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Modelling longitudinal polytomous animal data using Bayesian hierarchical models

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Abstract

The analysis of longitudinal categorical data can be complex and unfeasible due to the number of parameters involved, characterised by overparameterisation leading to model non-convergence, in addition to problems related to sample size and the presence or absence of overdispersion. In this context, we adopt the Bayesian hierarchical models as an alternative methodology to classical statistical techniques for analysing nominal polytomous data in longitudinal studies. The theoretical foundation is based on the use of non-informative priors and parameter estimation performed via Markov Chain Monte Carlo (MCMC) methods, which enable a robust and flexible data analysis framework. As a motivating example, the procedure is illustrated through an applied study in agrarian science, focusing on animal welfare, which assessed seven types of behaviours exhibited by pigs over twelve weeks. Model comparison based on the deviance information criterion (DIC) indicated that the model including the sex and enrichment interaction provided the best fit to the data. The results illustrate the applicability of Bayesian hierarchical models for the analysis of longitudinal nominal polytomous data. Since the computational procedures were implemented in the R software and the codes are available, this work will serve as support for those who need such analyses, especially in agricultural designs, where longitudinal categorical data are frequently encountered.

Keywords: Markov Chains; Nominal categorical data; Parameter estimation; Agricultural science.

1. Introduction

The importance of animal welfare is widely recognised in fields such as agricultural science, ethics, and animal production, reflecting the understanding that animal welfare influences not

only the health and quality of life of animals but also the quality of animal-derived products and, consequently, human health (Mkwanazi *et al.*, 2017). In this context, studies focused on animal welfare are fundamental, driving the development and application of advanced statistical methodologies for rigorous and reliable analyses.

Research on pig welfare has highlighted the significance of environmental enrichment through the use of toys and other objects to alleviate stress, stimulate growth, promote health, and improve the animals' zootechnical indicators (Li *et al.*, 2021; dos Santos *et al.*, 2021). Furthermore, environmental enrichment has positively impacted behavioural development and the learning capacity of pigs, enhancing activities such as tail wagging and playing, which are indicative of welfare (Ralph *et al.*, 2018). Therefore, implementing environmental enrichment in pig rearing systems represents an effective strategy to promote animal welfare, benefiting both the animals and producers (Giulioti *et al.*, 2019).

A crucial aspect of analysing data from animal welfare studies is the nature of the response variables involved. These variables are often nominal polytomous, meaning they are categorised without a natural order among categories. Frequently, these variables are observed over time in longitudinal studies, where the associated distribution is multinomial. A common approach for analysing nominal polytomous response variables in longitudinal contexts is the use of generalised mixed logits models (Hartzel *et al.*, 2001; Agresti & Hitchcock, 2005; Chan, 2023), in which one category is treated as the reference.

A recurring challenge in the use of these models is the potential for parameter estimation problems using the maximum likelihood method, in small-sample settings, a common feature of experimental designs with few units per treatment. Alternatively, the Bayesian approach, through the use of non-informative priors, allows for a more flexible and adaptable analysis of the data. This approach eliminates the need for restrictive prior assumptions, enabling the data to have a more direct influence on parameter inferences. Additionally, Bayesian estimation requires computationally intensive programming, such as Monte Carlo methods via Markov Chains (MCMC), particularly the Metropolis-Hastings algorithm and the Gibbs sampler (Gelman *et al.*, 2013). These are the most commonly used methodologies for obtaining summaries of the posterior joint distribution, which forms the basis of Bayesian inference. In this context, Bayesian hierarchical models for nominal polytomous data (Natarajan & Kass, 2000; Pettitt *et al.*, 2006; Gong *et al.*, 2004) emerge as a promising alternative. By incorporating a prior structure and utilising advanced computational techniques, these models enable efficient parameter estimation even in the presence of overparameterisation or complex data.

In this context, this study uses Bayesian hierarchical models as an alternative to classical statistical methods, employing non-informative priors and the MCMC method for parameter estimation.

2. Materials and Methods

2.1 Material

As a motivating study, we considered an experiment conducted by Tavares & Silva (2022) in a commercial pig slaughterhouse in Brazil between April and August 2019. The primary objective was to assess the impact of various environmental enrichment conditions on pig behaviour.



Figure 1. Branched chain and branched sisal rope environmental enrichments were inserted into the pens during the experiment conducted by Tavares (2023) between April and August 2019.

The experiment consisted of a randomized block design, that corresponds the three weight pigs groups: light (≥ 20.3 to < 24.8 kg), medium (≥ 24.8 to < 27.7 kg), and heavy (≥ 27.7 to < 33.8 kg), with a 2×3 factorial scheme (2 classifications according to the animal sex and 3 environmental enrichment types: branched chains, branched sisal ropes, and no enrichment) involving 432 pigs of both sexes, aged between 63 and 70 days, distributed in 72 pens, each containing 6 animals.

For each combination of enrichment conditions and sex, 12 animals were selected, designated as T1 – branched chain for males, T2 – branched sisal rope for males, T3 – an environment without enrichment for males, T4 – branched chain for females, T5 – branched sisal rope for females, and T6 – an environment without enrichment for females.

The response variables included behaviors such as (1) aggressiveness, (2) feeding, (3) calm, (4) animal interaction, (5) environmental interaction, (6) object interaction, and (7) locomotion. Animal behaviour observations were conducted by a single observer using the “Focal Analysis” method over 12 weeks.

2.2 Methods

Before establishing the statistical model, it is always important to conduct an exploratory analysis of the data. For the response, considering the seven classifications of animal behaviours as nominal polytomous variables, Correspondence Analysis was applied as an exploratory multivariate technique for investigating associations between categorical variables, aiming to reduce the dimensionality of the contingency table formed between the explanatory factor and the response variable (Johnson & Wichern, 2007; Greenacre, 2004). This method is based on the singular value decomposition of a transformation of the matrix of observed joint proportions, allowing the experimental units to be represented in a two-dimensional plane defined by the first principal coordinates. Additionally, as is standard in longitudinal studies, mean profile plots (Singer *et al.*, 2018) were used to explore seasonal variation in behaviours across weeks.

We adopted a Bayesian hierarchical model for nominal polytomous response variables. To establish notation, the random variable Y_{ijt} represents the type of behaviour adopted by the i -th pig, $i = 1, \dots, 72$, in the j -th behaviour classification, $j = 1, \dots, 7$ (aggressive, feeding, calm, animal interaction, environmental interaction, object interaction, and locomotion), evaluated in the t -th week, $t = 1, \dots, 12$, following a multinomial distribution, that is, $Y_{ijt} \sim \text{Multinomial}(y_{ijt}, \pi_{ijt})$. To account for potential dependencies among repeated observations on the same animal, a random effect for pigs (experimental units) is included in the model. By setting “Aggressive” behaviour ($j = 1$) as the reference category, the Bayesian hierarchical model for polytomous variables is defined as:

$$\begin{aligned}
 \eta_{ijt} &= \ln \left[\frac{\pi_{ijt}}{\pi_{i1t}} \right] \\
 &= \alpha_{jt} + \beta_{jt}(\text{block})_{jt} + \gamma_{jt}(\text{sex})_{jt} \\
 &\quad + \varphi_{jt}(\text{enrichment})_{jt} + \omega_{jt}(\text{sex} \times \text{enrichment})_{jt} + u_i,
 \end{aligned} \tag{1}$$

where α_{jt} is the intercept for the j -th classification of pig behaviour collected at the week t , $\beta_{jt}(\text{weight})_{jt}$ is the effect associated with the pig weight classification, $\gamma_{jt}(\text{sex})_{jt}$ is the effect of the sex, $\varphi_{jt}(\text{enrichment})_{jt}$ is the effect associated with the environmental enrichment condition, $\omega_{jt}(\text{sex} \times \text{enrichment})_{jt}$ is the interaction effect between enrichment condition and pig sex, and u_i is the random effect associated with the i -th observed pig, for which $u_i \sim N_n(0, \Sigma_j)$, where 0 is the mean vector, and Σ_j is the variance-covariance matrix.

The following model structures were considered:

1. **Model 1:** considers the block effect with the addition of sex, environmental enrichment condition, and random effects, given by:

$$\eta_{ijt} = \alpha_{jt} + \beta_{jt}(\text{block})_{jt} + \gamma_{jt}(\text{sex})_{jt} + \varphi_{jt}(\text{enrichment})_{jt} + u_i \tag{2}$$

2. **Model 2:** considers the interaction effect between pig sex and environmental enrichment conditions with random effects, which is given by:

$$\eta_{ijt} = \alpha_{jt} + \beta_{jt}(\text{block})_{jt} + \gamma_{jt}(\text{sex})_{jt} * \varphi_{jt}(\text{enrichment})_{jt} + \omega_{jt}(\text{sex} \times \text{enrichment})_{jt} + u_i \tag{3}$$

Model selection was performed using the deviance information criterion (DIC). Thus, this information criterion was used to check the effect of interaction by selecting the model which produced the lowest DIC.

The estimation of models 2 and 3 were conducted under the Bayesian approach. To capture the uncertainties of the individual effects u_i , which represent the specific variations associated with each pig, a normal prior distribution with mean 0 and variance 0.01 was used. These effects reflect the variability of pigs and the uncertainty associated with their influence on the model. Furthermore, for the parameters α_j , β_{jk} , γ_{js} , φ_{jc} , which can assume any real value, normal prior distributions with mean 0 and variance 0.01 were employed. These priors address the uncertainty related to the influence of these parameters on the model. Specifically:

$$\begin{aligned}
 u_i &\sim N(0, 0.01), \\
 \alpha_j &\sim N(0, 0.01), \\
 \beta_k &\sim N(0, 0.01), \\
 \gamma_s &\sim N(0, 0.01) \text{ and} \\
 \varphi_c &\sim N(0, 0.01).
 \end{aligned}$$

The posterior distribution was obtained using the Markov Chain Monte Carlo (MCMC) method. Four MCMC chains were used, each with 5000 iterations, followed by 1000 burn-in iterations at every 15 steps to assess chain convergence. Implementation was performed using JAGS (Plummer *et al.*, 2003) through the `rjags` package (Plummer, 2023), with R software (R Core Team, 2024). All codes used in the analyses are available: <https://github.com/GabrielRPalma/ModellingLongitudinalPolytomousData>. After the burn-in phase, the analysis proceeded to calculate 95% credibility intervals for the model

parameters (Gelman *et al.*, 2013). These intervals were calculated using the 2.5th and 97.5th percentiles of the posterior distributions of MCMC samples, providing a clear view of the uncertainty associated with the parameter estimates.

