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The reliability of wine sensory analysis results tested by different correlation models: the example of the impact of SARS-CoV-2 virus infection

Testiranje pouzdanosti rezultata senzornih ispitivanja vina različitim korelacijskim modelima: primjer utjecaja infekcije SARS-CoV-2 virusom

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ABSTRACT

Sensory testing is an indispensable part of wine certification, serving as a producer and consumer legal safety tool. Therefore, monitoring of sensory assessment should be a regular laboratory activity, given that subjective biases are a permanent potential source of result errors. These errors can be caused by internal or external factors that create personality and sensory skills. This paper presents the results of a qualitative and quantitative assessment of the work of eight certified wine assessors who overcame infection with the SARS-CoV-2 virus. It can cause sensory dysfunction, and the question is whether it affects the reliability of the results in sensory testing. Two factors were taken into statistics: an equal period of work before and after the infection (different number of analyses) and an equal analyses number (different time of work). Different correlation tests showed good compliance between the assessors and panels and consistency concerning the tested parameters, observed periods, and the number of analyses. In the case of two assessors, a significant discrepancy was found in the proportion of results within the most numerous scoring qualitative range for the "working time" factor. However, it was confirmed for the factor 'number of analyses' in the case of only one assessor. This study confirmed the importance of controlling sensory testing results and selecting appropriate statistical tools, particularly in extraordinary circumstances and regardless of the assessors' level of expertise. It enables control of potential bias, reliability of results, and confidence in the testing laboratory.

Keywords: sensory analysis results, correlations, wine expert assessors, COVID-19

SAŽETAK

Analiza senzorne kakvoće neizostavan je dio postupka certificiranja vina, služeći kao legalan alat zaštite proizvođača i potrošača. Praćenje senzornih ispitivanja bi stoga trebala biti redovita laboratorijska aktivnost, obzirom da je subjektivnost trajan potencijalan izvor pogrešaka u analitičkom procesu. Ove pogreške mogu biti uzrokovane unutarnjim ili vanjskim čimbenicima koji definiraju osobu i osjetilne sposobnosti. U ovom radu prikazani su rezultati kvalitativne i kvantitativne analize rada osam ovlaštenih ocjenjivača vina koji su preboljeli infekciju virusom SARS-CoV-2. Ova infekcija može uzrokovati disfunkciju osjetila pa je otvoreno pitanje može li posljedično imati utjecaja na pouzdanost rezultata u senzornim ispitivanjima. Statistička analiza temeljena je na dva faktora: jednakom periodu rada prije i poslije bolesti (različiti broj analiza) i jednakom broju analiza (različito vrijeme rada). Različiti korelacijski testovi pokazali su dobru do odličnu usklađenost između ocjenjivača i komisija te dosljednost u pogledu ispitivanih parametara, kvalitativnih raspona metode 100 bodova, promatranih razdoblja i broja analiza. U slučaju dva ocjenjivača utvrđeno je značajno odstupanje u udjelu rezultata u najbrojnijem bodovnom kvalitativnom rasponu, prije i nakon bolesti, za čimbenik „vrijeme rada“, ali je za čimbenik „broj analiza“ utvrđeno samo za jednog ocjenjivača. Ovo je istraživanje potvrdilo važnost kontrole rezultata senzornih ispitivanja i izbora odgovarajućih statističkih alata, osobito u izvanrednim okolnostima i bez obzira na razinu znanja i sposobnosti ocjenjivača. Ovakve analize dodatno omogućuju kontrolu potencijalnih pogrešaka, pouzdanost rezultata i povjerenje u ispitni laboratorij.

Ključne riječi: rezultati senzornih analiza, korelacije, ekspertni ocjenjivači vina, COVID-19

