J. Dairy Sci. 108:954–967
https://doi.org/10.3168/jds.2024-25159

A meta-analysis approach to evaluate the effects of early group housing on calf performance, health, and behavior during the preweaning period

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ABSTRACT

This study aimed to evaluate the effects of early group housing on the performance, health, and behavior of dairy calves during the preweaning period using systematic and meta-analysis approaches. Peer-reviewed articles written in English that compared dairy calves individually and group-housed with performance, health, or behavior outcomes were collected from Web of Science, PubMed, and CABDirect databases. The resulting articles (n = 850) underwent a 4-step appraisal process following the Preferred Reporting Items for Systematic Review and Meta-Analyses protocols, resulting in a final sample of 51 articles containing 85 studies. The weighted or standardized mean differences between individually housed and group-housed (pair or group with >2 calves) calves were analyzed for each variable using the DerSimonian and Laird methods. Heterogeneity between calf housing systems was evaluated by the χ^2 test and I^2 statistics. A meta-regression analysis was conducted to identify categorical covariate effects for variables with high heterogeneity. Most of the studies included in this review evaluated female calves (45.8%) weaned at 8 wk old (52.6%). Housing systems were mainly paired housing (55.3%), followed by groups of 3 to 6 calves (30.65) and groups of 7 to 15 calves (4.7%). We did not find studies with comparable outcomes for more robust health parameters (as occurrence of diseases), only blood parameters, that were not influenced by the housing system. However, weight gain and feed intake parameters were higher in group-housed calves. Through the meta-regression, we found that ADG was positively affected by the group housing in studies with calves housed in small pen areas (<1.5 m^2 per calf). Group-housed calves presented more active behaviors (feeding and playing) and less stress-related behaviors (self-grooming and interacting with the pen) than individually housed calves. The behavioral tests most used were novel object, human approach, novel environment, and social tests. Individually housed calves presented fewer vocalizations on these tests and spent more time interacting with humans during the human approach test than group-housed calves. Our findings provide consistent evidence that group housing improves the welfare of dairy calves; however, the effects on health parameters are still scarce and unclear.
Key words: dairy cattle, individual housing, growth, social enrichment, welfare

INTRODUCTION

Dairy calves are commonly separated from their dams shortly after birth and raised isolated from other individuals during preweaning (usually until 2 mo old; Cantor et al., 2019). These practices contrast with what occurs under natural conditions (Whalin et al., 2021) and citizens have a negative view of the practices (Placzek et al., 2021). Furthermore, isolated housing has detrimental effects on calves' early life. The stress caused by social isolation makes calves more fearful than those with social contact (Creel and Albright, 1988; Gaillard et al., 2014). Therefore, group housing has been studied to understand the importance of social interactions for calf development.

Calves can be housed with conspecifics of similar age or in complex groups with foster cows or their dams (Mandel et al., 2016). Pair and small group (<10 calves per group) housing are the most studied systems for dairy calves due to their easier management. The other options

Received May 13, 2024.
Accepted September 28, 2024.
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The list of standard abbreviations for JDS is available at adsa.org/jds-abbreviations-24. Nonstandard abbreviations are available in the Notes.

Table 1. Population, intervention, comparison, and outcome of search term strings used for the final search

Category	Search string
Population	(calf OR calves OR heifers) AND (dairy OR milking)
Interventions	(hous* OR rear*)
Comparison	(single OR individual*) AND (group* OR pair* OR foster OR mother OR dam) AND (compar* OR versus)
Outcome	(growth OR performance OR health OR behavio* OR cognitive OR welfare)

(e.g., foster cows or dams) are more difficult to manage but provide maternal care and a more natural-like social dynamic for calves (Loberg et al., 2007; Føske Johnsen et al., 2021). Although citizens usually consider group housing to be better than individual housing (Perttu et al., 2020; Sirovica et al., 2022), farmers believe that managing individually housed calves is easier and that these calves are less likely to get sick (Mahendran et al., 2022). However, some studies reported improved calf growth in pair- or group-housed systems compared with individually housed calves (Costa et al., 2015; Jensen et al., 2015; Mahendran et al., 2023), whereas others found no difference (Arave et al., 1985; Cobb et al., 2014; Wormsbecher et al., 2017).

Multiple factors could interact with a calf's performance, health, and behavior, including the calf's personality, milk allowance, and farm management (Neave et al., 2018; Hyde et al., 2021). Social isolation is a trending topic in the dairy industry (Costa et al., 2016; Nikkhah and Alimirzaei, 2022; Miller-Cushon, 2024). However, to our knowledge, no attempt has been made to summarize the available scientific information on the effects of group housing using meta-analysis approaches. Meta-analysis is an efficient tool for providing a deep analysis of the treatment effect, examining possible sources of heterogeneity in animal responses and identifying possible biases in studies (St-Pierre, 2001). In this study, we reviewed articles that compared individual and group rearing of dairy calves and compiled the results by performance, health, and behavior variables. Based on this, we aimed to investigate the effects of early group housing on the performance, health, and behavior of dairy calves during the preweaning period using systematic and meta-analysis approaches.

