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Cognitive processes among children with autism spectrum disorder

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Abstract

Although several attempts have been made to elucidate cognitive processes among children with autism spectrum disorders (ASD), research in this area yields inconsistent results. The aim of our research was to compare the performance of individuals with ASD and neurotypical (NT) individuals in terms of specific cognitive processes (verbal working memory, processing speed, perceptual reasoning, and selective attention). The research sample consisted of 20 children with ASD and 20 NT children, matched on age, sex and IQ. Participants were administered four experimental tasks, each of which involved one of the named cognitive processes. The results indicated significant deficits in individuals with ASD in verbal working memory and processing speed. On the contrary, there were no differences in perceptual reasoning and selective attention compared to NT individuals. The presented results and their practical impact are discussed in the light of previous findings.

Keywords: Cognitive processes, autism spectrum disorders, children, heterogeneity

Introduction

Autism spectrum disorders (ASD) include neurodevelopmental disorders characterized by deficits in social interaction, communication, and repetitive patterns of behavior, interests, or activities [1]. In ASD, the predominance of prevalence in individuals of the male gender is known, most reported in a ratio of 4:1 [2].

There are several possible reasons for the higher prevalence of ASD in men. One explanation is provided by the extreme male brain theory [3], the female protective effect theory has also gained support [2,4], and gender differences in symptomatology are also a possible explanation [5]. A separate area is the controversy about the sufficient sensitivity of diagnostic tools to the female autistic phenotype [6,7]. Considering the differences discussed, we can consider that ASD develops and manifests differentially according to gender. Clinically, this suggests that gender-specific cognitive assessments may be useful [8]. However, this does not detract from the importance of examining the cognition of this population.

As the number of children diagnosed with ASD increases, empirical investigations of the cognitive mechanisms underlying ASD are becoming dynamic. However, given the complexity of the topic, authors differ in their focus. Thus, certain areas of investigation have been outlined, among which we identify *cognitive theories in the context of ASD* [9], an attempt to capture a kind of *cognitive profile* of these individuals [10-13], or a view of the functioning of *individual cognitive processes* [14-16].

Cognitive Theories in the Context of ASD

One of the research areas identified by us posits that understanding of cognitive processing in ASD may be improved by considering multiple cognitive theories [8]. This may include theory of mind (ToM), which is one of the most important concepts in the field of social cognition, particularly for ASD. However, because this ability to mentalize develops differently in individuals with ASD, they show impairments that result in several areas of problems in everyday life, including the quality of pretend and symbolic play, recognizing emotions from facial expressions and understanding other people's internal mental states, impairments in the pragmatic level of speech, etc. [17].

Further, weak central coherence theory (WCC) [18] refers to the tendency of individuals with ASD not to perceive information as a whole, but to focus on (often irrelevant) details. Support for the WCC has been found particularly within visuospatial tasks. For example, the superior performance of children with ASD has been observed in the Embedded Figures Test [19]. Another example of a task in which individuals with ASD achieve high performance, paradoxically due to global processing difficulties, is Block Design [11,20].

The last of the theories is the theory of executive dysfunction, in which Hill [21] formalized empirical findings on executive function (EF) deficits in ASD, proposed to review and integrate the existing literature regarding EF and the link to ASD. The review focused on five EFs: inhibition, planning, generativity, mental flexibility, and self-monitoring. In addition to summarizing key findings regarding deficits in individuals with ASD in these domains (e.g., intact inhibition on the Stroop test, etc.), the review also highlighted considerable variability in EF performance across studies.

Cognitive Profile

Another area concentrates on identifying the cognitive profile of children with ASD using intelligence tests [10-13], in order to assess the level of cognitive abilities and identify the relative strengths and weaknesses of various cognitive domains [22]. Consistent with the above, some authors [10] found out that the mean distribution of IQ scores in Slovak children with ASD was only slightly reduced compared to the general population mean, and the extremes at both poles were significantly more represented, indicating the existence of significant intracognitive differences in children with ASD that make up their overall intellectual abilities. Regarding the WJIE II factors, individuals with ASD showed significantly higher verbal thinking abilities than cognitive efficiency [10]. These findings are consistent with several studies that have, however, used the WISC-IV [11-13].