In the following section, the results of the exploratory analyses and of the analysis based on hierarchical Bayesian models are presented and discussed.

3. Results and Discussion

Initially, the association between the behaviours of pigs (aggressive, feeding, calm, animal interaction, environmental interaction, object interaction, and locomotion) and the treatments to which they were subjected during the experiment (T1 – branched chain for males, T2 – branched sisal rope for males, T3 – unenriched environment for males, T4 – branched chain for females, T5 – branched sisal rope for females, and T6 – unenriched environment for females) was investigated using the chi-square test (χ^2). The test was significant ($p\text{-value} < 0.05$), indicating evidence of an association between pig behaviours and the treatments, which serves as the premise for correspondence analysis, presented in Figure 2, that illustrates this association.

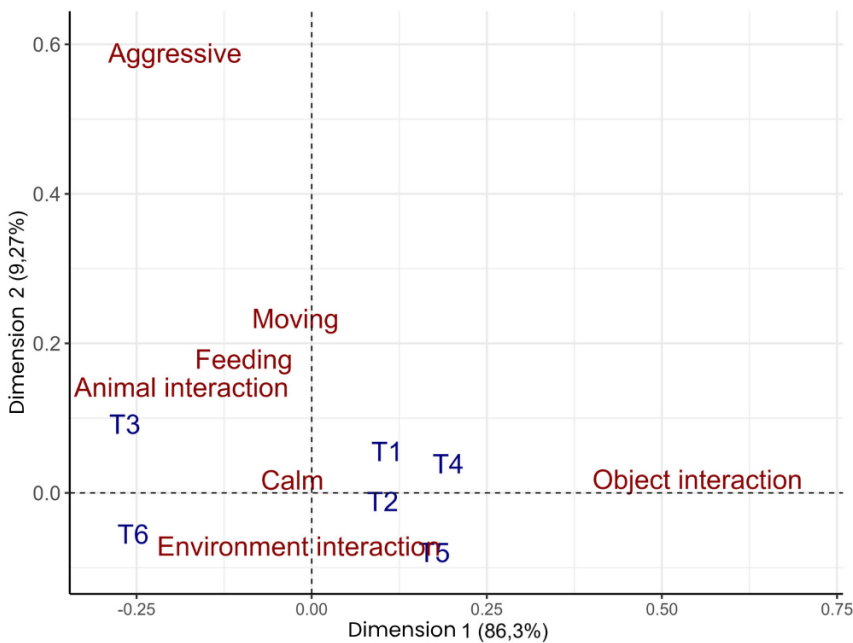


Figure 2. Representative graph of the types of behaviours attributed by pigs to different treatment conditions, according to the experiment conducted by Tavares(2023) between April and August 2019. The treatments are as follows: T1 - branched chain for males, T2 - branched sisal rope for males, T3 - unenriched environment for males, T4 - branched chain for females, T5 - branched sisal rope for females, and T6 - unenriched environment for females.

According to the correspondence analysis (Figure 2), the first two dimensions accounted for 96.1% of the total inertia, indicating that the data can be adequately represented in two dimensional space. It was observed that specific treatments, such as T3 (unenriched environment for male pigs) showed a possible tendency of association with the behaviours “Animal Interaction”, “Feeding”, and “Locomotion”, suggesting that male pigs without environmental enrichment tend to interact more with other animals or to move around more frequently. In contrast, treatments T5 (branched sisal

rope for females) and T6 (unenriched environment) appeared to be associated with the behaviour “Environment Interaction”. Treatments T1 (branched chain for male pigs), T2 (branched sisal rope for male pigs), and T4 (branched chain for female pigs) were positioned closer to the “Calm” behaviour, indicating that animals tended to remain calmer under these enrichment treatments. These interpretations are exploratory in nature, as Correspondence Analysis was used only as a preliminary descriptive tool to assess potential associations between treatments and behaviours, given that this stage was not intended for confirmatory inference.

The graph of the average profiles for each type of behaviour adopted by the pigs over the twelve weeks is described in Figure 3.

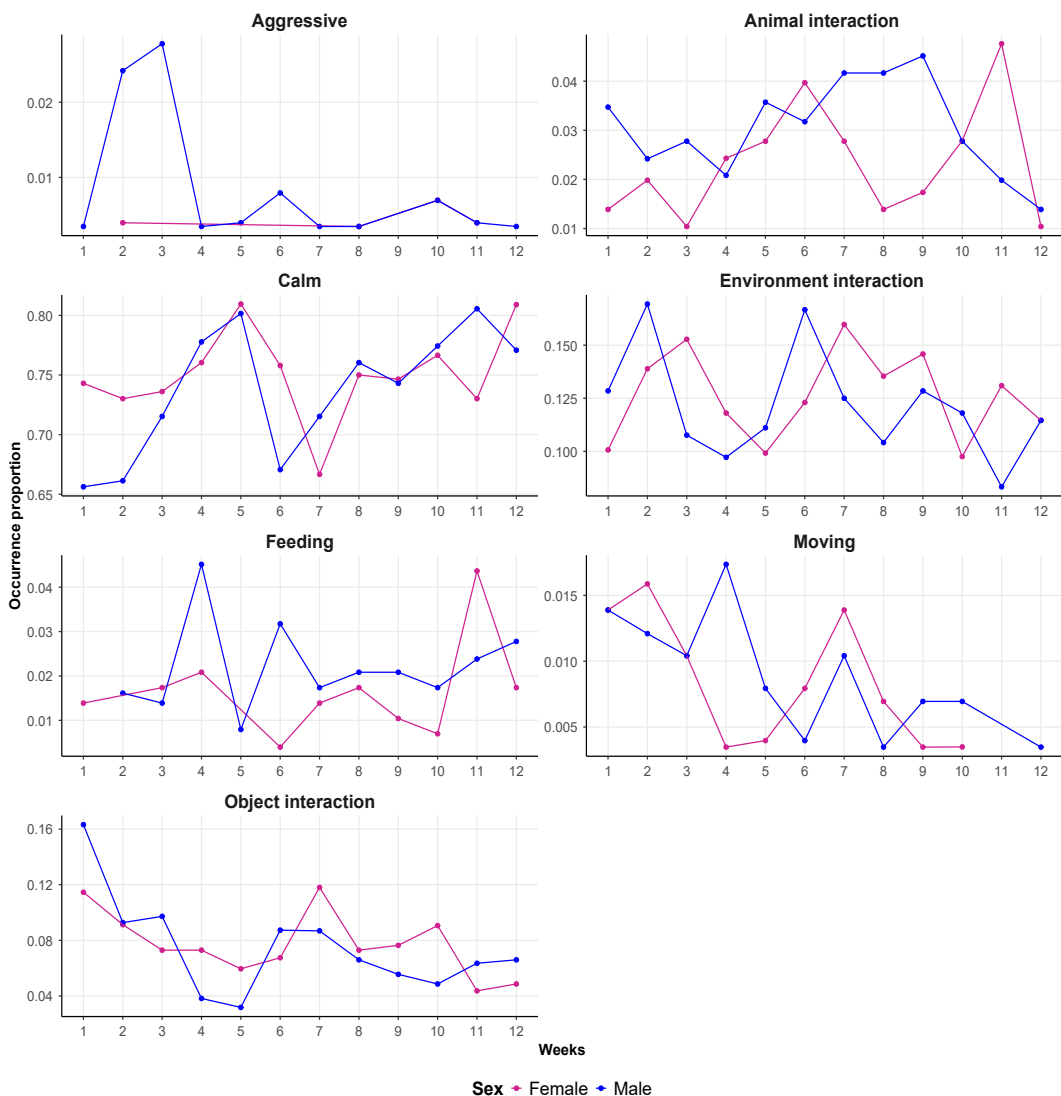


Figure 3. Graph of average profiles for each behavioural classification of pigs over the twelve observed weeks, according to the experiment conducted by Tavares (2023) between April and August 2019.

Our results show that over the twelve weeks, the “Calm” behaviour prevailed among both male

and female pigs throughout the experiment. In contrast, behaviours classified as “Aggressive”, “Animal Interaction”, and “Object Interaction” showed stability in their occurrence, with lower frequencies. Furthermore, the “Locomotion” behaviour showed a slight decrease over the weeks.

The proportions of each pig’s behaviour for each treatment are presented in Figure 4. It was noted that male pigs appeared to be more aggressive than females at the start of the study. Behaviour categories, including “Feeding”, “Animal Interaction”, and “Environmental Interaction”, showed variations that were not affected by the environmental enrichment condition applied.