METHODS

Search Strategy

This review was conducted following the guidelines of Preferred Reporting Items for Systematic Review and Meta-Analyses protocols (Page et al., 2021). The strategy of population, intervention, comparison, and outcome (Thomas et al., 2019) was used to select specific search terms for each category and to determine whether studies were eligible for the review. The Boolean operators (i.e., AND, OR, NOT) were integrated to string words together. The "*" symbol was employed to account for alternate spellings (e.g., American vs. British English). All the search terms are shown in Table 1. Peer-reviewed articles written in English and published before November 2023 were searched in the Web of Science (https://www.webofscience.com/), PubMed (https://pubmed.ncbi.nlm.nih.gov/), and CABDirect databases (https://www.cabidigitallibrary.org/).

Study Inclusion Criteria and Screening

Experimental studies were selected if they described the effects of group housing on the performance, health, behavior, or cognition of dairy calves. Thus, we considered studies that compared individual calf housing (control) to a group housing system (pair or group >2 calves), or calves reared with the dam or foster cow. Exclusion and inclusion criteria for the systematic review were developed a priori and agreed upon by all authors. The selection and assessment of eligibility were performed by 2 investigators (JPD and IPL), with disagreement resolved by a third investigator (MD).

The selection process was conducted with the aid of the application Rayyan (Ouzzani et al., 2016), which is recommended for title and abstract screening given its suitable platform and easy-to-use tools (Harrison et al., 2020). After uploading the references to Rayyan, duplicates were excluded (McKeown and Mir, 2021) and the remaining articles were evaluated based on a 4-step screening and appraisal process.

The first step was the removal of publications written in a language other than English, because of our inability to assess the methods and evaluate the results critically. In addition, theses, books, book chapters, conference papers, and reports were removed, as we could not be certain these sources had been peer-reviewed. In the second step, titles and abstracts were evaluated to identify and remove additional articles not relevant to the topic of interest (e.g., animal classes other than dairy cattle, such as articles addressing beef cattle, sheep, and buffalo, or those without comparison between individual vs. group housing). In the third step, titles and abstracts were screened again to identify and remove articles not using dairy calves (e.g., articles addressing heifers or cows). Finally, the fourth step was the full-text detailed