Individual Cognitive Processes

The third area focuses on the specifics of individual cognitive processes. For example, research focused exclusively on verbal working memory, which consists in actively maintaining verbal information, suggests the possible existence of preserved aspects of this function [16,23], respectively, it is difficult in finding a consensus regarding impairment of this function in children with ASD [24]. Another potential mechanism contributing to the heterogeneity of deficits in ASD is a fundamental impairment in the speed with which affected individuals can process information [25]. A growing number of studies have provided overwhelming evidence of a significant reduction in processing speed in children with ASD [11,22], or its association with symptoms in the field of communication [12]. However, there are studies that have not demonstrated reduced processing speed in subjects with ASD [13], or alternatively, have offered other explanations for the deficits [26]. Further, it is visual perception, which in the context of ASD is referred to as atypical, not deficient, indicating that the data cannot be processed in a blanket manner. Studies suggest that while they show difficulties when using social stimuli (e.g., discriminating faces or recognizing emotional expressions) [27], they achieve high performance on tasks using perceptual reasoning (i.e., the ability to manipulate visual stimuli, e.g., to organize them), such as Block Design [11,20]. Finally, there are variable manifestations of selective attention that are consistent with executive dysfunction [21], in which, for example, a preserved inhibition is assumed when the Stroop test is used [14,21]. In this case, it is manifested by comparable or lower reaction time (RT) compared to the NT group in the interference condition, which requires selection for relevant information (i.e., focusing attention on word color and suppressing verbal content) [14,28].

Purpose of the Present Study

Based on the empirical evidence presented and the literature analyzed on cognitive processes in children with ASD, we argue as follows. We suggest that the observed heterogeneity reported when trying to identify cognitive profile using intelligence tests [10-13], may be related to the focus of the subtests included in the indexes. In other words, by looking at the child's performance through indexes (or any broad domains), the specifics of individual cognitive processes, which are assessed by separate tests, can be overlooked. To our knowledge, there is no study to date that targets multiple cognitive processes simultaneously, but using other than intelligence tests. In such a case, research efforts have rather focused on verifying proposed cognitive theories [29]. At the same time, the literature is limited by the fact that some studies focus on only one cognitive process [15], which makes it difficult to compare them. We propose that empirical support for the issues outlined above requires a comprehensive analysis of cognitive processes to allow the confrontation of performance in different test methods.

Methods

Sample

The research sample (*N*=40) consisted of two groups of children, matched on age, gender, and IQ. The ASD group consisted of 20 children who had been previously diagnosed with ASD by a clinical specialist but also had to meet the presence of autistic traits, which we verified using the *Autism Spectrum Quotient – 10 items (AQ-10) (Child)* [30]. None of these children had other co-occurring disorders at the time of testing that could have affected their performance. The NT group included 20 children who did not receive this or any other clinical diagnosis. The age range of children in both groups was from 10 to 11 years (both groups had the same age mean and standard deviation, i.e., *M*=10.60; *SD*=0.503). The ratio of boys and girls included in the groups corresponded to the prevalence ratio of ASD across genders, i.e., 4:1 [2]. Both groups included children without intellectual disabilities (IQ≥70).

Materials

Raven's Coloured Progressive Matrices

The *Coloured Progressive Matrices* (CPM) [31] is a 36-item non-verbal intelligence test of average difficulty, which was used to match children on intellectual abilities. The CPM is suitable for diagnosing children from the last year of preschool age up to the age of 11, as well as for diagnosing older people (norms are available for children from 5.5 to 11.5 years and for healthy adults from 65 to 85 years) [31].

Autism Spectrum Quotient – 10 items (AQ-10) (Child)

The *AQ-10* [30] was used to capture autistic traits, consisting of statements answered by the parent of a child aged 4 to 11 years using a 4-point Likert scale. It is a rapid screening method with excellent internal consistency (α = .900), high sensitivity (95%) and specificity (97%) at a cut-off score of 6, i.e., the condition for inclusion of a child in the experimental group was to reach a score of 6 or higher. The mentioned questionnaire was used to ensure that individual participants were correctly assigned to either the ASD group or the NT group, as we did not conduct a diagnostic assessment.

Measuring Device

To record participants' responses, we used a 7.9-inch Apple iPad (5th generation) (hereinafter referred to as the iPad), with a Retina display and a resolution of 2048 × 1536 with a density of 264 pixels per inch. All the test methods presented below were administered on that iPad.