INTRODUCTION

Sensory analyses and assessors' monitoring

Sensory evaluation is a mandatory part of the standard protocol that precedes the marketing of Croatian wines with a Protected Designation of Origin (PDO). It is carried out following the EU Regulation (EU, 2013), national implementing legislation (POV, 2022) and international laboratory standard HR EN ISO/IEC 17025:2017, with technical conditions following EN ISO 8589:2007. The measuring instrument is a seven-member commission whose task is to test the wine quality concerning wine faults, evaluate the typicity and traceability of the organoleptic properties described in the PDO specification, and control sensory parameters influenced by specific production methods that can be declared. Numerous factors can potentially more or less burden the subjective dimension of this testing, and the assessor is permanently faced with challenges to avoid physiological and psychological bias. To ensure the reliability of sensory results, it is essential to control all external and internal factors in analytical work. A multidisciplinary approach seeks a tool that minimizes and neutralizes subjectivity (Parr, 2007). National criteria for assessors in this specific task of certifying Croatian wines with PDO ensure the highest level of expertise and therefore a significantly lower probability of bias in analytical work, as previously presented (Alpeza et al., 2022). The assessors are academically educated professionals in viticulture and enology, active in that sector, and certified experts in wine sensory testing. In addition to regular monitoring of their performance in standardized sensory tests, extraordinary monitoring should be conducted as needed (Alpeza et al, 2021). An example of extraordinary and necessary monitoring is when an assessor has experienced health issues that may affect their senses, such as a SARS-CoV-2 infection. Sensory disorders can introduce errors into analytical work in such cases. These errors must be identified, as the data from subjective analyses constitute a more complex matrix than they may initially appear. Consequently, developing novel methodologies and improving existing ones is a critical and ongoing endeavor. It is important to use appropriate statistical methods and interpret the results correctly (Næs et al., 2011; Khalafyan et al., 2021; Perez-Elortondo and Zannoni, 2021; Marques et al., 2022). This kind of PDO wine sensory evaluation is specific, particularly because methods do not have formal approval by the procedures in the EU, as it is proposed for chemical analyses. EU member states or PDOs can decide on the methods for sensory testing (Gomis-Bellmut et al, 2024. An additional burden arises because evaluations are typically not repeated except for one or two samples. The most demanding aspect of ensuring the quality of results is the lack of generally accepted statistical tools for controlling assessors/results, unlike sensory methods commonly used for research purposes (Marques et al., 2022). In the case of the sensory evaluation of wines with PDO in Croatia, seeking an appropriate assessor control tool that could be accepted and integrated into an operational routine system is challenging due to the sensory testing method (Alpeza et al., 2022). Therefore, we expanded the scope of research to include similar conditions related to the testing method (numerical, absolute) and the absence of repetition. Thus, papers that evaluate quality in international competitions can also be helpful.

SARS-CoV-2 infection and sensory dysfunction

According to the World Health Organization (WHO, 2024), the most common symptoms of the SARS-CoV-2 virus infection include smell and taste dysfunction (https://www.who.int/health-topics/coronavirus#tab=tab_3). These dysfunctions can be manifested in various ways and intensities: complete loss of smell or taste (anosmia, ageusia), diminished sense of smell or taste (hyposmia, hypogeusia), perception of smells or tastes that are not present (phantosmia, phantogeusia), qualitatively altered sense of smell or taste (dysosmia, parageusia), and intensely unpleasant or repulsive smells or tastes (Marshall, 2021). The most prominent symptom is partial loss of smell (hyposmia). Various studies have reported that patients exhibit similar intensities of olfactory

dysfunction, including anosmia, hyposmia, and taste disorders (Saniasiaya et al., 2020; Zhang and Ma, 2020). According to Qiu et al. (2022), taste disorders frequently accompany hyposmia. A meta-analysis of 83 studies encompassing 27492 patients diagnosed with COVID-19 from December 1, 2019, to July 23, 2020, revealed an overall prevalence of olfactory disorders at 47.85%. Among European patients, the prevalence was 54.4% (Saniasiaya et al., 2020). The exact number of patients in Croatia reporting hyposmia or anosmia as symptoms of SARS-CoV-2 infection remains unknown. However, limited data exist: Žaja et al. (2021) reported that 41% of COVID-19 patients in their study experienced hyposmia, while Milanković et al. (2022) found that 44% of patients exhibited symptoms of smell disorders.

Chemosensory dysfunction is prevalent in COVID-19, manifesting as isolated smell, taste, or combined dysfunction. These symptoms differ from those associated with other viruses by their sudden onset and rapid recovery (Butowt and von Bartheld, 2021). Although these alterations are often transient, they can persist in some cases after recovery, and some individuals may not be immediately aware of their reduced olfactory abilities (Boscolo-Rizzo et al., 2021). Most individuals regain their chemosensory function within the first 28 days, but a quarter of patients exhibit persistent dysfunction. Ludwig et al. (2023) found that patients tended to experience prolonged olfactory and gustatory dysfunction symptoms. Many patients reported symptoms even after 4-6 months, with hyposmia (53%), anosmia (12%), and hypogeusia (22%), in contrast to the 63% who recovered by 4-5 weeks in the cohort studied by Moein et al. (2020).

