organization of ritual action representations can reasonably be predicted.

To summarize, we know this much: Ritual behavior is, at the level of perception, characterized by formal features that make a ritual action sequence appear causally under-determined and intentionally under-specified. Action perception is highly dependent upon a perceptually accessible causal structure. The lack of a coherent causal structure reduces the predictability of an action sequence and makes the sequence dynamics less transparent. If an action sequence lacks predictability, it elicits an increased prediction error signal, which causes the event segmentation system to update its current event model by allocating more attentional resources to the perceptual environment.

Reduced predictability in an action sequence has several specific effects (e.g., increased prediction error signal and increased event segmentation rate), and it is, therefore, hypothesized 1) to reduce hierarchical organization of ritual action representations (i.e. the degree to which low-level event boundaries are represented as a subset of high-level event boundaries in ritual actions). The causal under-determination and associated lack of predictability are countered by expectations originating in the cultural context, which modulate action perception in the direction of system stability. Thus, it is hypothesized that 2) hierarchical organization of ritual action representations will be increased by expectation modulation. The present experimental study set out to test these two related hypotheses.

Previous studies

A recent experimental study has shown that non-functionality (i.e., the lack of causal coherence in an action sequence) increases the number of event boundaries (measured by segmentation rate) that are spontaneously placed in an observed action sequence (Nielbo and Sørensen 2011). A subsequent study used artificial neural networks to simulate perception of non-functional action sequences (Nielbo and Sørensen *in press*).[8] In this simulation study, variation in segmen-

8. For a thorough discussion of the relationship between experimental and simulation data see (Nielbo, Braxton, and Upal, 2012).

tation rate, and hence event boundaries, was modeled as the discrete outcome of transient increases in a continuous prediction error signal. The simulation showed that non-functionality decreases action predictability, elicits a chronically high prediction error signal, and increases the rate of sensory update. The simulation study therefore indicated that the lack of causal coherence can force a perceptual system to increase sensory update and allocate attentional resources to low-level perceptual details (Nielbo and Sørensen in press). This process, in turn, reduces the low-level hierarchical alignment with high-level action representations that utilize goal-structure to segment an action, because participants are allocating their resources to representations of highly detailed, but incoherent, information (c.f., Sørensen 2007). According to one interpretation the increase in segmentation rate and in prediction error reflect a more general effect of ritual behavior, namely that the behavioral form of ritual induces a high cognitive load and thereby depletes cognitive resources by focusing attentional and working memory resources on the low-level perceptual details and psycho-physics of the ritual (Schjødt, Sørensen, Nielbo, Xygalatas, Mitkidis and Bulbulia *in press*). The difference between instrumental and ritual actions in terms of cognitive load and resource depletion offers a possible perceptual account of the sustained dichotomization we find in typical folk taxonomies of action.

In the present study, we wanted to test the prediction that ritual behavior or, more specifically, non-functional action sequences, reduce the hierarchical alignment between low- and high-level action representations.

Another related issue is the effect of expectation modulation on representations of ritual actions. Since cultural information can maintain and reproduce itself through induction of expectations in social agents, the experimental study that tested spontaneous segmentation of non-functional actions also tested whether expectations related to specific actions can modulate action perception (Nielbo and Sørensen 2011). The study did not find any reliable effect of expectations on segmentation rate of functional and non-functional actions. This unexpected result was contradicted by the simulation study, which showed a particular strong effect of expectations on the prediction error signal during perception of non-functional actions (Nielbo and Sørensen, in press). Based on the simulation results, it was argued that when the perceptual input does not support predictability, abstract goal structures and weak causal scripts provided by the cultural context would support predictability. Two plausible interpretations for these findings can explain the discrepancy between the experimental and the simulation study. First, the expectation induction procedure was prior exposure to the actions (i.e. participants watched the actions before the segmentation task); this procedure might be inadequate to induce expectations that are strong enough to modulate segmentation rate. Second, it is possible that spontaneous segmentation rate is too crude a measure to track expectation modulation and that a measure with higher resolution is needed.

Given the simulation results that showed an effect of expectations on the prediction error signal, we wanted to retest possible effects of expectation modulation in a new study. To do this we modified the expectation induction procedure and hierarchical alignment was used as the dependent measure instead of segmentation rate. Both alterations were chosen with the purpose of increasing a possible modulation effect.

Experiment 1

Hierarchical alignment during perception of non-functional actions

Experiment 1 used a modified event segmentation paradigm. In the standard event segmentation paradigm, participants segment video-recorded action sequences, typically object manipulation tasks, into units by pressing a response button whenever they find it natural (Zacks, Tversky and Iyer 2001). The modification introduced a comparison between matched action sequences to examine whether a fine and a coarse level of segmentation temporally align during observation of functional or non-functional action sequences respectively (c.f., Nielbo and Sørensen 2011). The stimulus set consisted of filmed action sequences (i.e., movies). Participants were explicitly instructed to segment the sequences at a fine and a coarse level of segmentation, that is, to identify the components of the observed action sequences using the number of units that they found natural (c.f., Newtson 1973; Zacks, Tversky and Iyer 2001; Hard, Lozano and Tversky 2006). To analyze hierarchical alignment of segmentation, we relied on Zacks et al.'s method of discrete and continuous event segmentation analyses (Zacks, Tversky and Iyer 2001).

