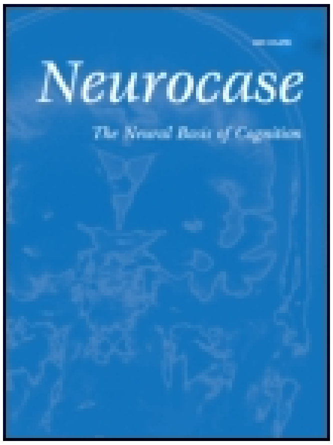

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The effect of attentional scope on spatial relation processing: A case study

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The effect of attentional scope on spatial relation processing: A case study

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Patient NC showed impairment on several tasks making use of coordinate spatial information, while categorical processing was at control level. Her assessment of local and global features of visual stimuli indicated that she had a local bias of attention, whereas controls showed a global bias. Her problems with coordinate tasks can be explained by this reduced global attentional focus. These findings confirm previous reports suggesting that the processing of categorical spatial relations benefits from a small scope of attention, whereas a relatively large scope of attention enhances coordinate spatial relation processing.

Keywords: Spatial relations; Spatial perception; Spatial attention; Susac's syndrome.

Spatial relations are an important component of how we perceive the world around us. We can process the spatial relations between objects, or an object and ourselves in two distinct ways: categorically, in abstract terms such as *left of* or *above*, and coordinately, in metric terms such as *2 meters away*. This distinction between categorical and coordinate spatial relations was originally suggested by Kosslyn (1987) and has been studied extensively over the years (for reviews see e.g., Jager & Postma, 2003; Laeng, Chabris, & Kosslyn, 2003). The main finding concerning these two types of spatial relations is that they rely on two separate processing mechanisms, as expressed by their lateralization patterns. A left hemisphere advantage is commonly found for categorical processing, whereas coordinate processing is linked to a right hemisphere advantage.

In several recent publications a possible link between scope, or spatial dimensions, of attention and categorical versus coordinate spatial relation processing is introduced (Borst & Kosslyn, 2010; Laeng, Okubo, Saneyoshi, & Michimata, 2011; Michimata, Saneyoshi, Okubo, & Laeng, 2011). These studies show that manipulation of attentional scope differentially affects performance on categorical and coordinate tasks: a smaller scope benefits categorical decisions, whereas coordinate decisions are made faster and more accurate with a larger scope of attention. These effects were shown for both exogenous and endogenous attenuation of attention.

The effects of attentional scope can contribute to the understanding of the nature of the distinction between categorical and coordinate processing. Kosslyn, Chabris, Marsolek, and Koening (1992) and Jacobs and Kosslyn (1994) put forward a model that emphasizes the role of receptive field sizes to explain this distinction. Small and non-overlapping receptive field sizes were found to favor categorical processing, and large and overlapping receptive field sizes benefit coordinate processing. Based on this model, Michimata et al. (2011) suggest that receptive field sizes are subject to dynamic,

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top-down modulation of the scope of attention, which explains the direct link between attention and spatial relation processing. However, these behavioral findings are slightly limited as the attentional scope was actively manipulated in these experiments, which may not generalize fully to these processes in situations where scope is not influenced externally. We present a case study in which attentional scope was markedly atypical, without any such manipulation. A wide range of spatial tasks was used to study how this affected her spatial performance.

Case description

NC is a 25-year-old female enrolled in a PhD program when she was diagnosed with Susac's syndrome, a rare microangiopathy consisting of a triad of encephalopathy, hearing loss and retinal occlusions (Susac, 2004). MRI of the brain showed multiple lacunes and white matter lesions throughout the brain, most pronounced in the right hemisphere and markedly in the corpus callosum. Her nationality is Brazilian, but she is proficient in English and could therefore be tested normally. She was referred by her physician for neuropsychological assessment because of cognitive complaints. Regular neuropsychological assessment was performed and included standardized tasks covering a wide range of cognitive domains: general cognitive functioning, language processing, long- and short-term memory, spatial perception, psychomotor speed, attention and concentration, executive functioning and visuoconstruction. This investigation pointed towards an impairment on the Judgment of Line Orientation test (JULO, 15-item short form; 3 out of 15 trials correct, 1st percentile). Furthermore, her performance on the Rey-Osterrieth Complex Figure test was intriguing. Her scores on this test were not at impaired level (scores >35th percentile), but the way she executed the tasks was striking. She drew single lines too long or too short (around ± 1 cm) and would then notice these errors and attempt to correct the length, which took considerable effort for her. Her self-reported complaints were along similar lines. She would have trouble completing forms at work if they required writing text in boxes. She solved this problem by using sticky notes on the forms. Overall, the neuropsychological assessment indicated slow information-processing speed (e.g., Trail Making Test Part A was in the first percentile) and a below average working memory span (e.g., Wechsler Adult Intelligence Scale III–Digit Span was in the 7th percentile). Performance on other cognitive domains (e.g., verbal memory, executive functioning) was within normal range.