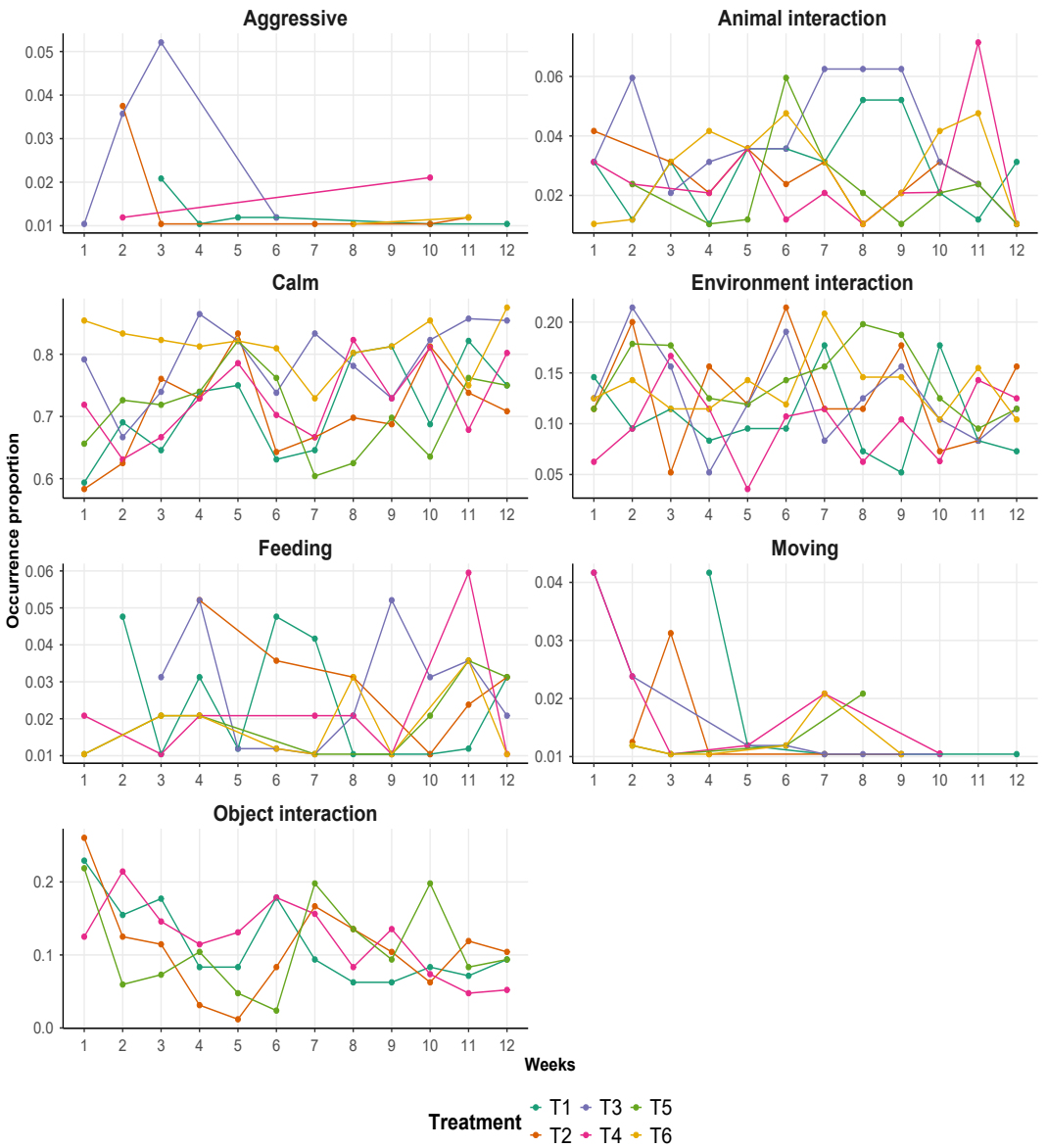


Figure 4. Average profiles for each behavioural classification of pigs under different treatment conditions over the twelve observed weeks, according to the experiment conducted by Tavares(2023) from April to August 2019. The treatments are: T1 - branched chain for males, T2 - branched sisal rope for males, T3 - unenriched environment for males, T4 - branched chain for females, T5 - branched sisal rope for females, and T6 - unenriched environment for females.

After the exploratory analyses, Bayesian hierarchical models were fitted to investigate the effects of sex and environmental enrichment on pig behaviour over time.

Next, Bayesian hierarchical models for nominal polytomous data were fitted, and the selection was made using the deviance information criterion (DIC), as presented in the section 2.2. The selection result is presented in Table 1.

Table 1. Linear predictor selection using the deviance information criterion (DIC), for the experiment conducted by Tavares & Silva, 2022 between April and August 2019

Model	Linear predictor	DIC
1	Sex + Enrichment + Random effect	10158,1
2	Sex × Enrichment + Random effect	10154,5

Through the comparison of the models, Model 2, which incorporates the interaction between sex and enrichment condition, yielded a lower DIC value (10154.5), suggesting that this model is more appropriate. The effect of the interaction, in practice, shows that the response to environmental enrichment depends on the level of the sex factor, as illustrated by the Figure 3.

Following the selection of the model with the lowest DIC value, convergence of the Markov chains was assessed using the Gelman–Rubin statistic ($\hat{R}$). For all model parameters, $\hat{R}$ values remained close to 1 and below the commonly adopted threshold of 1.1, indicating adequate chain convergence and stability of the estimation process. A complete summary of $\hat{R}$ values for all parameters, as well as a graphical representation of their distribution, is provided in Appendix B, offering additional support for the reliability of the posterior inferences. The numerical summaries of the posterior estimates of the β coefficients, including posterior means and 95% credible intervals, which support the graphical representations presented in Figures 5 to 10, are provided in Appendix A.

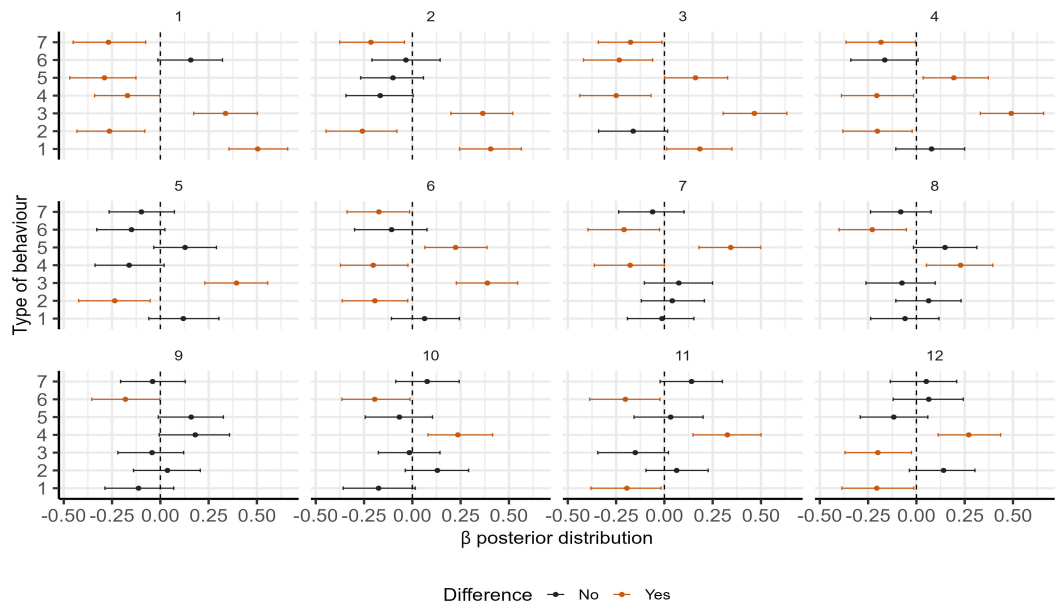


Figure 5. 95% credibility intervals for the estimates of β , derived from the posterior distribution, indicating the behaviour of female pigs under the environmental enrichment condition with sisal rope. The data were collected over 12 weeks of experimentation, observing the following behaviours: (1) Aggressive, (2) Feeding, (3) Calm, (4) Animal interaction, (5) Environmental interaction, (6) Object interaction, and (7) Locomotion.

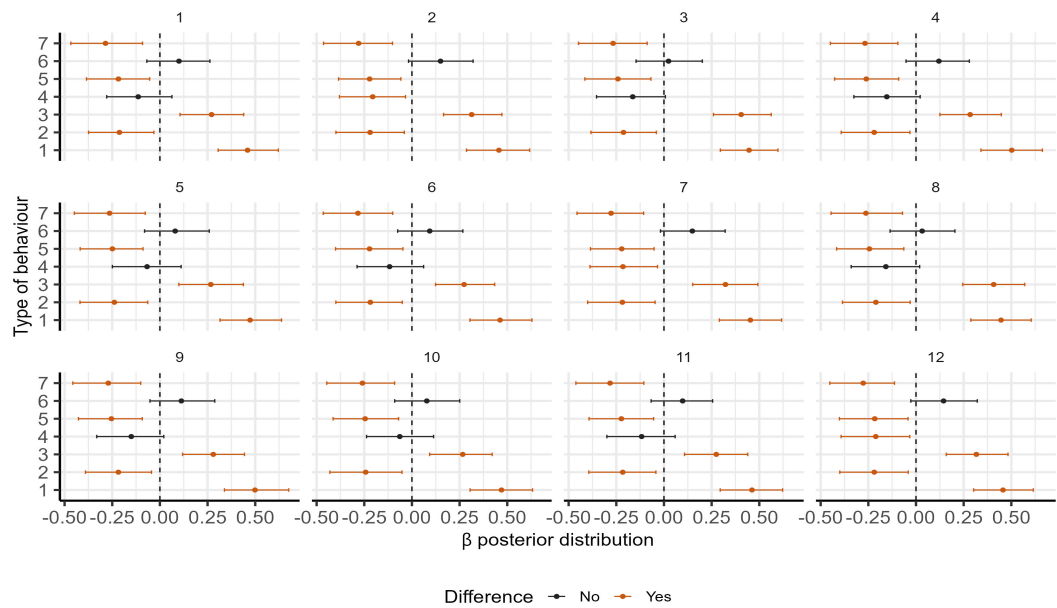


Figure 6. 95% credibility intervals for the estimates of β , derived from the posterior distribution, indicating the behaviour of female pigs under the environmental enrichment condition with a branched chain. The data were collected over 12 weeks of experimentation, observing the following behaviours: (1) Aggressive, (2) Feeding, (3) Calm, (4) Animal interaction, (5) Environmental interaction, (6) Object interaction, and (7) Locomotion.

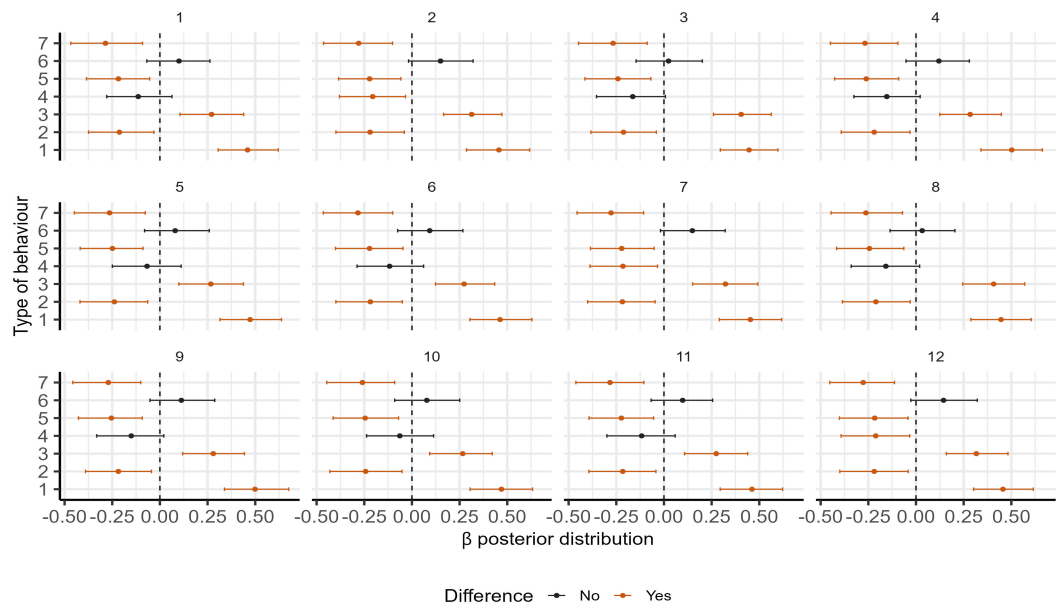


Figure 7. 95% credibility intervals for the estimates of β , derived from the posterior distribution, indicating the behaviour of female pigs without an environmental enrichment condition. The data were collected over 12 weeks of experimentation, observing the following behaviours: (1) Aggressive, (2) Feeding, (3) Calm, (4) Animal interaction, (5) Environmental interaction, (6) Object interaction, and (7) Locomotion.