Because non-functional action sequences are less causally integrated than functional action sequences and, therefore, increase segmentation rate and prediction error, as well as focus attentional resources at the fine level of perceptual detail and psychophysics, we predicted that in the non-functional condition the two levels of segmentation would be less temporally aligned than in the functional condition (c.f., Sørensen, 2007).

Method

Participants

The participants were 20 undergraduate students enrolled at Aarhus University.

Movie stimuli

The stimulus set comprised 24 action sequences. The action sequences were of 20 seconds' duration each and organized in two subsets:one functional and one non-functional subset). Twelve functional action sequences were originally filmed with a 3.1 megapixel video camcorder from a fixed position, showing only the hands, arms, and middle torso of a male actor (see Table 1). Since in this modified paradigm non-functional action sequences are modeled as transformations of functional action sequences, we chose low-frequency functional action sequences to remove potential effects of the participants' prior knowledge and thereby avoid a novelty confound in the non-functional condition. An expert group consisting of eight members of the *Religion, Cognition and Culture* research group was instructed to segment each functional action sequence at a fine-grained level. The group was not informed about the hypothesis being tested. The expert group's mean number of presses for each functional action sequence was then used to identify the relevant units. To generate the non-functional action sequences, we randomly reorganized the units within each functional action sequence, as they were identified by the expert group, with the constraint that a sequence identical to the functional was not allowed. Subsequently, the non-functional action sequences were filmed using the same procedure as the functional action sequences. The reason for filming the non-functional sequences instead of scrambling the functional sequences was that we wanted to retain a natural action flow. The final output was two subsets of action sequences, each containing 12 action sequences. Thus for each thematic action sequence we had one functional and one non-functional version. Each action sequence in one subset, therefore, mapped uniquely onto one, and only one, action sequence in the other subset.

Design

Table 1 The set of functional action sequences (movies) used in experiments 1 and 2.

Nr.	Action sequence	Nr.	Action sequence
1.	Cut the pages of a book open	7.	Insert light bulb in flashlight
2.	Set up a mandoline	8.	Sharpen knife on grindstone
3.	Measure map with opisometer	9.	Light multi-fuel burner
4.	Prepare smoking pipe	10.	Operate dumpling molder
5.	Assemble tattooing-machine	11.	Use tea egg infuser
6.	Use lime zester	12.	Change lighter flint in lighter

The experiment was a within subjects design with action type as the only factor with two levels: functional and non-functional.

Procedure

Experiment 1 consisted of three parts: 1) a fine/coarse segmentation part consisting of one full presentation of the entire stimulus set of both functional and non-functional action sequences; 2) a filler part consisting of a reading speed and comprehension task to prevent carry-over effect from parts 1 to 3; and 3) a coarse/fine segmentation part, again showing the entire stimulus set once but with the alternate segmentation instructions. Participants were randomly assigned to either the fine-then-coarse or coarse-then-fine presentation order. In parts 1 and 3, the stimulus presentation order was completely randomized between participants and parts.

The participants were placed in front of a monitor and a QWERTY-keyboard in separate rooms. They were instructed to use the keyboard, specifically ENTER, SPACE, and 1 to 9, to navigate and read further instructions on the monitor carefully. All further instructions were presented on the monitor in Danish.

Parts 1 and 3 initiated with the general segmentation instruction: "You will see a series of action sequences of approximately 20 seconds' duration. You have to press SPACE every time you think that one unit stops and a new begins. Segment every action sequence in accordance with the following instructions." Following the general instruction was either a fine or a coarse segmentation instruction, depending on the presentation order group. Every participant would go through both a fine and a coarse segmentation part. The fine segmentation instruction was as follows: "Segment every action sequence by pressing SPACE in the smallest units that you find natural." And the coarse segmentation instruction was: "Segment every action sequence by pressing SPACE in the largest units that you find natural."

Data analysis

In the analyses, an α-level of .05 was used for tests of statistical significance, p-values are only reported when $F > 1$, and eta-squared (η^2) was consistently used as effect size measure. When needed, the Bonferroni-Holm sequentially rejective multiple test with a family-wise α-level of .01 was used to correct p-values for multiple comparisons (Holm, 1979). Hierarchical organization was analyzed by means of the discrete and continuous analysis of hierarchical alignment developed by J.M. Zacks and colleagues (Zacks, Iyer and Tversky 2001). For the discrete analysis, the action sequences were divided into 1-sec bins. Because the hierarchical data showed a slight positive skew, a log-transformation (base *e*) was carried out before the analyses of variance. The Shapiro-Wilk *W* test (Shapiro and Wilk 1965) was used to confirm that the data did not deviate significantly from normality and Bartlett's test (Bartlett 1937) did not show any violation of the assumption of homoscedasticity.