Several assessors who participated in sensory testing of wines with PDO were infected with the SARS-CoV-2 virus, temporarily halting their participation in these activities. After confirming they were well and experienced no sensory dysfunction, they were reintegrated into the work. Their work and testing results were closely monitored after resuming their duties. Although routine monitoring has suggested the reliability of their results, it remains unclear if infection with the SARS-CoV-2 virus could cause long-term sense alternations and affect sensory competencies. To the best of our knowledge, there are no published scientific articles that address this issue. Therefore, we analyzed more extended periods of their work with different statistical tests to address this question. Some statistic presented in this paper is used for the first time in monitoring assessors in wine sensory testing in Croatia.

MATERIALS AND METHODS

The wine sensory analysis results of eight assessors who recovered from COVID-19 during 2020 and 2021 are processed. Each assessor reported infection and temporarily paused official sensory analysis duties. They all described symptoms and sensory dysfunctions they experienced. After informing the laboratory of their recovery, they were reinstated into sensory testing commissions. The described symptoms, disorders, and data from the analyzed results are presented in Table 1. The assessors' control charts were examined, including all results and graphics of deviations. According to internal evaluation quality standards explained in a study by Alpeza et al. (2022), the results that did not meet reliability requirements are excluded. For each assessor, the same work period was analyzed: 12 months before the infection and 12 months after the return to sensory activities post-recovery.

The data was processed at a few statistical levels. The first level was the calculations performed in each panel set of results: assessor/panel deviations and a linearity test between the variables. Scatter plot analyses were conducted for all tested parameters describing the relationship between individual assessors' ratings and those of the panel. The results indicated a satisfactory degree of linearity, which was clearly confirmed through graphical inspection. This verification supported the use of Pearson's correlation coefficients. Consequently, Pearson's r was employed for the first-level analysis. Those tests provide the first important information about assessor-panel compliance over time. Based on the magnitude of this coefficient, the direction and intensity of the linear correlation between the observed variables can be determined as a functional negative or positive.

Table 1. The data about assessors and analyzed results

Assessor	Panels/sensory testing, before infection (No) [a]	Panels/sensory testing, after infection (No)	Infection year, symptoms
A1	5 / 208	10 / 379	2020: anosmia for 1.5 weeks
A2	8 / 315	8 / 308	2021: no dysfunction
A3	10 / 388	13 / 452	2021: no dysfunction
A4	4 / 145	5 / 203	2020: anosmia for three weeks, ageusia for a few days
A5	7 / 248	8 / 287	2020: hyposmia for two days
A6	8 / 302	10 / 382	2020: anosmia for three weeks, ageusia for two weeks
A7	10 / 410	14 / 583	2020, hyposmia for three weeks, hypogeusia for 1.5 weeks
A8	9 / 353	12 / 418	2020: hyposmia for a week

[a]: The number of panels and sensory analysis during the 12-month working period

When the correlation coefficient value is positive (approaches to 1), as observed in our study, its sampling distribution (distribution of sample estimates) becomes asymmetric and deviates from a normal distribution. Consequently, Fisher's transformation is used for the estimation. Therefore, the next statistics level was Fisher's z-transformation of the correlation coefficient values to perform t-tests of differences between the sets of correlation coefficients of an individual assessor before and after the infection. A prerequisite for performing t-tests is a normal distribution and homoscedasticity of the variances, so Levene's tests of homogeneity of variances and Kolmogorov-Smirnov tests of checking data normal distribution were previously performed. Finally, the differences between the frequencies of the result ranks were analyzed by the test of proportions, where the results are expressed as percentage shares.

Considering that the tests based on the working period as a statistical factor involve testing samples with different numbers of analyses, the same tests were performed using a factor of an equal number of analyses.

The data were analyzed in Minitab Statistical Software, 2019 (Minitab, LLC, Pennsylvania, USA), and Statistica, version 12.0 (TIBCO/StatSoft, Tulsa, USA).