Measuring Verbal Working Memory

To measure verbal working memory, we constructed a test using the *Digit Span Task (Backwards-Only)* (DSB) [32] paradigm, as this test assesses children's ability to store verbal information in short-term memory and subsequently manipulate it. The test consisted of the examiner pronouncing a list of digits (in our version, these were recordings run through an iPad), at a rate of approximately one digit per second, while the participant's task was to immediately (verbally) reproduce the sequence of digits in reverse order (e.g., if the examiner said "one -two", the correct answer was "two-one"). This continued until the trial with nine digits. The total score, i.e., the number of correctly reproduced number series, was the dependent variable.

Measuring Processing Speed

The *Processing Speed Test* (PST) [33] was used to test cognitive processing speed, and the essence of the PST is in line with the already presented definition of processing speed, i.e., it reflects the ability to quickly recognize and process the same and different symbols [25]. The PST consisted of matching digits to symbols according to a key. This process was repeated for 120 seconds, after which the test was terminated. The number of digits correctly assigned during this two-minute interval was recorded, which represented the dependent variable.

Measuring Perceptual Reasoning

To assess perceptual reasoning, the *'Reverse' Computerized Block Design Task* (RCBDT) [34] was used, which evaluates "the construction of a global representation [...] to document the role of a deficit [...] in the local bias" (p. 1794). The task was to match an unsegmented stimulus to a corresponding segmented target stimulus presented between three segmented distractors that differed from the target by color inversion, local difference and rotation. The independent variables of the task were perceptual cohesiveness (PC; minimum, intermediate, maximum) × task uncertainty (TU; min, max) × size (4, 9, 16), resulting in 18 stimuli. The dependent variable was the correctness of the response, which the participant indicated by clicking on one of the four options. Unlike the original version, no time limit was set for task completion.

Measuring Selective Attention

The *Computerized Stroop Test* (CST) [35] assesses selective attention, or the ability to attend to specific characteristics of a stimulus while ignoring task-irrelevant characteristics. The test consisted of three parts: matching colors to their names (part 1), determining the colors of the circles (part 2, the congruent condition), and determining the colors with which the words were written but denoting other colors (part 3, the incongruent condition), and in each part the participant responded by touching on one of four options – four buttons at the bottom of the screen, each of which had one of the colors – red, green, blue and yellow. Subsequently, interference RT and the interference score (i.e., the differences of means in the third and second part) were calculated.

Procedure

Testing took place in the participants' everyday environments. The cognitive tasks were performed by each participant in a quiet room, while they were administered individually, i.e., there was only the participant and the administrator in the room, who supervised the progress and provided technical support when using the iPad. At the beginning of each participant's testing, he launched an application into which he always entered a randomly assigned identifier and the participant's age. Subsequently, in a randomly determined order, he gradually ran individual tasks.

While performing the tasks, the participant sat in a chair behind a table on which the iPad was placed at a distance of approximately 40 centimeters from the participant's eyes. The participant was not allowed to manipulate the iPad to ensure the same conditions for all participants. Each participant performed the tasks independently, thanks to the verbal instructions that were automatically triggered before the start of each test.

Results

Below we present our findings with respect to individual cognitive processes. All variables were normally distributed as checked by the Shapiro-Wilk test, but except for interference RT.

Verbal Working Memory

Insight into verbal working memory was obtained by performing an *t*-test for independent samples for the sum of correctly reproduced number series in the DSB task. A comparison of the ASD and NT group participants revealed significant differences in verbal working memory, $t(37.886)=9.875$, $p<0.001$. This, even based on the data in **Table 1**, could be interpreted that participants in the NT group performed significantly better than participants with ASD. In accordance with the above, the standardized effect size indicated a large effect, $d=3.123$, 95% CI_d [2.178, 4.049].

Table 1, Means, Standard Deviations and Significance of Parametric Statistical Comparisons of Participant Groups (ASD vs. NT) in Individual Test Methods .