Results and discussion

The mean coarse segmentation rate (i.e., the mean number of button-presses per action sequence of 20 sec duration) in the functional condition was ($M = 2.36$, $SD = .86$) and in the non-functional condition ($M = 2.29$, $SD = 1.04$). The mean fine segmentation rate in the functional condition was ($M = 4.48$, $SD = 1.43$) and in the non-functional ($M = 5.04$, $SD = 1.7$). The difference between segmentation levels was statistically significant, which confirms that participants understood hierarchical segmentation instructions: $F(1,19) = 118.22$, $p < .0001$, $\eta^2 = 0.8$.

Initially, the distributions of breakpoints in one-second bins, based on the participants' pooled segmentation of each action sequence, that is, the level of agreement of event boundaries, can be informative in terms of hierarchical organization (see Figure 1). There was some agreement across participants as to where boundaries fall within each action sequence, but also considerable variation (c.f., Zacks, Iyer and Tversky 2001). In the functional condition, there were statisti-

Table 2. Correlations, *p*-values, and *Z*-scores for correlations between the fine and the coarse level of segmentation for each action sequence in experiment 1.

Functional Action Sequences		Non-functional Action Sequences		Comparison
	R		*R*	*Z*
Sequence 1	0.6693*	Sequence 1	0.5603*	0.5712
Sequence 2	0.5540*	Sequence 2	0.4739*	0.3537
Sequence 3	0.7138*	Sequence 3	0.3312	1.7843
Sequence 4	0.3653	Sequence 4	0.3090	0.2059
Sequence 5	0.6183*	Sequence 5	0.5544*	0.3164
Sequence 6	0.7210*	Sequence 6	0.3643	1.7105
Sequence 7	0.7419*	Sequence 7	0.3462	1.9238
Sequence 8	0.6663*	Sequence 8	0.2713	1.7040
Sequence 9	0.5880*	Sequence 9	0.3128	1.1373
Sequence 10	0.4429*	Sequence 10	0.4246	0.0730
Sequence 11	0.7436*	Sequence 11	0.5293*	1.1967
Sequence 12	0.6130*	Sequence 12	0.6076*	0.0274

*: Statistical significant at the 95% ($\alpha = 0.05$) confidence level, ($Z = \pm 1.96$).

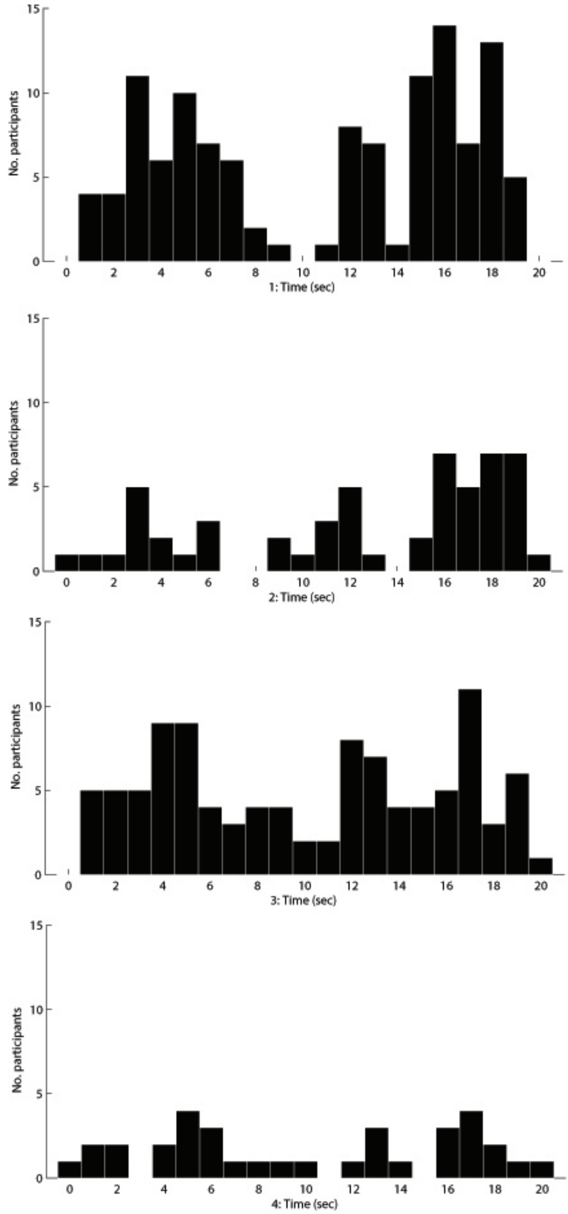


Figure 1. The distributions of breakpoints in one-second bins at the fine (histograms 1 and 3) and the coarse (histograms 2 and 4) level of segmentation for functional action sequence number 12 (histograms 1 and 2) and its non-functional counterpart (histograms 3 and 4).