RESULTS AND DISCUSSION

The analysis of assessors' deviation concerning the qualitative ranges of points

The 100-point scale is divided into four ranges corresponding to a qualitative standard: 1-57, 58-71, 72-81, and 82-100, as previously described by Alpeza et al. (2022). Based on these ranges, six different levels of deviation are possible. If an assessor's result means unacceptable quality and is furthest from the panel's result, the deviation is -3. Conversely, if the assessor's result signifies the best possible quality and is also furthest from the panel's result, the deviation is 3. The deviations of the assessors' results from the panel's results are presented in Table 2. Assessors 3 and 4 did not exhibit any results in the extreme deviation ranges; for the other assessors, such deviations were negligible (Table 2). Results with deviations of -2 and 2 are also considered irrelevant for most assessors. Most deviations were in levels 1 and -1, indicating the smallest score differences and a high level of agreement in quality perception between the assessors and the panels. Although a score deviation of just one point might seem minor, it could be significant given the assessors' understanding of the qualitative implications of the score ranges. Assessor 2 has a notable proportion of results in deviation levels -1 and 2.

Table 2. The assessor's results deviations in qualitative score intervals of the "100 points" method, before and after the infection

Assessor		Deviations in qualitative ranks of the "100 points" method (%)					
		-3	-2	-1	1	2	3
A1	Before [a]	0	0.96	7.21	12.98	2.40	0.48
	After [b]	0	0.26	3.96	6.60	3.43	1.05
A2	Before	0.32	0.95	14.92	6.66	10.48	1.9
	After	0.97	2.27	13.31	6.82	8.44	1.95
A3	Before	0	2.32	8.76	6.96	1.80	0
	After	0	3.76	7.52	5.97	2.65	0
A4	Before	0	0	7.59	13.1	0.69	0
	After	0	0.49	8.86	12.32	1.48	0
A5	Before	0.40	2.82	4.03	5.24	4.44	0.4
	After	0.35	2.09	6.97	3.81	1.74	0.69
A6	Before	0	2.65	4.96	5.96	1.32	0.33
	After	0	2.62	5.50	9.95	1.31	0.52
A7	Before	0	2.2	6.1	6.1	4.63	0.24
	After	0.34	3.60	5.84	9.43	5.32	0.55
A8	Before	0.28	4.25	6.79	7.08	4.82	0
	After	0.71	4.06	10.29	13.4	2.63	0.95

[a]: 12 months of work before the infection; [b]: 12 months of work after the infection.

However, there is no significant difference in his testing and quality perception before and after infection. He reported no symptoms or dysfunction in smell and taste, suggesting he may have different criteria for quality levels compared to the panels. Furthermore, assessor 4 shows a higher share of deviations in level 1 than the others, indicating a gentler approach to quality level demands. Importantly, his work is consistent and shows no fluctuations related to the infection. Variations in deviations can be a significant potential source of error, as they are unpredictable and difficult to control. Previous studies suggest continuous qualitative deviations are less risky for testing quality than oscillating ones (Khalafyan et al., 2021; Bodington, 2020). Monitoring assessors and understanding their subjective approaches allows for controlling and reducing potential errors.

Correlation analysis and T-test

The obtained correlation values using the Pearson's r model indicate good agreement and alignment between the assessors' work and the corresponding panels (Table 3). Specifically, 38% of the values fall within the coefficient range 0.76 to 1, indicating a very good to complete correlation, and 46% fall within the moderate to good correlation (0.51-0.75). Values indicating weak correlation (0.25-0.50), which are undesirable, were recorded in 11 out of 141 calculations. These observations did not affect the overall assessment of the quality of the assessors' work, as shown by the average values (Table 3). However, assessors 2, 7, and 8 showed some weaker agreement with the panels before and after infection, suggesting additional analyses of their work.