The posterior estimates β of the coefficients indicate that environmental enrichment conditions influenced the behaviour of female pigs over the course of 12 weeks. Overall, the 95% credibility intervals suggest that the “Aggressive” behaviour was present in the initial weeks, regardless of the type of enrichment to which the animals were exposed.

For female pigs exposed to the sisal rope, a transition from “Aggressive” to “Calm” behaviour was observed from the fourth week onwards. The “Object Interaction” behaviour showed significant posterior estimates β in week 3 and between weeks 7 and 11, suggesting that the sisal rope attracted interest at specific points during the experiment. However, in the final week, this behaviour was no longer significant, indicating a possible decline in interest in the object (Figure 5). Additionally, “Environmental Interaction” behaviour was more frequent in week 7, whereas “Animal Interaction” increased in weeks 8 and between weeks 10 and 12.

On the other hand, female pigs exposed to the branched chain displayed a consistent pattern of “Aggressive” behaviour throughout the experiment. Moreover, “Object Interaction” behaviour was not significant in any of the weeks, indicating that this type of enrichment was not appealing to the animals (Figure 6). These results suggest that the sisal rope may have been a more stimulating option for the pigs compared to the branched chain.

In the absence of enrichment, the posterior estimates β indicate that “Aggressive” behaviour predominated throughout the entire experiment (Figure 7). Furthermore, aside from “Object Interaction”, the only behaviour that did not reach significance was “Animal Interaction”. In contrast, the behaviours “Feeding”, “Environmental Interaction”, and “Locomotion” occurred less frequently, suggesting that the lack of stimuli limited behavioural variation and may have been associated with a higher level of stress.

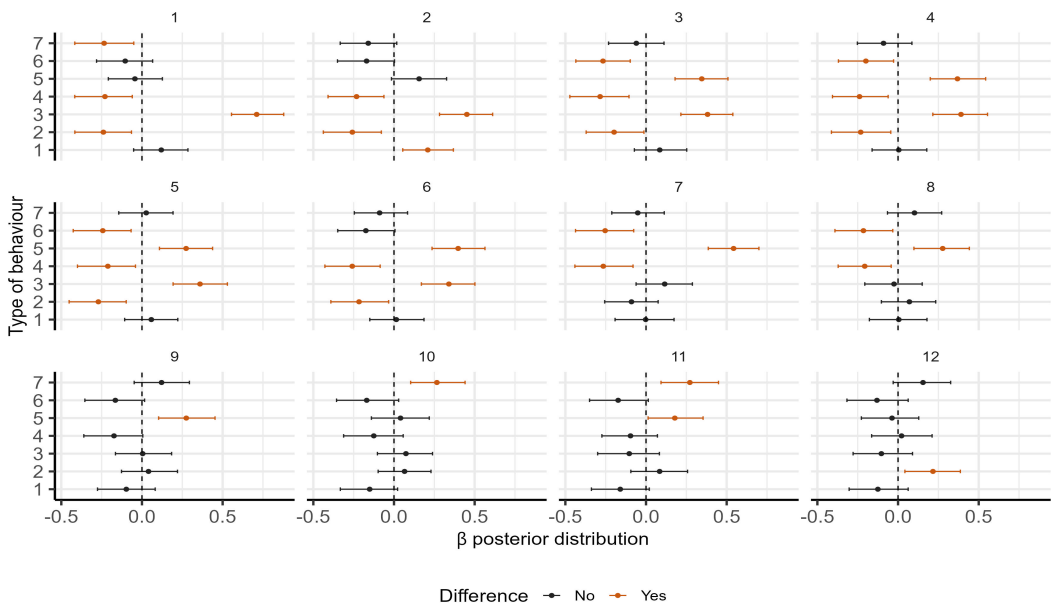


Figure 8. 95% credibility intervals for the estimates of β , derived from the posterior distribution, indicating the behaviour of male pigs under the environmental enrichment condition with sisal rope. The data were collected over 12 weeks of experimentation, observing the following behaviours: (1) Aggressive, (2) Feeding, (3) Calm, (4) Animal interaction, (5) Environmental interaction, (6) Object interaction, and (7) Locomotion.

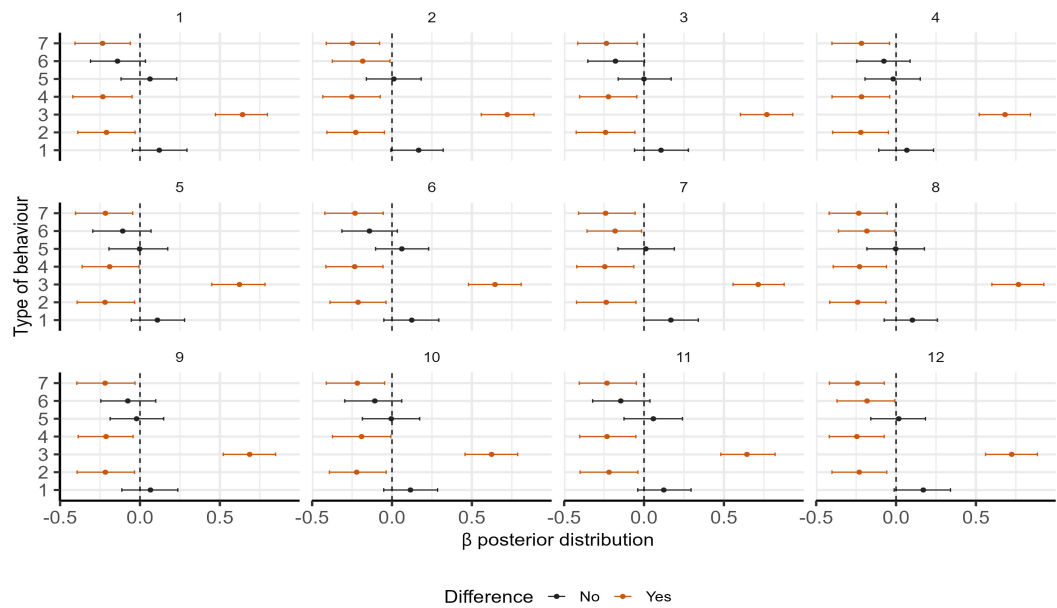


Figure 9. 95% credibility intervals for the estimates of β , derived from the posterior distribution, indicating the behaviour of male pigs under the environmental enrichment condition with a branched chain. The data were collected over 12 weeks of experimentation, observing the following behaviours: (1) Aggressive, (2) Feeding, (3) Calm, (4) Animal interaction, (5) Environmental interaction, (6) Object interaction, and (7) Locomotion.

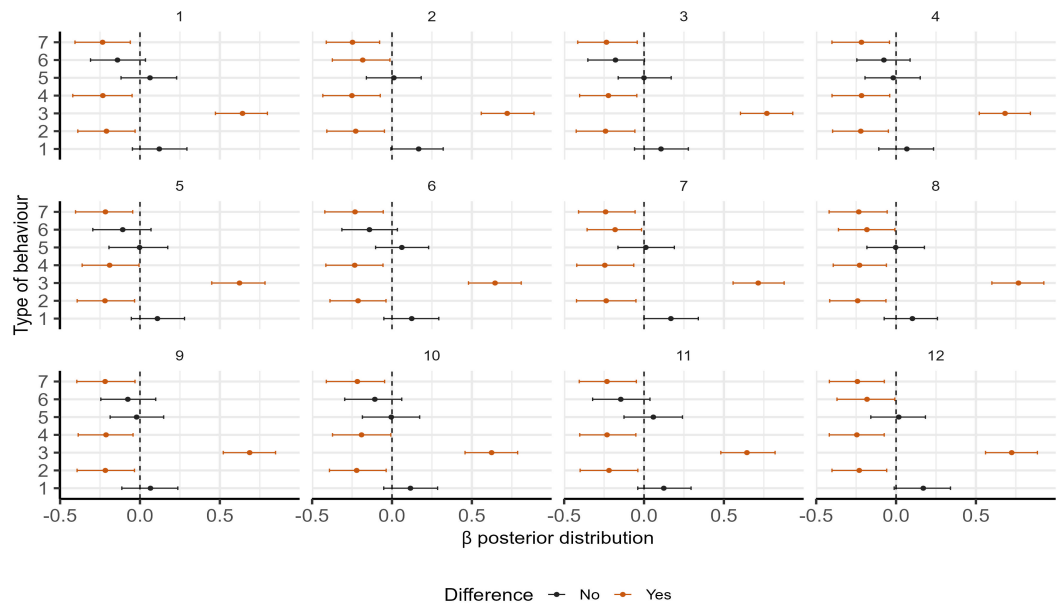


Figure 10. 95% credibility intervals for the estimates of β , derived from the posterior distribution, indicating the behaviour of male pigs without an environmental enrichment condition. The data were collected over 12 weeks of experimentation, observing the following behaviours: (1) Aggressive, (2) Feeding, (3) Calm, (4) Animal interaction, (5) Environmental interaction, (6) Object interaction, and (7) Locomotion.

The behaviour of male pigs (Figures 8, 9, and 10), the 95% credibility intervals indicate that when subjected to environmental enrichment with a sisal rope, the behaviour “Calm” was predominant during the first six weeks of the experiment compared to the other behaviours. “Object Interaction” was statistically significant between weeks 3 and 8, except for week 6, although the estimates suggest a low preference compared to other behaviours. Meanwhile, “Environment Interaction” was significant between weeks 3 and 11, except for week 10. In the final week of the experiment, the behaviour “Feeding” was the only one that remained significant.