cally reliable correlations between the fine and the coarse level of segmentation in 11 out of 12 action sequences at the $p < .05$ level of significance (see Table 2). In the non-functional condition only five out of 12 sequences were significantly correlated at the same level of significance. In other words, event boundaries in the functional condition showed hierarchical dependencies in more than twice as many of the movies as event boundaries in the non-functional condition. This result does seem to indicate that non-functionality reduces hierarchical organization. If the *r* values, however, are converted to *Z*-scores using the Fisher transformation, there is no reliable difference between the correlation coefficient for each functional action sequence and its counterpart in the non-functional set at the 95% ($\alpha = 0.05$) confidence level, ($Z = \pm 1.96$). The comparison, therefore, points to the provisional character of a purely correlative analysis and emphasizes the need for a different approach to hierarchical organization.

Two such types of analyses that are widely used in the event segmentation literature are the discrete and continuous analyses of hierarchical alignment, specifically of discrete overlaps (*Overlaps*) between coarse and fine event boundaries and the continuous average distance (*AvgDist*) between coarse and fine event boundaries (Zacks, Tversky, and Iyer 2001; Zacks 2004; Hard, Lozano and Tversky 2006; Hard, Recchia and Tversky 2011). In the discrete analysis an event boundary refers to the one second bin that a given participant's segmentation tap falls into, while in the continuous analysis it refers to the actual time, measured in milliseconds, of the segmentation tap (Zacks, Tversky, and Iyer 2001). The analyses are mutually dependent and estimate how well the event boundaries at the fine level of segmentation coincide with event boundaries at the coarse level by comparing the degree of alignment with a model of chance level alignment ($Overlaps_0$ and $AvgDist_0$) for every single experimental participant. Importantly, if the discrete analysis rejects the zero-model, there are significantly more overlaps of event boundary than chance level predicts. If the continuous analysis confirms hierarchical alignment, there is a shorter average distance between event boundaries than predicted by the zero-model.

To test for the presence of hierarchical alignment of fine and coarse segmentation levels, a series of repeated measures one-way ANOVAs were carried out on the discrete and continuous analyses of hierarchical alignment. The discrete analysis comparing mean *Overlaps* and $Overlaps_0$ scores for each participant in the functional condition showed that hierarchical alignment was reliably present above chance level ($M = 1.04$, $SD = 1.65$, $M_0 = .49$, $SD_0 = 1.79$): $F(1,19) = 86.7$, $p < .0001$, $\eta^2 = 0.82$. The ANOVA of the mean *AvgDist* and $AvgDist_0$ scores for each participant in the functional condition supported the discrete analysis ($M = 925.2$ ms, $SD = 1.6$ ms, $M_0 = 1719.9$ ms, $SD_0 = 1.5$ ms): $F(1,19) = 35$, $p <$

.0001, $\eta^2 = 0.65$. The same two analyses were performed on the non-functional data. The discrete analysis showed that hierarchical alignment was significantly higher than the zero model predicted ($M = .71$, $SD = 2.08$, $M_0 = .54$, $SD_0 = 1.9$): $F(1, 19) = 14.13$, $p < .01$, $\eta^2 = .43$. The continuous analysis also corroborated the discrete analysis in the non-functional condition ($M = 1022.5$ ms, $SD = 1.7$ ms, $M_0 = 1366.4$ ms, $SD_0 = 1.4$ ms): $F(1,19) = 9.7$, $p < .01$, $\eta^2 = 0.34$.

To compare the two action type conditions, we calculated relative hierarchical alignment, that is, the difference between actual hierarchical alignment and the corresponding zero-model in each condition, specifically $Overlaps - Overlaps_0$ in the discrete analysis and $AvgDist_0 - AvgDist$ in the continuous analysis. Notice that both measures will be positive if the zero-model is rejected. A repeated measures one-way ANOVA was carried out on these relative measures. The analysis showed that relative hierarchical alignment was significantly higher in the functional condition ($M = 2.12$, $SD = 1.43$) than in the non-functional condition ($M = 1.31$, $SD = 1.46$): $F(1,19) = 34.15$, $p < .0001$, $\eta^2 = .64$. The continuous analysis validated the discrete analysis with ($M = 1.84$, $SD = 1.58$) in the functional condition and ($M = 1.34$ ms, $SD = 1.58$) in the non-functional condition: $F(1,19) = 10.64$, $p < .005$, $\eta^2 = .36$.

Experiment 1 supports the claim that hierarchical organization is present in both functional and non-functional action representations. In both conditions, hierarchical alignment was well above chance level, indicating that event boundaries at a low level of event representation coincided with, or rather was a subset of, event boundaries at a high level of event representation. The experiment further confirmed that in the non-functional condition, participants reduced hierarchical organization in their action representations, compared to the hierarchical organization of action representations in the functional condition.