Table 3. Assessor results/panel results correlations

Assessor		No	Pearson correlation coefficients (rP)			
			Min	Max	AS	MED
A1	Before [a]	5	0.74	0.92	0.85	0.88
	After [b]	10	0.68	0.99	0.87	0.91
A2	Before	8	0.46	0.91	0.62	0.64
	After	8	0.41	0.75	0.61	0.59
A3	Before	10	0.67	1	0.84	0.86
	After	13	0.72	0.92	0.8	0.77
A4	Before	4	0.63	1	0.87	0.81
	After	5	0.71	0.92	0.83	0.82
A5	Before	7	0.41	0.93	0.76	0.78
	After	8	0.59	1	0.79	0.83
A6	Before	8	0.48	0.99	0.82	0.84
	After	10	0.54	0.99	0.76	0.82
A7	Before	10	0.57	0.94	0.71	0.69
	After	14	0.33	0.95	0.65	0.68
A8	Before	9	0.42	0.99	0.68	0.71
	After	12	0.38	0.98	0.72	0.74

[a]: 12 months of work before the infection; [b]: 12 months of work after the infection; Rp: Pearson coefficient; No: number of correlation tests; Min: minimal value; Max: maximal value; AS: arithmetic mean; MED: median.

Pre-tests were conducted to verify the feasibility of testing differences between groups of correlation coefficients. Fisher's transformations are normally distributed, and homoscedasticity is absent in only one case, indicating that the T-tests are appropriate. In this context, the T-test enhances the assessor's work control by determining whether the variability of correlation coefficients between groups (before and after infection) is greater than the variability within groups. We found no significant differences between tested assessors relative to the panels, indicating no impact of SARS-CoV-2 virus infection on the assessor/commission concordance (Table 4).

Table 4. The differences among correlations, the results of T-tests

Assessor	Mean before [a]	Mean after [a]	t-value	df	p
A1	1.32	1.54	-0.72	13	0.49
A2	0.82	0.7	0.91	14	0.38
A3	1.38	1.15	1.29	21	0.21
A4	1.84	2.22	-0.59	8	0.57
A5	1.04	1.61	-1.52	13	0.15
A6	1.38	1.28	0.29	17	0.78
A7	0.97	0.85	0.63	21	0.54
A8	1.10	1.10	0.01	19	1.00

[a]: Fisher’s z' value

The tests of the distribution proportions

Another testing method, results distribution proportion, was used to analyse the validity of the results and the assessors' work concerning COVID-19. This paper presents the results of proportion tests for deviation rank 0. This rank indicates results without deviation, meaning the assessors' results are positioned within the same qualitative range as the panel's results. This rank is the most numerous and can be considered a sufficient testing parameter in making general conclusions about the assessors' competencies. The tests showed some deviations in the cases of Assessor 1 and Assessor 8. Their results' compliance with the commission's results in rank 0 was significantly different regarding the factor of equal testing time before and after the infection. Assessor 1 had significantly higher results agreement after overcoming the infection, suggesting improved competencies. Regarding Assessor 8, certain statistical findings indicate inconsistency in his testing performance (Tables 2 and 3). It is evident that Assessor 8 had significantly better results before the infection and demonstrated significantly stronger agreement with the commission (Table 5).

As previously explained, the first factor in the statistical analysis was the 12 months before and after the infection, which resulted in varying data sets for testing. Considering that the frequency of participation in sensory testing could affect the assessor's performance, the same statistical tests were conducted using another factor of an equal number of analyses (Table 6). The results of this test confirmed the statistical significance of differences found in Assessor 1's case based on the time factor. Notably, Assessor 8 exhibited better agreement with the panel's results in the short term after the infection than in the long term. This test did not confirm the findings based on the "time" factor. This raises the question of whether the infection is the cause of his variability or if there is another subjective error source (Stone, 2012).

These two tests presented the importance of the methodology chosen in controlling sensory testing. Thanks to these two tests, certain conclusions can be drawn in the case of Assessor 8 regarding the impact of the infection on his work. The deviations in his sensory testing are not attributable to infection. The need for a more comprehensive analysis of his results is evident to ensure their reliability.

Sensory testing is associated with the constant issue of potential physiological and psychological errors, as the detectors in the measuring instrument are senses connected to all dimensions of humans, which can influence the calculation of the result (Chen and Dalton, 2005).