	ASD group		NT group		*p*
	M	*SD*	*M*	*SD*	
DSB	3.05	1.28	7.15	1.35	<0.001
PST	16.30	7.79	48.10	6.59	<0.001
RCBDT	16.45	1.11	16.35	0.99	0.764
CST	249.80	138.93	298.90	88.50	0.192

Note. DSB – Digit Span Task (Backwards-Only), maximum score = 16; PST – Processing Speed Test, the number of correct answers in a time interval is recorded, i.e., it has no maximum score; RCBDT – 'Reverse' Computerized Block Design Task, maximum score = 18; CST – Computerized Stroop Test, in the above table we only report the interference RT in milliseconds. For a more detailed analysis of the CST, see Table 2.

Processing Speed

Based on the *t*-test for independent samples, where we compared participants with ASD against the NT group in the PST task, we can conclude that the performance of participants with ASD was significantly slower compared to the NT group, $t(36.969)=13.938$, $p<0.001$, as documented in **Table 1**. Cohen's *d* value yielded a large effect size, $d=4.408$, 95% CI_d [3.402, ∞].

Perceptual Reasoning

We tested participants' perceptual abilities with the RCBDT task, which was assessed using a repeated measures analysis of variance (ANOVA) with the between-subjects factor group (ASD vs. NT) and within-subjects factors PC (minimum, intermediate, maximum), TU (min, max), and size (4, 9, 16). Results of the analysis showed no significant difference between participant groups in perceptual reasoning, $F(1, 38)=0.092$, $p=0.764$, along with a small effect size, $\eta^2_p=0.002$.

All within-subject managed factors (PC, TU, and size) were found to significantly influence the dependent variable, PC: $F(2, 76)=11.060$, $p<0.001$, $\eta^2_p=0.225$, TU: $F(1, 38)=14.241$, $p<0.001$, $\eta^2_p=0.273$, number of dice: $F(2, 76)=13.134$, $p<0.001$, $\eta^2_p=0.257$. It should also be noted that none of the interactions of the within-subject factors with group proved statistically significant.

Selective Attention

We performed the analysis of selective attention using independent *t*-tests for the mean RTs and correct responses ASD participants versus NT participants across treatment conditions in the CST task.

Table 2 summarizes the descriptive and inferential statistics obtained for the RTs and interference scores. In the case of interference RT, the larger the difference between the non-congruent (part 3) and congruent (part 2) part, the larger the effect of interference on attentional bias to the stimulus of interest. Regarding the interference score (i.e., error rate), the lower (or more negative) the score resulting from the difference between the third and the second part, the greater the interference effect, i.e., the lower the ability to respond

Table 2. Median and Nonparametric Statistical Comparisons of the Performance of Groups of Participants (ASD vs. NT) in the CST Conditions.

		Mdn		*U*	*p*	r_{rb}	$95\%CI_{rrb}$	
		ASD	**NT**				**lower**	**upper**
Part 1	RT	-	-	-	-	-	-	-
	Score	23	24	334.5	<0.001	0.673	0.424	0.827
Part 2	RT	1487	780	0	<0.001	-1.000	-1.000	-1.000
	Score	24	24	241.5	0.074	0.207	-1.511	0.517
Part 3	RT	1698	1072	0	<0.001	-1.000	-1.000	-1.000
	score	22	24	340.0	<0.001	0.700	0.466	0.842
Interference	RT	See Table 1 for the interference RT analysis.						
	Score	-2	0	328.5	<0.001	0.643	0.380	0.809

Note. RTs are given in milliseconds.
Part 1 – inclusion criterion, i.e., each participant had to achieve at least 80%;
part 2 – determination of the colors of the circles, the congruent condition;
part 3 – determination of the colors of the written words, the incongruent condition;
interference – differences of the means in the third and second parts.

correctly to the target stimulus (in this case, the color with which the word was written) in the presence of the distractor stimulus (the presented word that names the color) [28]. The table excludes interference RT, in which a between-group difference was not demonstrated, $t(32.240)=1.333$, $p=0.192$ (see also **Table 1**), with an effect size suggesting a small to moderate effect, $d=0.422$, 95% CI_d [-.210, 1.047].

Discussion

The presented work focused on selected cognitive processes in children with ASD, their performance was compared to the performance of NT children, matched on age, gender and IQ. We used a between-group design to identify the performance of individuals with ASD versus the NT group in terms of specific cognitive processes selection of which reflected previous research [11,12,14,20,21,23,24].