Experiment 2

Expectation modulation of perception of non-functional events

The purpose of experiment 2 was to assess the possible modulation effect of expectations on hierarchical organization in non-functional action sequences. Although a previous experimental study did not show such an effect on spontaneous segmentation rate, a simulation study clearly indicated the effect's possibility (Nielbo and Sørensen 2011, *in press*). Because we did not find an experimental effect in the previous manipulation, a narration procedure was chosen to induce expectations. Participants were simply instructed to verbally narrate what happened in the observed action sequences. The rationale behind this procedure was that verbalizing event perception in a continuous narration is, due to the abstractness of language, an optimal procedure for building event schemas. It was assumed that if participants were instructed to represent perceptual details in abstract chunks of natural language, this instruction would facilitate their action encoding and schema construction. In terms of ecological validity, narration also seems a more natural way of associating abstract knowledge with non-functional events, in comparison to prior exposure alone.

In light of the results from experiment 1 and of previous studies using computer simulations (Nielbo and Sørensen, *in press*), we predicted that expectations would increase hierarchical alignment particularly in the non-functional condition compared to the non-functional condition without induction of expectations because non-functional stimuli do not support hierarchical organization perceptually and, therefore, should be particularly sensitive to compensatory expectation-driven modulations.

Method

Participants

Participants were 23 undergraduate students enrolled at Aarhus University.

Movie stimuli

Experiment 2 used a stimulus set identical to the one used in experiment 1 (see Table 1). For the task familiarization part (see below), an action sequence, 'inserting a vinyl record in multiple sleeves,' was filmed. The action sequence was originally excluded from the stimulus set because it was causally ambiguous (i.e., both functional and non-functional) due to the lack of a necessary order (i.e., the sequence could be initiated at any sub-action) but had a goal (i.e., the vinyl record inserted in all the sleeves). As task familiarization stimulus, it would, therefore, be less likely to prime the participants in either direction.

Design

The experimental design was a within subject 2 (functional/non-functional action type) x 2 (with/without expectation induction) factorial design.

Procedure

Experiment 2 was composed of five parts: 1) a task familiarization part consisting of two segmentation trials (fine/coarse or coarse/fine presentation order) and a narration trial; 2) an expectation induction part in which half of the functional and half of the non-functional action sequences were shown once, each followed by an interval in which participants were instructed to narrate what happened in the action sequence; 3) a fine/coarse segmentation part consisting of one full presentation of the entire stimulus set; 4) a filler part consisting of a word recognition and reading speed task; and 5) a coarse/fine segmentation part similar to part 3, but with the alternate segmentation instructions.

As in experiment 1, participants were randomly assigned to the fine-then-coarse or coarse-then-fine presentation order group, and the order in the two segmentation trials of part 1 was completely randomized. The selection of action sequences in part 2 was randomized across participants but with the constraint that any given participant would see matching functional and non-functional action sequences. In parts 3, 4, and 5 the stimulus presentation order was completely randomized across participants and parts.

As in experiment 1, participants were initially placed in front of a monitor and a QWERTY-keyboard in separate rooms. They were instructed to use the keyboard, specifically ENTER, SPACE, and 1 to 9, to navigate and read instructions on the monitor carefully. All instructions were in Danish.

The task familiarization part initiated with a “this is a short test” instruction and ended with “the test is now over.” During this part, the participants were instructed trial by trial, using the standard instruction from the task with which they were familiarized.

In the expectation induction part, the participants were instructed to narrate what happened in the action sequence into a head-mounted microphone, specifically: “When the action sequence is finished, you have to use the microphone to narrate what happened in the action sequence.” In each narration trial, the participants were instructed that they should “now use the microphone to narrate what had happened in the action sequence” after each full presentation of an action sequence.

Parts 3 and 5 were identical to the event segmentation parts in experiment 1 (parts 1 and 3); that is, they initiated with the general segmentation instruction: “You will see a series of action sequences of approximately 20 seconds’ duration. You have to press SPACE every time you think that one unit stops and a new begins. Segment every action sequence in accordance with the following instructions.” Following the general segmentation would be either a fine or a coarse segmentation instruction, depending on what order group. Every participant would go through both a coarse and a fine segmentation part. The fine segmentation instruction was as follows: “Segment every action sequence by pressing SPACE in the smallest units that you find natural.” And the coarse segmentation instruction: “Segment every action sequence by pressing SPACE in the largest units that you find natural.”

The rationale behind the familiarization task (part 1) was twofold. First, we wanted to familiarize the participants with the task because, during piloting, the participants expressed some difficulty at getting used to the task environment. Second, we wanted a task-driven criterion for sorting away potential outliers, namely that if a given participant did not follow instructions satisfactorily during part 1, the participant would be disregarded in the analysis. In this case, "satisfactorily" meant that a) the participant placed more event boundaries during the fine event segmentation trial than during the coarse event segmentation trial; and b) the participant did narrate during the narration trial.