Task selection

Based on the score on the JULO and the task execution of the Rey-Osterrieth Complex Figure test, NC was invited for a test battery specifically aimed at her pattern of performance. As she was tested 5 months after the initial investigation, the full version of the JULO (30 trials) was used, as well as the modified Taylor Complex Figure test, both copy and delay, as an equivalent of the Rey Complex Figure test.

As impairment on the JULO and drawing accurate line lengths could indicate a specific metric problem, various tests on spatial relation processing were included, testing both categorical and coordinate performance. To assess whether the impairment found for NC was strictly visual, a tactile spatial relation task was also included.

The Visual Object and Space Perception test battery (VOSP) and the Overlapping Figures test taken from the Birmingham Object Recognition Battery (BORB) were included as well to exclude visual agnosia, and to obtain a more general assessment of her spatial performance. Observations during these tests indicated an unusual way to reach answers: NC appeared to focus mainly on elements of the pictures, instead of at the whole picture. For instance when the task was to determine whether an X was present in a scrambled picture, she would only search for one of the diagonal lines. Based on these observations, a task assessing her performance on local and global spatial perception by means of Navon letters (a large letter built up by small letters) was included.

Finally, her specific self-reported problems were studied by using several writing and drawing exercises.

METHODS

Participants

Two different control groups were used, each consisting of six right-handed females, matched for age and education level to NC. The descriptives of

TABLE 1
Descriptive statistics of case NC, and the two control groups used

	NC	*Control group 1*	*Control group 2*
N	–	6	6
Age	25	22.5 (1.5)	24.8 (1.5)
Education level	7	6.5 (0.5)	7 (0.0)

Education level based on Verhage (1964) (1 = lowest, 7 = highest). Control group 1 was used for comparisons on the cross dot task, the scene perception task, and the odd one out task. Control group 2 was used for comparisons on the tactile task, the local/global perception task, and the writing and drawing exercises. Standard deviation in parentheses.

NC and the two control groups are presented in Table 1. For the existing standardized tests, available norms were used. All participants provided informed consent.

Tasks

The standardized tests that were used were the judgment of line orientation (JULO) (Benton, Varney, & Hamsher, 1978), the Visual Object Spatial Perception test battery (Warrington & James, 1991), and the Overlapping Figures test (taken from the Birmingham Object Recognition Battery; Riddoch & Humphreys, 1993). In addition, the Taylor Complex Figure test was used. NC was instructed to copy the figure and to draw it from memory after 30 minutes. Also, she was asked to select the elements that were present in the figure from 24 single elements, half of which were taken from the Taylor figure and the other half from the Rey figure.

The first of the spatial relation tasks was the *cross dot task*, as previously used in a clinical population (Van der Ham et al., in press). A "+" shaped cross was presented with a dot at one of forty possible positions for 150 ms. After a 2000-ms delay a second cross and dot combination was shown, for 150 ms. For the categorical part of the task, the instruction was to indicate whether the dot had appeared in the same quadrant of the cross in both images or not. The coordinate instruction was to compare the distance of the dot to the center of the cross in both images. For both instructions two types of stimuli were used, one set with a large cross and one set with a small cross. In each of the four conditions (categorical large, categorical small, coordinate large, coordinate small) 20 trials were presented. Responses were provided by button presses.