For male pigs exposed to environmental enrichment with a branched chain, a greater preference for the “Calm” behaviour was also observed throughout the experiment. However, an interesting aspect was these animals’ interest in “Object interaction” in the final week of the experiment. Nevertheless, compared to enrichment with a sisal rope, “Object interaction” was less pronounced when the branched chain was used. Finally, for male pigs that were not subjected to any type of environmental enrichment, the most preferred behaviour was “Calm”.

The results indicate that environmental enrichment influenced the behaviour of the pigs, with variations between the types of enrichment to which they were subjected. The sisal rope reduced the “Aggressive” behaviour, particularly among the females, while also stimulating behaviours such as “Environment Interaction” and “Object Interaction”. In contrast, the branched chain had a lesser effect on the types of behaviours adopted by the animals and was associated with “Aggressive” behaviour, especially in the females. The absence of enrichment resulted in the predominance of “Aggressive” behaviour among the females and less behavioural diversity in the males, suggesting potential impacts on animal welfare.

This study presents characteristics that should be considered when interpreting the results and that motivated the adoption of a Bayesian approach. The experimental design, with a reduced number of units per treatment–sex combination, combined with the fact that the response variable comprises seven behavioural categories, naturally results in an unbalanced data structure, with sparse frequencies in some categories. These conditions pose challenges for classical maximum likelihood–based estimation methods, which may exhibit instability or convergence difficulties in scenarios of overparameterisation. In this context, Bayesian hierarchical models constitute a suitable alternative, as they incorporate variability among observational units and allow for more stable estimates, even in the presence of modest sample sizes and multiple response categories.

4. Conclusions

This study explored the use of Bayesian hierarchical models as an alternative to the analysis of nominal polytomous data in longitudinal studies, addressing the issues of maximum likelihood estimation often associated with overparameterisation. Therefore, this study did not aim to compare with classical statistical methods, especially because in our study, there is no convergence due to the excess of parameters.

The process was illustrated with an application in the field of Animal Science involving seven response categories, and the results indicated that Bayesian hierarchical models provide robust estimates and consistent interpretations in relation to the experiment. Furthermore, when applied in animal science, these models revealed valuable insights into animal behaviour, with practical implications for management and welfare. Additionally, the results confirm that Bayesian hierarchical models offer robust estimates and consistent interpretations, demonstrating their efficacy in the analysis of longitudinal nominal polytomous data while addressing convergence issues.

Finally, it is concluded that the use of Bayesian hierarchical models for nominal polytomous data in future research is recommended, not only in animal science but also in other areas of agricultural and biological sciences. This approach, combined with the development of accessible computational tools, has the potential to significantly enhance the analysis of complex data in longitudinal contexts,

enriching empirical research across various scientific domains. For future work, residual analysis and diagnostic techniques should be explored for these classes of models.

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Conflicts of Interest

The authors declare no conflict of interest.

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Appendix A

This appendix presents the complete numerical estimates that support the graphical representations shown in Figures 5 to 10 of the main text. Separate tables report the posterior means and 95% credible intervals of the (β) estimates, obtained from the posterior distribution, for the effect of sex on the behavioural categories evaluated over the experimental period. Each table corresponds directly to a specific figure, providing the numerical values underlying the respective graphical visualisation.

Table A.1. Posterior means and 95% credible intervals of the (β) estimates, derived from the posterior distribution, corresponding to the results presented in the Figure 5, indicating the behaviour of female pigs under the environmental enrichment condition with sisal rope. Observations were carried out over 12 weeks of experimentation, considering the following behaviours: (1) aggressive, (2) feeding, (3) calm, (4) animal interaction, (5) environment interaction, (6) object interaction, and (7) locomotion

Time	Category	Posterior mean	95% credible interval	Effect
1	1	0.506	[0.338, 0.669]	Positive
1	2	-0.263	[-0.455, -0.078]	Negative
1	3	0.337	[0.170, 0.491]	Positive
1	4	-0.175	[-0.360, -0.008]	Negative
1	5	-0.294	[-0.455, -0.132]	Negative
1	6	0.160	[-0.001, 0.329]	Not significant
1	7	-0.265	[-0.447, -0.086]	Negative
2	1	0.402	[0.236, 0.561]	Positive
2	2	-0.254	[-0.430, -0.076]	Negative
2	3	0.364	[0.201, 0.518]	Positive
2	4	-0.163	[-0.339, 0.019]	Not significant
2	5	-0.098	[-0.274, 0.068]	Not significant
2	6	-0.029	[-0.206, 0.150]	Not significant
2	7	-0.217	[-0.392, -0.049]	Negative
3	1	0.184	[0.005, 0.356]	Positive
3	2	-0.162	[-0.343, 0.013]	Not significant
3	3	0.473	[0.318, 0.634]	Positive
3	4	-0.248	[-0.428, -0.071]	Negative
3	5	0.167	[-0.001, 0.324]	Not significant
3	6	-0.236	[-0.419, -0.054]	Negative
3	7	-0.176	[-0.350, 0.000]	Not significant
4	1	0.079	[-0.093, 0.259]	Not significant
4	2	-0.210	[-0.384, -0.031]	Negative
4	3	0.496	[0.329, 0.647]	Positive
4	4	-0.198	[-0.382, -0.023]	Negative
4	5	0.189	[0.019, 0.357]	Positive
4	6	-0.164	[-0.347, 0.012]	Not significant
4	7	-0.186	[-0.359, -0.026]	Negative
5	1	0.121	[-0.062, 0.298]	Not significant
5	2	-0.239	[-0.416, -0.066]	Negative
5	3	0.393	[0.235, 0.553]	Positive
5	4	-0.159	[-0.345, 0.021]	Not significant
5	5	0.130	[-0.032, 0.289]	Not significant
5	6	-0.138	[-0.314, 0.043]	Not significant
5	7	-0.103	[-0.270, 0.066]	Not significant
6	1	0.060	[-0.124, 0.253]	Not significant
6	2	-0.190	[-0.379, -0.011]	Negative
6	3	0.391	[0.217, 0.559]	Positive
6	4	-0.198	[-0.389, -0.014]	Negative
6	5	0.219	[0.045, 0.382]	Positive
6	6	-0.108	[-0.301, 0.066]	Not significant
6	7	-0.172	[-0.340, -0.007]	Negative
7	1	-0.015	[-0.194, 0.162]	Not significant
7	2	0.039	[-0.146, 0.206]	Not significant
7	3	0.077	[-0.086, 0.255]	Not significant

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Time	Category	Posterior mean	95% credible interval	Effect
7	4	-0.174	[-0.349, 0.002]	Not significant
7	5	0.339	[0.182, 0.504]	Positive
7	6	-0.218	[-0.406, -0.041]	Negative
7	7	-0.061	[-0.235, 0.114]	Not significant
8	1	-0.060	[-0.228, 0.121]	Not significant
8	2	0.065	[-0.111, 0.230]	Not significant
8	3	-0.072	[-0.252, 0.109]	Not significant
8	4	0.218	[0.054, 0.386]	Positive
8	5	0.155	[-0.023, 0.325]	Not significant
8	6	-0.229	[-0.412, -0.056]	Negative
8	7	-0.085	[-0.254, 0.076]	Not significant
9	1	-0.118	[-0.306, 0.068]	Not significant
9	2	0.038	[-0.134, 0.206]	Not significant
9	3	-0.040	[-0.221, 0.122]	Not significant
9	4	0.182	[0.018, 0.358]	Positive
9	5	0.162	[-0.003, 0.328]	Not significant
9	6	-0.182	[-0.360, 0.001]	Not significant
9	7	-0.039	[-0.207, 0.130]	Not significant
10	1	-0.174	[-0.355, 0.004]	Not significant
10	2	0.134	[-0.037, 0.297]	Not significant
10	3	-0.014	[-0.191, 0.169]	Not significant
10	4	0.239	[0.067, 0.409]	Positive
10	5	-0.066	[-0.245, 0.104]	Not significant
10	6	-0.189	[-0.377, -0.015]	Negative
10	7	0.077	[-0.098, 0.235]	Not significant
11	1	-0.201	[-0.377, -0.018]	Negative
11	2	0.061	[-0.105, 0.227]	Not significant
11	3	-0.149	[-0.329, 0.027]	Not significant
11	4	0.327	[0.160, 0.491]	Positive
11	5	0.032	[-0.144, 0.209]	Not significant
11	6	-0.204	[-0.376, -0.033]	Negative
11	7	0.132	[-0.029, 0.307]	Not significant
12	1	-0.210	[-0.394, -0.037]	Negative
12	2	0.138	[-0.025, 0.302]	Not significant
12	3	-0.199	[-0.378, -0.017]	Negative
12	4	0.267	[0.095, 0.441]	Positive
12	5	-0.117	[-0.289, 0.053]	Not significant
12	6	0.062	[-0.110, 0.237]	Not significant
12	7	0.051	[-0.126, 0.226]	Not significant

Table A.2. Posterior means and 95% credible intervals of the (β) estimates, derived from the posterior distribution, corresponding to the results presented in the Figure 6, indicating the behaviour of female pigs under the environmental enrichment condition with branched chain. Observations were carried out over 12 weeks of experimentation, considering the following behaviours: (1) aggressive, (2) feeding, (3) calm, (4) animal interaction, (5) environment interaction, (6) object interaction, and (7) locomotion

Time	Category	Posterior mean	95% credible interval	Effect
1	1	0.460	[0.299, 0.624]	Positive
1	2	-0.217	[-0.393, -0.032]	Negative
1	3	0.274	[0.110, 0.429]	Positive
1	4	-0.113	[-0.283, 0.060]	Not significant
1	5	-0.223	[-0.402, -0.048]	Negative
1	6	0.098	[-0.071, 0.259]	Not significant
1	7	-0.283	[-0.469, -0.095]	Negative
2	1	0.457	[0.295, 0.633]	Positive
2	2	-0.222	[-0.404, -0.039]	Negative
2	3	0.316	[0.142, 0.470]	Positive