The data analyses of experiment 2 were carried out using the same technical specifications and types of analyses as experiment 1. One participant was excluded from the analysis because the participant did not follow instructions satisfyingly during the familiarization task. Again the hierarchical data was log transformed (base *e*) to compensate for positive skewness and the Shapiro-Wilk *W* test and Bartlett's test was used to confirm that the data conformed to normality and homoscedasticity.

Results and discussion

At the coarse segmentation level, the mean segmentation rate with narration in the functional condition was (M = 3.14, SD = 1.28) and in the non-functional condition (M = 3.29, SD = 1.59). The mean segmentation rate without narration was in the functional condition (M = 3.8, SD = 1.58) and in the non-functional (M = 4.1, SD = 2.38). At the fine segmentation level, the mean segmentation rate with narration in the functional condition was (M = 6.62, SD = 2.8) and in the non-functional condition (M = 6.9, SD = 2.56). The mean segmentation rate without narration was in the functional condition (M = 7.71, SD = 3.31) and in the non-functional (M = 8.41, SD = 2.87). The difference between levels of segmentation was statistically significant and participants, therefore, appear to have understood the hierarchical segmentation instructions: $F(1, 21) = 87.78$, $p < .0001$, $\eta^2 = .81$.

The histograms of the participants' pooled segmentation of each action sequence are similar to experiment 1; that is, agreement is apparent but so is variation (see Figure 2). Correlations between the fine and coarse level of segmentation are stronger in experiment 2 than in experiment 1 for both the functional and non-functional condition, but this increase occurs in both expectation conditions (see Table 3). The correlation coefficients are statistically significant for all the functional action sequences at the $p < .05$ level of significance. In the non-functional condition, 10 out of 12 action sequences show a significant correlation at the $p < .05$ level. Comparisons based on r to Z Fisher transformation show that only two functional action sequences are more strongly correlated than their non-functional counterparts at the 95% ($\alpha = 0.05$) confidence level, ($Z = \pm 1.96$). The action sequences are, however, equally distributed across the expectation factor. As in experiment 1, the correlation analysis alone is inconclusive and analyses of hierarchical alignment are, therefore, a more promising approach.

Table 3. Correlations, *p*-values, and *Z*-scores for correlations between the fine and the coarse level of segmentation for each action sequence in experiment 2.

	Functional Action Sequences		Non-functional Action Sequences		Comparison
		r		*r*	*Z*
Expectations (+)	Sequence 1	0.7628*	Sequence 1	0.4840*	1.5380
	Sequence 2	0.8552*	Sequence 2	0.7670*	0.8503
	Sequence 3	0.7021*	Sequence 3	0.4862*	1.1030
	Sequence 4	0.5953*	Sequence 4	0.3862	0.9028
	Sequence 5	0.7510*	Sequence 5	0.5842*	0.9930
	Sequence 6	0.8945*	Sequence 6	0.6411*	2.2167*
Expectations (−)	Sequence 7	0.6530*	Sequence 7	0.4300	1.0390
	Sequence 8	0.8838*	Sequence 8	0.5127*	2.6781*
	Sequence 9	0.7505*	Sequence 9	0.7886*	-0.3036
	Sequence 10	0.6020*	Sequence 10	0.8006*	-1.3090
	Sequence 11	0.7305*	Sequence 11	0.5865*	0.8341
	Sequence 12	0.7589*	Sequence 12	0.7625*	-0.0276

*: Statistical significant at the 95% (α = 0.05) confidence level, ($Z = \pm 1.96$).

To test expectation modulation of hierarchical alignment in non-functional action sequences, a series of repeated measures one-way ANOVAs were first carried out on the measures of hierarchical alignment at the different levels of expectation and action type separately and, afterward, the main repeated measures two-way ANOVA was, as in the previous experiment, performed on the relative measures of hierarchical alignment, including both the expectation factor and the action type factor.

In the functional condition with narration, both the discrete and continuous analysis showed above chance hierarchical alignment: Discrete ($M = 2.41$, $SD = 1.48$, $M_0 = .92$, $SD_0 = 2.18$): $F(1, 21) = 101.25$, $p < .0001$, $\eta^2 = .83$; Continuous ($M = 454.4$ ms, $SD = 1.3$ ms, $M_0 = 1164.4$ ms, $SD_0 = 1.5$ ms): $F(1, 21) = 108.4$, $p < .0001$, $\eta^2 = .83$. Similar results were found in the functional condition without narration: Discrete ($M = 2.72$, $SD = 1.57$, $M_0 = 1.36$, $SD_0 = 2.12$): $F(1, 21) = 77.59$, $p < .0001$, $\eta^2 = .79$; Continuous ($M = 454.9$ ms, $SD = 1.3$ ms, $M_0 = 982.4$ ms, $SD_0 = 1.5$ ms): $F(1, 21) = 105.3$, $p < .0001$, $\eta^2 = .83$.