The second spatial relations task was the *scene perception task*, also previously reported (Van der Ham, van Zandvoort, Frijns, Kappelle, & Postma, 2011). In this task two identical scenes were presented simultaneously on a computer screen. The participant was asked to determine which item had changed position from one scene to the other. Those position changes were either coordinate (only metrically different) or coordinate + categorical (moved to a different position that was also categorically different with regard to the nearest other object in the room). Each set of scene was presented for a maximum of 30 seconds. Participants indicated verbally which object had moved, and the experimenter recorded response times by pressing a button if the correct answer was provided. In total 32 trials were presented.

The *odd one out task* was the third spatial relations task. This task consisted of two parts, one with a categorical and one with a coordinate instruction. Participants were presented with a large grey square (500 × 500 pixels) with four identical colored object drawings (approximately 50 × 50 pixels each) at different positions, on a computer screen. In the categorical part, three of those objects were placed in one of the quadrants of the square, and one object outside this quadrant. The instruction was to indicate which object was the odd one out based on its position, by means of pointing at it on a touch screen. The instruction for the coordinate part was to pay attention to the shortest distance from the object to the edge of the square. During the instruction distances or quadrants were illustrated by means of transparent overlays on stimuli presented on paper. This information was not present during the actual experiment. Importantly, the stimuli were constructed in such a way that distance could not be used as a valid cue for category membership or category membership as a valid cue for distance information.

One object would have a different distance (at least 50 pixels) from the other three. Both the categorical and coordinate part consisted of 16 trials.

The final spatial relations test was the *tactile spatial relations* test. A digital caliper with two metal points was used to administer the tactile stimuli to the palm of the dominant hand. The task consisted of two sequential two-point stimuli. Those stimuli could either be both on one side of the hand (left or right) or mixed (one left, one right) and were placed 1, 2, 3, or 4 cm apart. First, the categorical instruction was given, to assess whether both stimuli were presented on the same side of the hand, followed by the coordinate instruction to compare the distance between the two points in both stimuli, those were either identical or different. If they were different, they were different by at least 2 cm. For both instructions 16 trials were presented. Responses were provided verbally by indicating "same" or "different".

The *local global spatial perception task* made use of Navon letter figures (Navon, 1977). In this task, the objective was to detect a target letter in a presented stimulus, consisting of a large letter (global feature) made up of a set of identical small letters (local feature), which were incongruent with the large letter (Martin, 1979a, 1979b). The target letter was shown in half the trials and could be presented either as a global or as a local feature. The letters used were capital letters E, H, O, and S, which were 145×225 pixels in global size (4×6.5 degrees of visual angle) and 20×30 pixels in local size (0.6×0.9 degrees of visual angle). In total 120 trials were presented, evenly spread for visual field and the different letter combinations. The target letters were S for 60 trials, and H for remaining 60 trials. Each stimulus was presented for 150 ms at the center of the screen, after which a maximum of 2000 ms was allowed for a response. The visual angles of the stimuli was taken from previous reports in literature (e.g., Christman, Kitterle, & Hellige, 1991). The relative difference in performance between the trials in which a local and global feature was present, was interpreted as the attentional bias: a higher performance on the local trials compared to the global trials indicated a local bias and a higher performance level on the global trials compared to the local trials was interpreted as a global bias (e.g., Amirkhiabani & Lovegrove, 1996).

To assess which problems NC might experience in daily life, several practical exercises were carried out. She was asked to write a sentence "The girl in the yellow dress was skipping" on a blank piece of paper, and followed by the instruction to write that sentence between two horizontal lines that would have a decreasing distance between them, step by step. The largest distance was 1 cm, which decreased with 1-mm steps until the participant could not fit the text between them. Drawing was also observed by a number of incomplete line drawings from which either the left or the right side was missing. The instruction was to complete the drawing by mirroring the visible half. Line drawings ranged in difficulty from simple shapes, like a hexagon and a heart, to complex images like a scarecrow and a flower. NC was also asked to do a walking test, in which she was led around a floor of the psychology department building. She walked two different routes, both with a rectangular shape, and consisting of four turns. She was asked to draw the routes to scale and to indicate the distance of each element of the route in meters.

Procedure

NC was tested in three separate sessions spread over 10 weeks, also including several other tasks not reported here. Control data for the tasks that have been reported previously were extracted from existing datasets. Six PhD students from the psychology department were invited to take part in the tasks developed specifically for this case study. All controls performed the tasks in the same order, and where possible order effects of categorical and coordinate versions of a task were controlled for. Each task was introduced verbally along with examples of stimuli on paper to ensure the instructions were clear, in particular for NC.