To examine the specifics of working memory in individuals with ASD, we focused exclusively on verbal working memory, mainly due to discrepancies between studies [24]. Our results indicated significant deficits in individuals with ASD as compared to NT individuals. However, their performance was consistent with other studies [13], but also with the cognitive profile of the Slovak research sample [10], where participants with ASD showed the second lowest scores among the WJIE II subtests precisely in the Numbers Reversed subtest, which uses a comparable paradigm to the DSB test we administered. Moreover, this finding clarifies potential methodological shortcomings of the meta-analysis [23] that reported significantly more impairment in spatial working memory than verbal working memory, but the results may have been distorted due to a lack of systematic literature search [36]. We are therefore more inclined to the explanation that children with ASD, compared to NT children, do not show modulation of increasing brain activation with increasing cognitive load, which may have been why they showed difficulties with increasing verbal information [37]. Furthermore, for correct reverse reproduction of number series backwards is needed not only the retention of verbal information, but also its manipulation, which requires the central executive, in which individuals with ASD are deficient [21,38].

Analysis of group differences in the processing speed test showed significant deficits in individuals with ASD compared to NT individuals, which was consistent with previous findings [10-12]. Some of the authors [11,12] relied on the WISC-IV subtests to make inferences about the processing speed of individuals with ASD, one of which, the Coding subtest, closely resembles our modified PST in the nature of the task. Whereas in the Coding subtest the participant's task is to redraw symbols to the corresponding numbers, in the administered PST the participant had the task of matching the numbers to the corresponding symbols from the presented key, which he or she could do by clicking on one of the buttons at the bottom of the iPad screen. Kenworthy et al. [26] suggest that a consequence of this difference between tests could be that processing speed in individuals with ASD could also appear as intact, as it minimizes motor tasks that subsequently do not interfere with the ability to perceptually process the stimuli. Based on the above, they caution that deficits in processing speed in individuals with ASD may reflect difficulties in integrating visual processing with motor output rather than processing speed per se. However, despite the digitization of the task and a significant reduction in motor tasks, individuals with ASD were lagging behind in performance in the present research. It is therefore possible that their performance on the PST did indeed reflect impaired cognitive processing speed in individuals with ASD, possibly in combination with some signs of motor deficits, but probably not motor deficits alone.

In contrast, the difference in perceptual reasoning between the ASD and NT group did not appear to be significant, supporting previous research [11]. Moreover, the perceptual processing characteristics of individuals with ASD demonstrated in the RCBDT task are consistent with WCC theory [18] and provide the basis for the phenomenon known as "looking at the trees but not at the forest" [20]. Deficits in holistic processing as perceived by the WCC may therefore have facilitated the performance of individuals with ASD on the administered task [33]. However, one should also consider that a ceiling effect may have occurred in the task, given the low error rates of both groups of participants. This is also pointed out by Caron et al. [33], who additionally explain this by the segmentation of the picture, as this significantly reduces the difficulty of the task.

Finally, we examined selective attention. Research generally suggests that it is either intact [14,21] or that it is not the most prominent deficit among the EFs in ASD [39]. However, our findings are not consistent across the components of the modified version of the Stroop test, the CST, and therefore no firm conclusion can be reached. According to our results, individuals with ASD show significantly lower performance than NT individuals for the RT in the congruent condition (part 2), and the RT and score in the incongruent condition (part 3). Significantly increased RTs in both the congruent and incongruent condition indicate general deficits in attention in children with ASD, which have already been reported [40]. The results further implicated interference, providing insights directly into selective attention [14,28]. Based on these results, it appears that interference (i.e., error) scores are likely to be more specific to the diagnosis of ASD than interference RT. Specifically, in our analysis, we observed a significant between-group difference in inference score, but did not detect a difference in interference RT. In general, its presence reflects the fact that participants find a word semantically interfering when trying to name the color it is written in. This consequently slows down the participants' RTs compared to the congruent condition, in which they have to name the colors without semantic conflict [14]. However, based on our results, it appears that children with ASD may have been differentially affected by word meaning than NT children when asked to respond to the color in which the word was written. This can explain the lower interference RT for ASD participants (although this was not a statistically significant result when compared to the NT group), and also the significantly lower interference score. Our findings thus suggest, along with previous research [14], that reading comprehension level may have influenced the size of the interference effect, which may lead to inaccurate conclusions regarding selective attention in individuals with ASD. This claim can be supported by the results of individuals with ASD in the first part of the task, which was an inclusion criterion. Although all subjects met this criterion, the scores of the ASD individuals were significantly lower than those of the NT individuals, indicating deficits in reading. Moreover, individual differences in the effects of inner speech may have been present in our results, the inability to apply which may have accounted for the lower interference score. Although this proposed explanation is consistent with the ToM [17], hypotheses of preserved selective attention have often overlooked interference scores and sought support only in the comparable or lower interference RT of individuals with ASD versus the NT group [14,21], on which basis we chose to express only cautious support for our finding.