The zero-models were also rejected by both analyses of hierarchical alignment in the non-functional condition with narration, although the effect sizes were smaller: Discrete ($M = 1.48$, $SD = 2.08$, $M_0 = 1.01$, $SD_0 = 2.16$): $F(1, 21) = 34.16$, $p < .0001$, $\eta^2 = .62$; Continuous ($M = 645.5$ ms, $SD = 1.6$ ms, $M_0 = 953.4$ ms, SD_0

Figure 2. (opposite page) The distributions of breakpoints in one-second bins for action sequence 2 (histograms 1, 2, 5, 6) and action sequence 12 (histograms 3, 4, 7, 8) in the functional condition (histograms 1-4) and the non-functional condition (histograms 5-8). The breakpoints are shown for the fine (histograms 1, 3, 5, 7) and the coarse (histograms 1, 4, 6, 8) level of segmentation in the expectation condition with narration (histograms 1, 2, 5, 6) and without narration (histograms 3, 4, 7, 8).

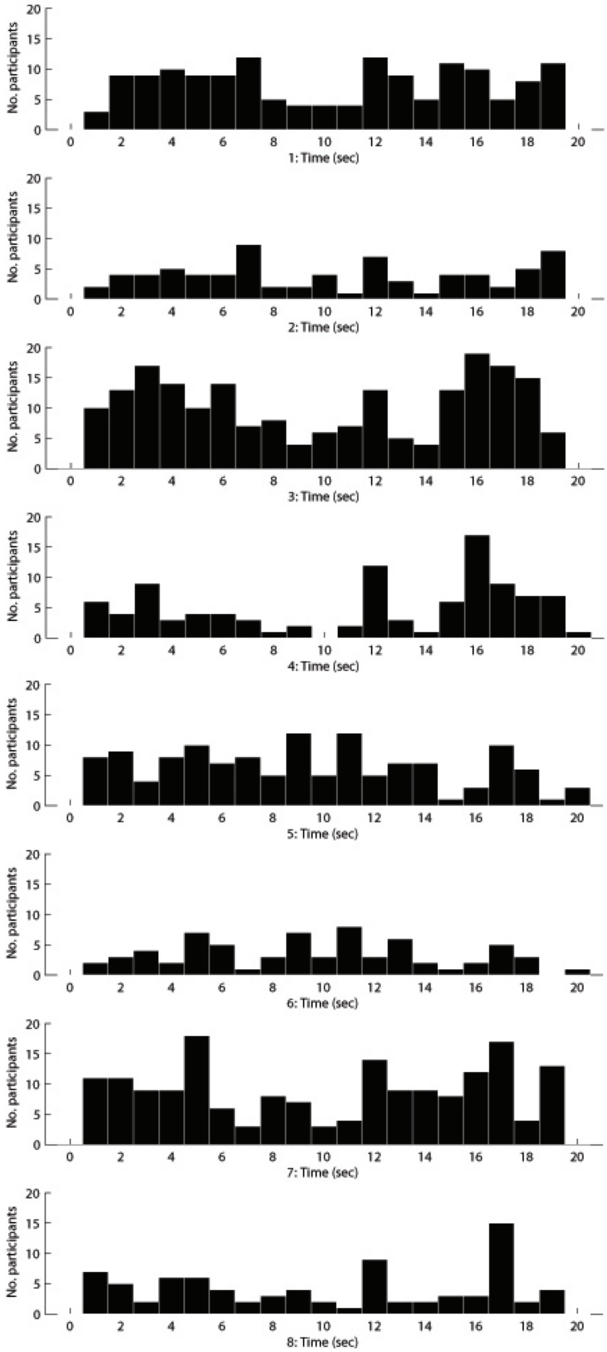
= 1.6 ms): $F(1, 21) = 26.28$, $p < .0001$, $\eta^2 = .56$. The same pattern was present in the non-functional condition lacking narration: Discrete ($M = 1.86$, $SD = 2.14$, $M_0 = 1.43$, $SD_0 = 2.23$): $F(1, 21) = 14.31$, $p <.01$, $\eta^2 = .41$; Continuous ($M = 566.8$ ms, $SD = 1.5$ ms , $M_0 = 772.8$ ms, $SD_0 = 1.4$ ms): $F(1, 21) = 25.84$, $p < .0001$, $\eta^2 = .55$.

A repeated measures two-way ANOVA on the discrete relative mean hierarchical alignment for each participant, with expectation as the first factor and action type as the second, showed a non-significant tendency for expectation: $F(1, 21) = 2.79$, $p = .11$, $\eta^2 = .12$; a reliable main effect of action type $F(1, 21) = 58.41$, $p < .0001$, $\eta^2 = .74$; and no interaction: $F(1, 21) < 1$. A similar analysis of the continuous measure, however, showed a significant main effect of expectation: $F(1, 21) = 5.25$, $p < .05$, $\eta^2 = .2$; again, a reliable main effect of action type: $F(1, 21) = 40.06$, $p < .0001$, $\eta^2 = .66$; and no significant expectation by action type interaction: $F(1, 21) < 1$.