RESULTS

Standardized tests

On the long version of the JULO NC answered correctly on 18 out of 30 trials. This score indicates impaired performance (4th percentile). A closer examination of her errors showed that she only made errors on oblique lines, not the horizontal or vertical ones. When she made an error, she would name one of the two closest lines.

On the VOSP her scores were within normal range (within one standard deviation from the average), except for the silhouettes and progressive

TABLE 2
All means on the spatial relations tasks for both NC and the controls

	NC				*Controls (N = 6)*			
	cat		*coo*		*cat*		*coo*	
	Acc	*RT*	*Acc*	*RT*	*Acc*	*RT*	*Acc*	*RT*
Cross dot large	95	1654*	75	2155*	96 (5)	935 (133)	68 (12)	1265 (182)
Cross dot small	95	1942*	60	2025*	99 (2)	1217 (117)	78 (10)	1213 (435)
Scene perception	100	6277	93	8494	93 (6)	6672 (1013)	97 (8)	7476 (2430)
Odd one out	100	–	60*	–	100 (0)	–	89 (7)	–
Tactile	100	–	83	–	100 (0)	–	83 (17)	–

Accuracy in percentages, Response Time in milliseconds, standard deviations in parentheses. Acc, Accuracy; RT, Response Time; cat, categorical; coo, coordinate. *$p < .05$.

silhouettes subtests. Here she was at cut-off level (5th percentile). Performance on the VOSP was not indicative of visual agnosia. However, observations throughout the battery indicated that she focused mainly on parts of objects and shapes instead of at the whole figure. On the Overlapping Figures of the BORB test she scored within normal range.

In her performance on the Taylor Complex Figure test, similar observations were made as for the Rey Complex Figure test during the general neuropsychological examination. She performed at average level (>50th percentile), because almost all elements are present in the drawing. However, many lines were too short or too long, with exaggerated corrections. After the delay she omitted 9 elements in the drawing, resulting in a score of 18 (20–35th percentile). In the recognition task, she misjudged 7 out of 24 elements.

Spatial relations tasks

The performance on all spatial relations tasks of both NC and the controls is provided in Table 2. Her scores on these tasks were impaired as compared to the controls only for the response times on all four conditions of the cross dot task and on the accuracy of the coordinate part of the odd one out task. The increase in the cross dot task is not surprising, as the presentation time of the stimuli is brief (150 ms), and there is no differential effect of any of the conditions. However, it should be noted that the controls show improved performance on the coordinate task when a small cross is used, compared to the large cross. This is consistent with previous findings in a larger sample of healthy controls (Van der Ham et al., in press). In contrast, NC shows the exact opposite effect by 15% in accuracy. This may indicate the use of a different strategy. For the odd one out, she is significantly impaired in making coordinate decisions, and not in making categorical decisions. NC is not impaired on any of the other tasks.

Local global spatial perception

In Table 3 the mean performance on the local global spatial perception task is shown and in Figure 1 the attentional bias on this task is depicted. This bias was calculated with the formula: (ERlocal–ERglobal)/(ERlocal + ERglobal) × 100, with ER representing the error rate, the same formula was used for the response times. As a global bias is normally found, a positive value indicates a global bias and a local bias is indicated by a negative value (all in percentages). Single case Bayesian statistics based on Crawford and Garthwaite (2007) was used to compare NC's biases to the controls'. The Bayesian p value for the error rate bias was <.01, and for the response time bias it was <.05. Both indicated a stronger local bias for NC, compared to the controls.

TABLE 3
Mean performance on the local global spatial perception task for both NC and the controls

	NC		*Controls (N = 6)*	
	Acc	*RT*	*Acc*	*RT*
Local	92	1754	85 (13)	865 (237)
Global	82	2017	99 (3)	808 (178)

Accuracy in percentages, Response Time in milliseconds, standard deviations in parentheses. Acc, Accuracy; RT, Response Time.