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Time	Category	Posterior mean	95% credible interval	Effect
2	4	-0.216	[-0.390, -0.035]	Negative
2	5	-0.224	[-0.379, -0.044]	Negative
2	6	0.148	[-0.019, 0.320]	Not significant
2	7	-0.274	[-0.458, -0.093]	Negative
3	1	0.441	[0.280, 0.605]	Positive
3	2	-0.204	[-0.379, -0.030]	Negative
3	3	0.403	[0.235, 0.564]	Positive
3	4	-0.162	[-0.333, 0.013]	Not significant
3	5	-0.244	[-0.410, -0.083]	Negative
3	6	0.026	[-0.136, 0.196]	Not significant
3	7	-0.267	[-0.457, -0.088]	Negative
4	1	0.499	[0.323, 0.671]	Positive
4	2	-0.218	[-0.396, -0.038]	Negative
4	3	0.282	[0.112, 0.443]	Positive
4	4	-0.153	[-0.336, 0.017]	Not significant
4	5	-0.261	[-0.437, -0.091]	Negative
4	6	0.115	[-0.062, 0.288]	Not significant
4	7	-0.267	[-0.443, -0.094]	Negative
5	1	0.475	[0.312, 0.631]	Positive
5	2	-0.241	[-0.418, -0.063]	Negative
5	3	0.263	[0.096, 0.436]	Positive
5	4	-0.062	[-0.242, 0.107]	Not significant
5	5	-0.245	[-0.415, -0.079]	Negative
5	6	0.081	[-0.086, 0.243]	Not significant
5	7	-0.264	[-0.433, -0.074]	Negative
6	1	0.465	[0.300, 0.625]	Positive
6	2	-0.216	[-0.393, -0.047]	Negative
6	3	0.274	[0.117, 0.429]	Positive
6	4	-0.114	[-0.293, 0.053]	Not significant
6	5	-0.224	[-0.386, -0.063]	Negative
6	6	0.099	[-0.074, 0.265]	Not significant
6	7	-0.281	[-0.471, -0.095]	Negative
7	1	0.457	[0.289, 0.616]	Positive
7	2	-0.218	[-0.389, -0.049]	Negative
7	3	0.321	[0.157, 0.483]	Positive
7	4	-0.213	[-0.390, -0.044]	Negative
7	5	-0.224	[-0.398, -0.056]	Negative
7	6	0.147	[-0.035, 0.323]	Not significant
7	7	-0.279	[-0.455, -0.093]	Negative
8	1	0.447	[0.286, 0.610]	Positive
8	2	-0.207	[-0.386, -0.035]	Negative
8	3	0.407	[0.231, 0.570]	Positive
8	4	-0.168	[-0.348, 0.003]	Not significant
8	5	-0.242	[-0.415, -0.071]	Negative
8	6	0.029	[-0.140, 0.196]	Not significant
8	7	-0.266	[-0.448, -0.096]	Negative
9	1	0.500	[0.338, 0.649]	Positive
9	2	-0.220	[-0.396, -0.037]	Negative
9	3	0.281	[0.111, 0.450]	Positive
9	4	-0.146	[-0.330, 0.031]	Not significant
9	5	-0.257	[-0.421, -0.095]	Negative
9	6	0.121	[-0.044, 0.287]	Not significant
9	7	-0.267	[-0.442, -0.090]	Negative
10	1	0.474	[0.306, 0.641]	Positive
10	2	-0.244	[-0.436, -0.055]	Negative
10	3	0.263	[0.101, 0.440]	Positive
10	4	-0.068	[-0.245, 0.116]	Not significant
10	5	-0.244	[-0.431, -0.076]	Negative
10	6	0.078	[-0.089, 0.242]	Not significant
10	7	-0.264	[-0.442, -0.083]	Negative

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Time	Category	Posterior mean	95% credible interval	Effect
11	1	0.459	[0.297, 0.624]	Positive
11	2	-0.213	[-0.398, -0.035]	Negative
11	3	0.271	[0.100, 0.431]	Positive
11	4	-0.112	[-0.282, 0.060]	Not significant
11	5	-0.226	[-0.398, -0.056]	Negative
11	6	0.097	[-0.071, 0.263]	Not significant
11	7	-0.283	[-0.459, -0.105]	Negative
12	1	0.458	[0.294, 0.617]	Positive
12	2	-0.216	[-0.402, -0.036]	Negative
12	3	0.314	[0.138, 0.483]	Positive
12	4	-0.211	[-0.379, -0.036]	Negative
12	5	-0.216	[-0.386, -0.035]	Negative
12	6	0.148	[-0.014, 0.314]	Not significant
12	7	-0.274	[-0.450, -0.093]	Negative

Table A.3. Posterior means and 95% credible intervals of the (β) estimates, derived from the posterior distribution, corresponding to the results presented in the Figure 7, indicating the behaviour of female pigs without an environmental enrichment condition. Observations were carried out over 12 weeks of experimentation, considering the following behaviours: (1) aggressive, (2) feeding, (3) calm, (4) animal interaction, (5) environment interaction, (6) object interaction, and (7) locomotion

Time	Category	Posterior mean	95% credible interval	Effect
1	1	0.561	[0.396, 0.712]	Positive
1	2	-0.266	[-0.455, -0.088]	Negative
1	3	0.337	[0.170, 0.494]	Positive
1	4	-0.122	[-0.309, 0.043]	Not significant
1	5	-0.241	[-0.423, -0.080]	Negative
1	6	-0.002	[-0.168, 0.170]	Not significant
1	7	-0.265	[-0.442, -0.086]	Negative
2	1	0.558	[0.388, 0.716]	Positive
2	2	-0.247	[-0.421, -0.068]	Negative
2	3	0.283	[0.114, 0.444]	Positive
2	4	-0.190	[-0.371, -0.014]	Negative
2	5	-0.180	[-0.347, -0.019]	Negative
2	6	0.046	[-0.136, 0.221]	Not significant
2	7	-0.266	[-0.462, -0.083]	Negative
3	1	0.584	[0.421, 0.744]	Positive
3	2	-0.253	[-0.445, -0.046]	Negative
3	3	0.420	[0.256, 0.585]	Positive
3	4	-0.184	[-0.359, 0.004]	Not significant
3	5	-0.256	[-0.425, -0.080]	Negative
3	6	-0.040	[-0.221, 0.143]	Not significant
3	7	-0.264	[-0.450, -0.088]	Negative
4	1	0.577	[0.415, 0.740]	Positive
4	2	-0.269	[-0.451, -0.085]	Negative
4	3	0.407	[0.242, 0.573]	Positive
4	4	-0.226	[-0.410, -0.042]	Negative
4	5	-0.204	[-0.368, -0.033]	Negative
4	6	-0.006	[-0.178, 0.167]	Not significant
4	7	-0.263	[-0.438, -0.094]	Negative
5	1	0.492	[0.330, 0.664]	Positive
5	2	-0.241	[-0.412, -0.062]	Negative
5	3	0.275	[0.120, 0.449]	Positive
5	4	-0.143	[-0.316, 0.025]	Not significant
5	5	-0.200	[-0.356, -0.034]	Negative
5	6	0.079	[-0.081, 0.251]	Not significant
5	7	-0.258	[-0.439, -0.059]	Negative

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Time	Category	Posterior mean	95% credible interval	Effect
6	1	0.557	[0.402, 0.714]	Positive
6	2	-0.265	[-0.453, -0.087]	Negative
6	3	0.334	[0.172, 0.508]	Positive
6	4	-0.124	[-0.307, 0.049]	Not significant
6	5	-0.237	[-0.402, -0.073]	Negative
6	6	-0.002	[-0.177, 0.168]	Not significant
6	7	-0.266	[-0.451, -0.086]	Negative
7	1	0.563	[0.408, 0.718]	Positive
7	2	-0.245	[-0.428, -0.062]	Negative
7	3	0.286	[0.131, 0.452]	Positive
7	4	-0.193	[-0.360, -0.007]	Negative
7	5	-0.182	[-0.348, -0.010]	Negative
7	6	0.047	[-0.126, 0.215]	Not significant
7	7	-0.267	[-0.454, -0.079]	Negative
8	1	0.590	[0.419, 0.749]	Positive
8	2	-0.256	[-0.424, -0.073]	Negative
8	3	0.418	[0.254, 0.585]	Positive
8	4	-0.188	[-0.358, -0.004]	Negative
8	5	-0.254	[-0.413, -0.070]	Negative
8	6	-0.046	[-0.215, 0.133]	Not significant
8	7	-0.261	[-0.444, -0.094]	Negative
9	1	0.576	[0.423, 0.745]	Positive
9	2	-0.276	[-0.456, -0.102]	Negative
9	3	0.401	[0.235, 0.561]	Positive
9	4	-0.235	[-0.422, -0.056]	Negative
9	5	-0.205	[-0.370, -0.045]	Negative
9	6	-0.010	[-0.184, 0.163]	Not significant
9	7	-0.262	[-0.444, -0.096]	Negative
10	1	0.493	[0.330, 0.661]	Positive
10	2	-0.242	[-0.420, -0.055]	Negative
10	3	0.276	[0.099, 0.433]	Positive
10	4	-0.148	[-0.324, 0.023]	Not significant
10	5	-0.199	[-0.376, -0.042]	Negative
10	6	0.077	[-0.102, 0.246]	Not significant
10	7	-0.260	[-0.452, -0.062]	Negative
11	1	0.560	[0.402, 0.710]	Positive
11	2	-0.264	[-0.438, -0.091]	Negative
11	3	0.331	[0.168, 0.505]	Positive
11	4	-0.129	[-0.310, 0.041]	Not significant
11	5	-0.240	[-0.414, -0.063]	Negative
11	6	-0.002	[-0.172, 0.163]	Not significant
11	7	-0.268	[-0.462, -0.098]	Negative
12	1	0.557	[0.395, 0.719]	Positive
12	2	-0.248	[-0.433, -0.080]	Negative
12	3	0.284	[0.124, 0.447]	Positive
12	4	-0.193	[-0.364, -0.021]	Negative
12	5	-0.181	[-0.335, -0.010]	Negative
12	6	0.041	[-0.138, 0.213]	Not significant
12	7	-0.266	[-0.430, -0.098]	Negative

Table A.4. Posterior means and 95% credible intervals of the (β) estimates, derived from the posterior distribution, corresponding to the results presented in the Figure 8, indicating the behaviour of male pigs under the environmental enrichment condition with sisal rope. Observations were carried out over 12 weeks of experimentation, considering the following behaviours: (1) aggressive, (2) feeding, (3) calm, (4) animal interaction, (5) environment interaction, (6) object interaction, and (7) locomotion