Experiment 2 lends further support to the existence of hierarchical organization in representations of both functional and non-functional actions, as well as the reduced hierarchical organization in representations of non-functional actions. The finding that demands most consideration is the tendency for expectation modulation to increase hierarchical alignment independent of action type. Although the effect is small and not statistically significant in the discrete analysis, it is indisputably present, which is confirmed by the more precise measure of hierarchical alignment used in the continuous analysis. That being said, the effect of expectations is still marginal compared to the effect of action type. That expectation modulation seems to have a very little effect on hierarchical alignment is still perplexing, especially in comparison to the massive modulation effect shown in previous simulation studies (Nielbo and Sørensen in press). To determine whether the lack of expectation modulation effect originates in insufficient theorizing or in inadequate experimentation further experiments are needed.

General discussion

It has been argued that the increase of segmentation rate elicited by non-functional actions has two possibly related explanations, namely that 1) action integration is complicated by non-functionality due to the difficulty of goal-attri-


No. participants
1: Time (sec)
2: Time (sec)
3: Time (sec)
4: Time (sec)
5: Time (sec)
6: Time (sec)
7: Time (sec)
8: Time (sec)

bution, or 2) that the lack of causal coherence focuses attention on low-level perceptual detail, which, in turn, reduces hierarchical organization of action representations (Nielbo and Sørensen 2011). The present study clearly supports the latter explanation because both experiments showed that non-functionality reliably reduces hierarchical alignment. Importantly, hierarchical alignment is present at above chance levels in both conditions, meaning that the event segmentation system can rely on standard resources to process both instrumental and ritual behavior. These findings do not exclude the possibility of explanation 1, the empirical reality of which must be established in a new set of experiments.

Concerning the role of expectation modulation in event perception of non-functional actions, the present study found a statistical tendency, which might indicate that a modulation effect is there, but methodological issues are limiting our capacity to track it. Alternatively, it might be the case that at the level of action understanding, which this and previous studies target, the effects of expectations are minor compared to the effects of perceptual features. If this alternative is correct then ritualized behaviors will, independently of cultural priors, elicit distinct perceptual effects that, all things being equal, can be used to establish distinct categories for dynamic objects. The instrumental-ritualized behavioral taxonomy, on this alternative account, would likely originate in perception.

Our study is consistent with the claim that non-functionality elicits an increased prediction error signal in the event segmentation system which has distinct perceptual and cognitive effects, one of which is reduced hierarchical organization. The emergence of distinct dynamic object categories based on a prediction error account of the event segmentation system is one possible explanation of the near universal occurrence of the aforementioned dual taxonomy of behavior. This proposed account could explain why ritual behavior, in contrast to instrumental behavior, is perceived and understood with a local scope of attention.[9] Since an increased error signal will result in allocation of attentional and working memory resources to low-level perceptual details and psycho-physics, the unfolding of a ritual action is processed with a finer perceptual granularity, depleting resources that otherwise would support construction of a global scope of attention. According to this explanation, the representational landscape of ritual behavior is more hierarchically 'blurred' or unordered in comparison with the very hierarchical landscape of instrumental behavior. Action initiation and termination, therefore, become harder to determine in the case of ritual behavior because the behavior lacks a coherent causal structure that can support a global or more hierarchical representation. One interesting

9. This local scope in ritual action perception is sometimes described through a tunnel-metaphor of ritual behavior (Bloch 1989).

effect of this type of resource depletion is that observation and execution of non-functional actions is likely to block or reduce online memory encoding and reflective thinking. Because working memory is computationally limited, these cognitive operations lack sufficient resources to be executed concurrent with non-functional actions. Several interrelated phenomena can partly be explained by this depletion effect. Since encoding is blocked during the online processing of non-functional action, the actions do not, at least semantically, acquire meaning directly (c.f., Staal 1977, 1990; Sperber 1975). However, since considerable computational resources are invested in the actions and their sensory structure is salient to the human event segmentation system, it is likely that observers and performers will be highly receptive to post-action semantic ascription (Schjødt, Sørensen, Nielbo, Xygalatas, Mitkidis and Bulbulia *in press*). In the domain of socio-cultural rituals, the receptivity might express itself in a greater or more uncritical acceptance of social authority, while, in the domains of individual rituals, the receptivity might support the generation and maintenance of fictional scenarios and obsessive thoughts (Boyer and Liénard 2006; c.f. Otgaar, Alberts and Cuppens 2012).

Conclusion

In conclusion, we have shown that hierarchical organization is present in representation of actions that are either causally transparent or causally under-determined. In the last case, however, hierarchical organization is reduced and expectation modulation only has a limited effect on this reduction. These findings can, in part, explain the widespread instrumental-ritual behavioral taxonomy and suggest that ritual behavior has specific effects through the mechanism of resource depletion.

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