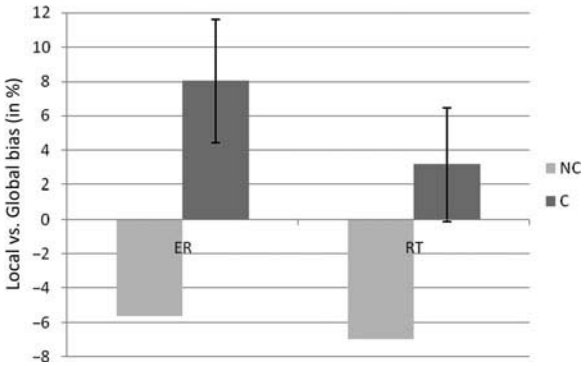

Figure 1. The ratio of local versus global performance for NC and controls. Positive values indicate a global bias, negative values indicate a local bias. Error bars represent the standard error of the mean (SEM).

Practical exercises

In the writing exercise, a change in handwriting was noticeable when NC had to write between the two horizontal lines. Her writing became less fluent appeared to take more effort. Moreover, in the smallest aperture she could write between, she left out the word "girl" in the sentence. The controls were able to write between apertures that were 1–2 mm smaller compared to the smallest aperture of NC.

During drawing NC had some problems with sizing lines of her drawing, in particular with the simpler images. For instance, her half of the drawing of the pentagon was considerably wider than the half provided. An example of these drawings is provided in Figure 2. In this example a five-point star was to be completed. NC's drawing clearly shows repeated attempts at correcting the image and clearly deviant angles of the lines. This drawing illustrates her self-reported problems with writing and drawing as well as the observations described earlier.

In the walking task, NC was able to draw complete rectangles reflecting the routes she walked. However, both drawings were nearly squares and highly similar even though she had walked two clearly rectangular routes that were also clearly different from each other. The distances she provided were underestimations, and held little relation to the drawing: a line representing 8 m was almost as short as a line representing 4 m.

DISCUSSION

In this study case NC is reported with a specific problem in judgment of line orientation and atypical behavior during the Rey-Osterrieth Complex

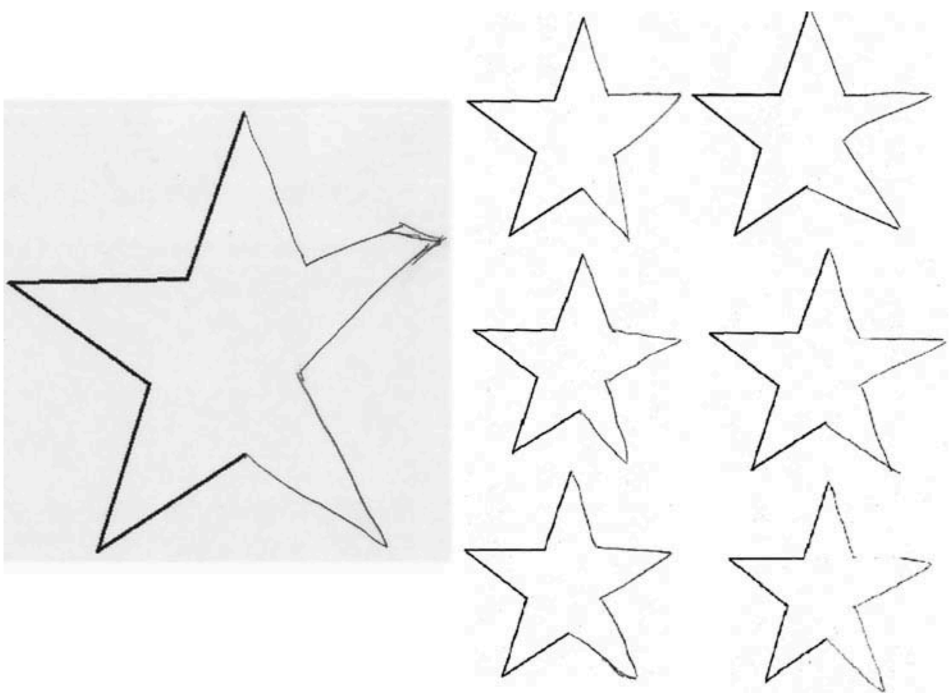

Figure 2. One of the drawings made by NC, where she was asked to mirror half of the star figure. This illustrates her corrective behavior and impaired ability to correctly copy simple geometric shapes. To the right of the star completed by NC, the drawings of all six control participants are depicted.