Table 5. Testing the proportion of the results without deviations, the same period of assessors' work before and after the infection

Assessor	p_1 (%)	N	p_2 (%)	N	$H_0: p_1 = p_2$ $H_1: p_1 \neq p_2$
A1	75.96	208	84.7	379	P = 0.0089 *
A2	64.76	315	66.23	308	P = 0.6966
A3	80.15	388	80.09	452	P = 0.9827
A4	79.63	162	76.85	203	P = 0.5235
A5	82.66	248	84.32	287	P = 0.6055
A6	83.44	302	80.11	382	P = 0.2646
A7	80.73	410	74.96	583	P = 0.0325
A8	76.77	353	67.94	418	P = 0.0003*

p_1: Share of results with zero deviation before the infection; p_2: Share of results with zero deviation after the infection. *: The significance level for testing hypotheses H_0 and H_1 is $P<0.001$.

Table 6. Significance of differences in the proportion of the results without deviations with a factor of an equal number of sensory testing

Assessor	N	p_1 (%)	p_2 (%)	$H_0 : p_1 = p_2$ $H_1 : p_1 \neq p_2$
A1	208	75.96	86.06	P = 0.0086 *
A2	308	64.94	66.23	P = 0.7361
A3	388	80.15	80.67	P = 0.8552
A4	162	79.63	77.16	P = 0.5891
A5	248	82.66	85.48	P = 0.3908
A6	302	83.44	79.81	P = 0.2494
A7	410	80.73	76.34	P = 0.1258
A8	353	76.77	68.27	P = 0.0114

p_1: share of results with zero deviation before the infection; p_2: share of results with zero deviation after the infection; *: The significance level for testing hypotheses H_0 and H_1 is $P<0.001$.

Research has shown that even wine experts can experience inconsistencies in their sensory evaluations, indicating potential sensory bias even within this specific group (Tempere et al., 2012; Tempere et al., 2014). Our study has demonstrated that SARS-CoV-2 virus infection did not significantly influence professional wine assessors' analytical competencies, regardless of symptoms or various breaks in work. Research indicates that individuals who have experienced COVID-19 with some sensory disturbances may exhibit highly variable recovery times and may not always be aware of these sensory disturbances after recovering from the primary symptoms. Our findings align with the results of Niklassen et al. (2021), who describe the occurrence and progression of sensory disorders in COVID-19, emphasizing olfactory issues. According to Qiu et al. (2022), some studies report a shorter recovery time for anosmia and hyposmia, up to a maximum of three weeks. Patients in France generally recognized anosmia 4.4 days after infection, lasting an average of 8.96 days, with 98% recovering within 28 days (Klopfenstein et al., 2020). In other studies, most patients (70-80%) indicated complete recovery from chemosensory disturbances within 1-2 months (Printza et al., 2021; Speth et al., 2020).

Given its complexity and constant evolution, wine is an especially intriguing product. No other beverage compares to wine in terms of the interest it has attracted from researchers in recent decades. As the complexity and multidimensionality of wine become more apparent, the number of different scientific fields that find wine intriguing increases (Spence, 2020). Professional wine assessors bear an increasing responsibility as intermediaries between wine producers and consumers. They play a pivotal role in shaping quality through direct and indirect involvement, depending on their specific responsibilities. This growing responsibility is also evident in the professionalization of sensory testing and the control of all the factors involved in that work. This paper has demonstrated the feasibility of employing statistical tools suitable for routine assessor control in sensory evaluation laboratories and under non-standard circumstances.

CONCLUSION

The results of this study indicate that appropriate correlation tests can be reliable and useful in specific assessors' monitoring. Different tests use in the study did not find that the SARS-CoV-2 virus infection

causes changes affecting the sensory abilities of tested professional wine assessors. Although some assessors exhibited less pronounced compliance with the panels, these deviations were consistent throughout the observed period, reflecting their perception of quality and consistency in work rather than the impact of infection and COVID-19. The results of the proportion test, based on the factor "equal period of work in sensory testing" of 12 months before and after the illness, showed significant deviations in the case of one assessor's results compared to the panels. The various statistical tests in this study confirmed the validity of the standard methods used in wine assessors' monitoring, the reliability of sensory test results, and the importance of ongoing competence evaluation. Given the limited number of assessors tested and their specialized references, drawing a general conclusion about the impact of this infection on their sensory competence is challenging. This example demonstrates the importance of using multiple statistical tools to control the assessor's work. This way, the level of testing quality control and prevention of potential errors caused by the assessors is improved. Consequently, the reliability of the results is enhanced, and trust in the test laboratory is fostered.

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