Time	Category	Posterior mean	95% credible interval	Effect
1	1	0.118	[-0.046, 0.280]	Not significant
1	2	-0.238	[-0.406, -0.073]	Negative
1	3	0.713	[0.552, 0.873]	Positive
1	4	-0.228	[-0.432, -0.052]	Negative
1	5	-0.040	[-0.214, 0.136]	Not significant
1	6	-0.096	[-0.268, 0.090]	Not significant
1	7	-0.233	[-0.418, -0.049]	Negative
2	1	0.208	[0.036, 0.388]	Positive
2	2	-0.256	[-0.416, -0.076]	Negative
2	3	0.450	[0.278, 0.611]	Positive
2	4	-0.233	[-0.415, -0.056]	Negative
2	5	0.153	[-0.019, 0.332]	Not significant
2	6	-0.172	[-0.350, -0.005]	Negative
2	7	-0.156	[-0.326, 0.014]	Not significant
3	1	0.091	[-0.081, 0.259]	Not significant
3	2	-0.201	[-0.371, -0.026]	Negative
3	3	0.373	[0.201, 0.540]	Positive
3	4	-0.285	[-0.456, -0.113]	Negative
3	5	0.345	[0.182, 0.501]	Positive
3	6	-0.263	[-0.440, -0.090]	Negative
3	7	-0.064	[-0.229, 0.101]	Not significant
4	1	-0.000	[-0.175, 0.159]	Not significant
4	2	-0.234	[-0.409, -0.065]	Negative
4	3	0.397	[0.243, 0.556]	Positive
4	4	-0.237	[-0.415, -0.054]	Negative
4	5	0.368	[0.196, 0.532]	Positive
4	6	-0.203	[-0.379, -0.034]	Negative
4	7	-0.093	[-0.258, 0.072]	Not significant
5	1	0.058	[-0.120, 0.224]	Not significant
5	2	-0.272	[-0.440, -0.079]	Negative
5	3	0.357	[0.185, 0.522]	Positive
5	4	-0.216	[-0.387, -0.041]	Negative
5	5	0.273	[0.106, 0.424]	Positive
5	6	-0.245	[-0.419, -0.062]	Negative
5	7	0.028	[-0.146, 0.200]	Not significant
6	1	0.015	[-0.154, 0.191]	Not significant
6	2	-0.216	[-0.385, -0.038]	Negative
6	3	0.333	[0.176, 0.499]	Positive
6	4	-0.256	[-0.430, -0.082]	Negative
6	5	0.397	[0.232, 0.554]	Positive
6	6	-0.177	[-0.358, 0.009]	Not significant
6	7	-0.096	[-0.260, 0.059]	Not significant
7	1	-0.002	[-0.174, 0.169]	Not significant
7	2	-0.092	[-0.258, 0.072]	Not significant
7	3	0.121	[-0.039, 0.287]	Not significant
7	4	-0.271	[-0.444, -0.105]	Negative
7	5	0.540	[0.388, 0.699]	Positive
7	6	-0.249	[-0.421, -0.081]	Negative
7	7	-0.050	[-0.220, 0.118]	Not significant
8	1	0.009	[-0.170, 0.185]	Not significant
8	2	0.064	[-0.112, 0.230]	Not significant
8	3	-0.023	[-0.208, 0.151]	Not significant
8	4	-0.211	[-0.385, -0.023]	Negative

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Time	Category	Posterior mean	95% credible interval	Effect
8	5	0.276	[0.109, 0.449]	Positive
8	6	-0.218	[-0.399, -0.029]	Negative
8	7	0.095	[-0.089, 0.268]	Not significant
9	1	-0.094	[-0.261, 0.077]	Not significant
9	2	0.037	[-0.145, 0.210]	Not significant
9	3	0.005	[-0.175, 0.190]	Not significant
9	4	-0.179	[-0.357, 0.004]	Not significant
9	5	0.271	[0.105, 0.444]	Positive
9	6	-0.170	[-0.344, 0.014]	Not significant
9	7	0.118	[-0.048, 0.277]	Not significant
10	1	-0.141	[-0.321, 0.044]	Not significant
10	2	0.067	[-0.103, 0.236]	Not significant
10	3	0.078	[-0.105, 0.251]	Not significant
10	4	-0.126	[-0.305, 0.052]	Not significant
10	5	0.036	[-0.147, 0.206]	Not significant
10	6	-0.174	[-0.359, 0.004]	Not significant
10	7	0.260	[0.078, 0.431]	Positive
11	1	-0.166	[-0.347, 0.019]	Not significant
11	2	0.077	[-0.093, 0.243]	Not significant
11	3	-0.101	[-0.278, 0.064]	Not significant
11	4	-0.099	[-0.275, 0.079]	Not significant
11	5	0.179	[-0.004, 0.365]	Not significant
11	6	-0.172	[-0.355, 0.021]	Not significant
11	7	0.274	[0.106, 0.459]	Positive
12	1	-0.125	[-0.314, 0.052]	Not significant
12	2	0.221	[0.059, 0.390]	Positive
12	3	-0.104	[-0.282, 0.081]	Not significant
12	4	0.025	[-0.158, 0.210]	Not significant
12	5	-0.032	[-0.209, 0.150]	Not significant
12	6	-0.134	[-0.317, 0.051]	Not significant
12	7	0.159	[-0.018, 0.340]	Not significant

Table A.5. Posterior means and 95% credible intervals of the (β) estimates, derived from the posterior distribution, corresponding to the results presented in the Figure 9, indicating the behaviour of male pigs under the environmental enrichment condition with branched chain. Observations were carried out over 12 weeks of experimentation, considering the following behaviours: (1) aggressive, (2) feeding, (3) calm, (4) animal interaction, (5) environment interaction, (6) object interaction, and (7) locomotion

Time	Category	Posterior mean	95% credible interval	Effect
1	1	0.1233	[-0.046, 0.307]	Not significant
1	2	-0.2158	[-0.411, -0.038]	Negative
1	3	0.6452	[0.477, 0.804]	Positive
1	4	-0.2331	[-0.399, -0.062]	Negative
1	5	0.0561	[-0.123, 0.230]	Not significant
1	6	-0.1379	[-0.320, 0.045]	Not significant
1	7	-0.2301	[-0.416, -0.053]	Negative
2	1	0.1686	[0.005, 0.345]	Positive
2	2	-0.2312	[-0.408, -0.066]	Negative
2	3	0.7198	[0.540, 0.895]	Positive
2	4	-0.2467	[-0.426, -0.071]	Negative
2	5	0.0149	[-0.151, 0.184]	Not significant
2	6	-0.1756	[-0.349, 0.010]	Not significant
2	7	-0.2381	[-0.422, -0.057]	Negative
3	1	0.1000	[-0.068, 0.272]	Not significant
3	2	-0.2364	[-0.410, -0.055]	Negative
3	3	0.7719	[0.606, 0.945]	Positive
3	4	-0.2262	[-0.409, -0.042]	Negative

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Time	Category	Posterior mean	95% credible interval	Effect
3	5	0.0016	[-0.171, 0.168]	Not significant
3	6	-0.1737	[-0.352, 0.004]	Not significant
3	7	-0.2368	[-0.419, -0.055]	Negative
4	1	0.0615	[-0.103, 0.239]	Not significant
4	2	-0.2172	[-0.411, -0.042]	Negative
4	3	0.6845	[0.526, 0.853]	Positive
4	4	-0.2111	[-0.391, -0.039]	Negative
4	5	-0.0238	[-0.193, 0.147]	Not significant
4	6	-0.0764	[-0.254, 0.109]	Not significant
4	7	-0.2213	[-0.396, -0.049]	Negative
5	1	0.1098	[-0.059, 0.288]	Not significant
5	2	-0.2182	[-0.404, -0.030]	Negative
5	3	0.6201	[0.456, 0.781]	Positive
5	4	-0.1877	[-0.365, -0.006]	Negative
5	5	-0.0032	[-0.187, 0.163]	Not significant
5	6	-0.1071	[-0.285, 0.063]	Not significant
5	7	-0.2146	[-0.387, -0.026]	Negative
6	1	0.1223	[-0.049, 0.285]	Not significant
6	2	-0.2141	[-0.391, -0.032]	Negative
6	3	0.6432	[0.471, 0.810]	Positive
6	4	-0.2360	[-0.421, -0.056]	Negative
6	5	0.0602	[-0.122, 0.233]	Not significant
6	6	-0.1452	[-0.318, 0.029]	Not significant
6	7	-0.2336	[-0.411, -0.053]	Negative
7	1	0.1671	[0.003, 0.343]	Positive
7	2	-0.2297	[-0.406, -0.053]	Negative
7	3	0.7228	[0.557, 0.873]	Positive
7	4	-0.2456	[-0.431, -0.064]	Negative
7	5	0.0154	[-0.153, 0.181]	Not significant
7	6	-0.1813	[-0.357, -0.011]	Negative
7	7	-0.2365	[-0.403, -0.063]	Negative
8	1	0.1036	[-0.070, 0.275]	Not significant
8	2	-0.2345	[-0.423, -0.059]	Negative
8	3	0.7706	[0.609, 0.928]	Positive
8	4	-0.2272	[-0.411, -0.040]	Negative
8	5	-0.0040	[-0.188, 0.169]	Not significant
8	6	-0.1769	[-0.354, 0.007]	Not significant
8	7	-0.2293	[-0.407, -0.052]	Negative
9	1	0.0664	[-0.099, 0.232]	Not significant
9	2	-0.2255	[-0.412, -0.050]	Negative
9	3	0.6861	[0.527, 0.861]	Positive
9	4	-0.2117	[-0.383, -0.025]	Negative
9	5	-0.0206	[-0.189, 0.137]	Not significant
9	6	-0.0705	[-0.241, 0.097]	Not significant
9	7	-0.2230	[-0.396, -0.058]	Negative
10	1	0.1132	[-0.056, 0.284]	Not significant
10	2	-0.2223	[-0.388, -0.050]	Negative
10	3	0.6245	[0.465, 0.784]	Positive
10	4	-0.1886	[-0.368, -0.012]	Negative
10	5	0.0009	[-0.172, 0.174]	Not significant
10	6	-0.1133	[-0.290, 0.056]	Not significant
10	7	-0.2188	[-0.402, -0.047]	Negative
11	1	0.1237	[-0.042, 0.283]	Not significant
11	2	-0.2161	[-0.388, -0.041]	Negative
11	3	0.6413	[0.482, 0.806]	Positive
11	4	-0.2347	[-0.423, -0.056]	Negative
11	5	0.0577	[-0.106, 0.226]	Not significant
11	6	-0.1420	[-0.313, 0.029]	Not significant
11	7	-0.2317	[-0.412, -0.055]	Negative
12	1	0.1650	[-0.002, 0.317]	Not significant