Figure test during a general neuropsychological examination. Follow up tasks specifically aimed at testing spatial perception suggest that both could be caused by a specific impairment in processing coordinate spatial relations. In judging line orientations she has a specific problem with the oblique lines, which can be considered coordinate, as opposed to the horizontal and vertical lines, which are categorical. Furthermore, her copy of the complex figure shows coordinate under- and overestimations of line length.

The set of tasks specifically assessing categorical and coordinate performance indicates that she performs significantly worse than the controls on the coordinate part of the odd one out task, in which she has to compare coordinate properties of the position of four objects. In addition, she is differently affected by context in coordinate processing, as shown by her performance on the coordinate part of the cross dot task. Whereas healthy controls prefer a small cross to estimate distances, NC seems to benefit from the information provided by the large cross, which indicates a different approach to the task. These coordinate problems are complemented by the observations made during the practical exercises; her writing, drawing and map drawing suffer from inaccurate coordinate processing. Strikingly, she is not impaired on all coordinate tasks, as she is able to detect changes in complex visual scenes and is not impaired in coordinate accuracy on the cross dot task. This suggests that besides a basic coordinate impairment, other task properties, besides instruction, may affect NC's performance. It should be noted that the lack of impairment in the scene perception task does not seem to reflect lack of sensitivity of this task, as impairment was found in a sample of stroke patients with comparable cognitive abilities (van der Ham et al., 2011).

This coordinate impairment is further substantiated by the location of the lesions visible in NC's brain scan, as many studies have reported that coordinate information is mainly processed by the right hemisphere. However, due to the diffuse and progressive nature of these lesions in Susac's disease it is not possible to provide reliable quantitative measures of lateralization in lesion size.

A potential alternative explanation for the results found here could be that NC's impairment is linked to difficult spatial tasks, which would result in coordinate impairment as categorical tasks are typically easier. This matter has been raised before in the field of spatial relation processing (e.g., Martin, Houssemand, Schiltz, Burnod, & Alexandre, 2008; Sergent, 1991), but has been refuted as well (e.g., Kosslyn et al., 1992; van der Ham, Raemaekers, van Wezel, Oleksiak, & Postma, 2009). Also for the current findings it does not seem to be a satisfactory alternative, as some of the coordinate tasks for which impairment is found (e.g., the line orientation task) are easier than categorical tasks for which no impairment is found (e.g., in the scene perception task in which complex visual images were used, her accuracy was 100%). Furthermore, NC had an above average performance in several complex tasks in the regular neuropsychological assessment (e.g., Location Learning Test (70–85 percentile), Corsi block tapping task (>70 percentile)). It could be that differences in difficulty contributed to the current findings, but they cannot be viewed as the single cause of the impairments observed.

Importantly, the odd one out task had the largest stimuli and for the coordinate task it requires the participants to scan the whole stimulus in order to respond. Therefore, a global, larger scope of attention is required for this task. The local global spatial perception task clearly shows that the naturally occurring scope of attention of NC, as measured by her bias towards local stimuli, is significantly smaller than that of healthy controls. In fact, her clear local bias could explain many of the findings and observations made. As discussed in the introduction, it has been suggested that by actively varying the scope of attention, the performance level on categorical and coordinate tasks can be differentially manipulated. Laeng et al. (2011) and Michimata et al. (2011) argue that this is caused by a top-down and dynamic influence on receptive field sizes. This notion leads to a link between a local, or small scope of attention and categorical performance, and between a global, large scope of attention and coordinate processing. The current case study supports this theory by showing that by simply assessing spontaneously occurring biases in the scope of attention, without experimental manipulation, such a link is also found. The data suggest that NC is biased towards a small scope of attention, inhibiting her from correctly processing coordinate spatial relations in her environment.

It should be noted that the haptic spatial relations task showed comparable performance of NC and controls, suggesting that her impairment is restricted to visual sensory processing. In addition, the practical exercises indicate that this coordinate problem may not be limited to a scale of centimeters, but also affects how short routes of circa 20 m are processed. It could be argued that such routes require a more global scope of attention, to take in all necessary environmental information.

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