At this point, we would additionally like to make a case for the relevance of digitalization of tasks. Williams et al. [41] suggest that the use of computers in testing children with ASD can be an effective means of addressing many potential problems simultaneously, including social and linguistic demands of testing and motivation issues. We add that the use of digital devices (in our case, the iPad) is also effective in terms of the objectivity of the instructions used (each participant received identical instructions), recording and processing of the results, further highlighting the potentially high reliability of the RT measurement. However, this raises the question of whether our results are equivalent to those of traditional tests, i.e., non-digitized tests. Studies in which authors have compared individuals' performance on experimenter-administered tasks versus performance on computerized versions of the tasks suggest that these versions of the tasks may be interchangeable, as they have not demonstrated a difference in the performance of individuals with ASD across task variations [42]. Due to these facts, we consider comparisons of our results with those of even traditional forms of testing to be permissible. However, we believe that it is important for clinical judgment to critically interpret the information, considering both the benefits and potential drawbacks that may have arisen when using digitized tasks.

Limitations and Implications for Future Research

The interpretation of our research results must also be taken into account in terms of several limitations. Firstly, we selected children with ASD from specialized school facilities, but we did not clinically verify their diagnosis, only the presence of autistic traits. Although this research contributes to a better understanding of the specific cognitive processes of children with ASD, the heterogeneity in research regarding the spectrum of autistic disorders might indicate that our ASD group is not perfectly comparable to other such groups. Secondly, the size and specifics of the research sample (e.g., average intellect) make it impossible to generalize our findings to the broader population of children with ASD. It is also important to note that this is a clinical and hard-to-reach population. Finally, it is necessary to reflect on the unverified convergent validity of the experimental tasks we used, as well as their scope. For future research, we therefore propose to use other standardized methods (at least to verify their correlation with the experimental tasks), but also to extend the tests we used to include more stimuli, which could clarify the ceiling effect, but could also provide interesting information on the effect of task difficulty. Further, we are thinking of extending the research to analyze gender differences in the cognitive processes, which, however, requires a larger and more gender-balanced sample.

Implications for Practice

However, our research overall points to the fact that a comprehensive approach is needed when testing the cognitive processes of children with ASD to differentiate between the child's strengths and weaknesses, which may also bring interesting practical implications. From a clinical perspective, our findings regarding preserved ability of local stimulus processing may allow us to design perceptual skills training programs that could be useful for individuals with ASD in choosing an appropriate job application. Conversely, findings regarding deficits in processing speed (including low RTs with higher error rates in selective attention) may lead to measures that provide individuals with ASD with more time to complete certain activities, or to omit the use of time-limited tasks. Moreover, these findings emphasize the need to consider the specifics of a given cognitive process subtype (rather than the entire domain) when designing an intervention.

Conclusion

There is a gap in the literature in the context of ASD, in our opinion, due to the homogeneity of the test methods used when attempting to capture the cognitive profile of individuals with ASD. We therefore see benefit in testing specific cognitive processes, which reduces heterogeneity in the literature. Moreover, testing narrower cognitive processes and comparing them within a single research sample has interesting implications for future research as well as for practice (e.g., by supporting the findings on impaired processing speed, we propose to eliminate time-limited tasks for children with ASD).

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Authors' contributions	**ES**	**MJ**
Research concept and design	√	√
Collection and/or assembly of data	√	--
Data analysis and interpretation	√	√
Writing the article	√	--
Critical revision of the article	--	√
Final approval of article	√	√
Statistical analysis	√	√

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