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Time	Category	Posterior mean	95% credible interval	Effect
12	2	-0.2288	[-0.408, -0.063]	Negative
12	3	0.7154	[0.560, 0.871]	Positive
12	4	-0.2500	[-0.429, -0.070]	Negative
12	5	0.0062	[-0.161, 0.173]	Not significant
12	6	-0.1848	[-0.358, -0.016]	Negative
12	7	-0.2436	[-0.418, -0.068]	Negative

Table A.6. Posterior means and 95% credible intervals of the (β) estimates, derived from the posterior distribution, corresponding to the results presented in the Figure 10, indicating the behaviour of male pigs without an environmental enrichment condition. Observations were carried out over 12 weeks of experimentation, considering the following behaviours: (1) aggressive, (2) feeding, (3) calm, (4) animal interaction, (5) environment interaction, (6) object interaction, and (7) locomotion

Time	Category	Posterior mean	95% credible interval	Effect
1	1	0.0260	[-0.141, 0.195]	Not significant
1	2	-0.2046	[-0.377, -0.031]	Negative
1	3	0.7243	[0.556, 0.887]	Positive
1	4	-0.2165	[-0.379, -0.052]	Negative
1	5	0.0766	[-0.092, 0.244]	Not significant
1	6	-0.1955	[-0.373, -0.013]	Negative
1	7	-0.1949	[-0.379, -0.013]	Negative
2	1	0.1218	[-0.047, 0.295]	Not significant
2	2	-0.2279	[-0.407, -0.041]	Negative
2	3	0.6912	[0.530, 0.847]	Positive
2	4	-0.2340	[-0.413, -0.058]	Negative
2	5	0.0877	[-0.085, 0.267]	Not significant
2	6	-0.2179	[-0.399, -0.030]	Negative
2	7	-0.2245	[-0.404, -0.045]	Negative
3	1	0.0051	[-0.162, 0.182]	Not significant
3	2	-0.2140	[-0.405, -0.029]	Negative
3	3	0.8173	[0.659, 0.974]	Positive
3	4	-0.2118	[-0.381, -0.029]	Negative
3	5	0.0234	[-0.138, 0.196]	Not significant
3	6	-0.1993	[-0.379, -0.021]	Negative
3	7	-0.2190	[-0.390, -0.064]	Negative
4	1	-0.0416	[-0.226, 0.131]	Not significant
4	2	-0.2215	[-0.416, -0.039]	Negative
4	3	0.8371	[0.674, 0.994]	Positive
4	4	-0.2290	[-0.402, -0.052]	Negative
4	5	0.0699	[-0.094, 0.237]	Not significant
4	6	-0.1907	[-0.370, -0.018]	Negative
4	7	-0.2231	[-0.408, -0.037]	Negative
5	1	0.0241	[-0.144, 0.194]	Not significant
5	2	-0.2051	[-0.389, -0.025]	Negative
5	3	0.6687	[0.499, 0.838]	Positive
5	4	-0.1892	[-0.374, -0.011]	Negative
5	5	0.0565	[-0.119, 0.230]	Not significant
5	6	-0.1288	[-0.301, 0.041]	Not significant
5	7	-0.2103	[-0.392, -0.032]	Negative
6	1	0.0253	[-0.148, 0.192]	Not significant
6	2	-0.2026	[-0.380, -0.010]	Negative
6	3	0.7227	[0.561, 0.901]	Positive
6	4	-0.2095	[-0.393, -0.023]	Negative
6	5	0.0806	[-0.092, 0.264]	Not significant
6	6	-0.1974	[-0.376, -0.020]	Negative
6	7	-0.2075	[-0.396, -0.029]	Negative
7	1	0.1208	[-0.047, 0.284]	Not significant

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Time	Category	Posterior mean	95% credible interval	Effect
7	2	-0.2293	[-0.417, -0.047]	Negative
7	3	0.6915	[0.534, 0.855]	Positive
7	4	-0.2324	[-0.417, -0.055]	Negative
7	5	0.0869	[-0.065, 0.264]	Not significant
7	6	-0.2189	[-0.408, -0.038]	Negative
7	7	-0.2234	[-0.402, -0.045]	Negative
8	1	0.0051	[-0.157, 0.170]	Not significant
8	2	-0.2164	[-0.383, -0.042]	Negative
8	3	0.8146	[0.663, 0.977]	Positive
8	4	-0.2158	[-0.396, -0.035]	Negative
8	5	0.0250	[-0.155, 0.200]	Not significant
8	6	-0.2007	[-0.378, -0.027]	Negative
8	7	-0.2114	[-0.384, -0.029]	Negative
9	1	-0.0448	[-0.206, 0.120]	Not significant
9	2	-0.2180	[-0.406, -0.030]	Negative
9	3	0.8388	[0.679, 1.003]	Positive
9	4	-0.2204	[-0.400, -0.045]	Negative
9	5	0.0661	[-0.099, 0.238]	Not significant
9	6	-0.1850	[-0.360, -0.017]	Negative
9	7	-0.2253	[-0.409, -0.050]	Negative
10	1	0.0233	[-0.142, 0.188]	Not significant
10	2	-0.2116	[-0.397, -0.030]	Negative
10	3	0.6683	[0.506, 0.840]	Positive
10	4	-0.1910	[-0.375, -0.019]	Negative
10	5	0.0531	[-0.130, 0.222]	Not significant
10	6	-0.1291	[-0.315, 0.047]	Not significant
10	7	-0.2077	[-0.384, -0.026]	Negative
11	1	0.0244	[-0.151, 0.195]	Not significant
11	2	-0.2088	[-0.385, -0.027]	Negative
11	3	0.7230	[0.567, 0.878]	Positive
11	4	-0.2139	[-0.389, -0.045]	Negative
11	5	0.0834	[-0.083, 0.262]	Not significant
11	6	-0.2014	[-0.376, -0.032]	Negative
11	7	-0.2054	[-0.383, -0.017]	Negative
12	1	0.1190	[-0.043, 0.288]	Not significant
12	2	-0.2291	[-0.396, -0.053]	Negative
12	3	0.6960	[0.525, 0.857]	Positive
12	4	-0.2285	[-0.420, -0.050]	Negative
12	5	0.0916	[-0.081, 0.260]	Not significant
12	6	-0.2138	[-0.385, -0.038]	Negative
12	7	-0.2268	[-0.400, -0.045]	Negative

Appendix B

This Appendix presents the convergence diagnostics of the selected Bayesian hierarchical model, chosen based on the Deviance Information Criterion (DIC). Convergence of the Markov chain Monte Carlo (MCMC) simulations was assessed using the Gelman–Rubin statistic ($\hat{R}$), which measures the degree of agreement among multiple chains initiated from dispersed starting values.

Overall, the estimated $\hat{R}$ values remained close to 1 and below the commonly adopted threshold of 1.1, indicating satisfactory convergence of the chains and stability of the posterior estimates.

In total, 6,793 parameters were evaluated. The $\hat{R}$ values ranged from 0.999 to 1.015, with a median of 1.001 and a mean of 1.002. Only 53 parameters exhibited $\hat{R}$ values greater than 1.01, and none exceeded the thresholds of 1.05 or 1.10, which are commonly associated with convergence issues. These results provide consistent evidence of adequate chain convergence and stability of the estimation process.

Table B.1 reports the largest $\hat{R}$ values observed among the model parameters, corresponding to the latent probabilities of the multinomial model. In addition, Figure B.1 displays the empirical distribution of $\hat{R}$ values across all parameters, allowing for a graphical assessment of convergence. No evidence of lack of convergence or poor chain mixing was observed, supporting the reliability of the posterior inferences presented in the main text.

Table B.1. Largest values of the Gelman–Rubin statistic ($\hat{R}$) associated with the probability parameters of the hierarchical multinomial model, organised by experimental unit, category, and observation time

Experimental unit	Category	Time	$\hat{R}$
16	1	10	1.014959
23	1	10	1.014959
24	1	10	1.014959
34	1	10	1.014959
38	1	10	1.014959
41	1	10	1.014959
46	1	10	1.014959
53	1	10	1.014959
20	4	12	1.014692
45	4	12	1.014692
61	4	12	1.014692
2	4	12	1.014692
29	4	12	1.014692
39	4	12	1.014692
48	4	12	1.014692
59	4	12	1.014692
13	1	10	1.013650
17	1	10	1.013650
32	1	10	1.013650
42	1	10	1.013650

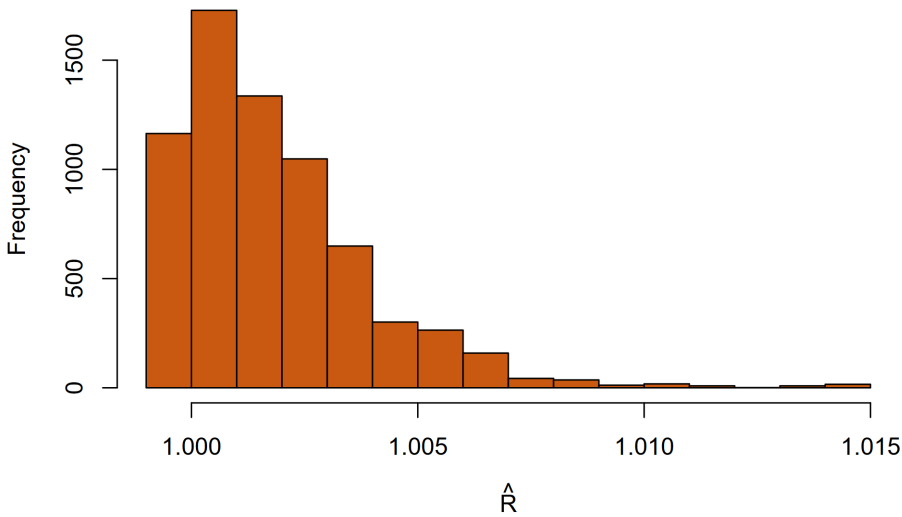


Figure B.1. Empirical distribution of the Gelman–Rubin statistic ($\hat{R}$) for all parameters of the Bayesian hierarchical multinomial model. The dashed line indicates the threshold of 1.1, commonly adopted as a reference for assessing Markov chain convergence.

The convergence diagnostics presented in this appendix do not indicate any issues in the estimation of the hierarchical Bayesian multinomial model. In particular, the values of the Gelman–Rubin statistic ($\hat{R}$) remained close to 1 for all monitored parameters, suggesting adequate convergence of the Markov chains. Consequently, the results reported in Section 3 can be regarded as computationally stable.