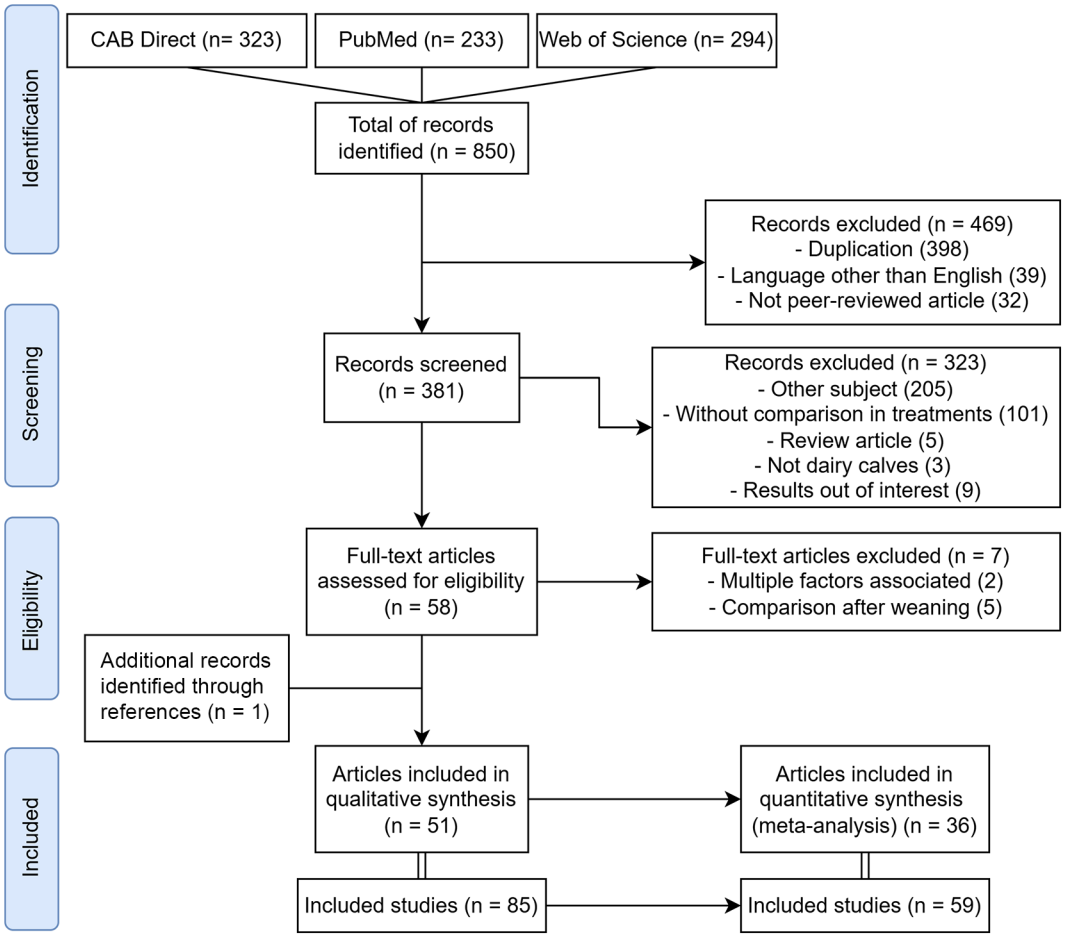

Figure 1. Flowchart following Preferred Reporting Items for Systematic Review and Meta-Analyses guidelines (Page et al., 2021) showing the process to identify and screen articles for eligibility and inclusion in this systematic review and meta-analysis.

reading of the remaining articles for a thorough selection. Additionally, the reference lists of the remaining articles were checked to identify additional studies not found in the search process; if potential articles were identified, their full text was evaluated. We uncovered one additional study, which did not contain the search terms we used, but instead used the term "artificial" for individual or single housing.

Articles containing experimental research were excluded if the experiment did not address the relationship between individual and group housing and behavior, performance, health, or cognitive parameters in dairy calves. Furthermore, we only included in our review studies that evaluated calves housed in pairs or groups formed before 2 wk of age (≤14 d) and that presented measurements during the preweaning period. No additional restrictions were placed upon publication year, sample size, journal, or overall quality. The remaining articles were included in the systematic review and meta-analysis. For the meta-analysis, articles were included if they reported mean values and corresponding errors for the variables comparing individual housing (control) to a group housing system.

Data Extraction Strategy and Synthesis Procedures

When applicable, the selected articles were divided into studies, as one article could have one or more studies. An article was divided into 2 studies (or more) when 2 or more treatments were applied to different calf housing systems. For example, Dong et al. (2017) evaluated 2 methods of supplying milk to individually housed calves and to group-housed calves.

The data extracted from each study included in the systematic analysis were classified as follows: basic study characteristics (authors, journal, year of publication, country); collection period (days); milk allowance per day; weaning age; sex class; housing type; total space available per calf (m^2); group size; outcomes (performance, health, behavior, and cognitive parameters); and

Table 2. Effects of group housing on the performance, feed intake, and health parameters found in the studies included in the meta-analysis

Parameter	Individual housing,[3] mean (SD)	n[4]	Group housing WMD$_{Random\ effect}$[5] (95% CI)	*P*-value	Heterogeneity[1] I^2, %	*P*-value	Funnel test[2] *P*-value
Performance							
Weaning weight, kg	77.81 (19.12)	17	1.436 (0.09, 2.78)	0.037	42.93	0.025	0.776
ADG, kg/d	0.65 (0.21)	27	0.056 (0.03, 0.08)	0.001	75.63	<.0001	0.069
Feed intake							
DMI, kg/d	1.26 (0.39)	7	0.039 (−0.03, 0.11)	0.268	52.15	0.062	0.395
Concentrate intake, kg/d	0.53 (0.46)	10	0.037 (0.01, 0.07)	0.021	53.29	0.023	0.633
Health							
Packed cell volume, %	28.67 (6.09)	4	1.926 (−3.75, 7.60)	0.506	99.08	<.0001	0.699
Blood glucose, mg/dL	81.42 (12.69)	5	0.775 (−3.62, 5.17)	0.729	16.67	0.308	0.147
BUN, mg/dL	11.84 (7.42)	5	0.091 (−0.71, 0.89)	0.823	0.00	0.453	0.749
Tumor necrosis factor, ng/L	599.1 (483.3)	6	16.615 (−9.91, 43.15)	0.219	0.00	0.936	0.491

[1]I^2 = proportion of total variation of size effect estimates that is due to heterogeneity; *P*-value to χ^2 (Q) test of heterogeneity.

[2]Egger's regression asymmetry test.

[3]Control system (individual housing).

[4]Number of comparisons of control and group housing.

[5]WMD$_{Random\ effect}$ = weighted mean differences between individual (control) and group housing systems.

main findings. Data extraction was performed through Microsoft Excel (Microsoft Corp., version 2409) by the first author and verified by 2 authors (RNST and MD). During the data extraction, the references of retrieved articles were searched independently and checked for any additional studies not captured by the initial search. For the meta-analysis, the mean values, and corresponding errors for each variable of studies were extracted.

Statistical Analysis

The meta-analysis was performed in R version 4.3.2 (R Core Team, 2023) using the Metafor package (version 4.2-0; Viechtbauer and Viechtbauer, 2015). A forest graph (forest plot) was created using STATA software (version 16.0, StataCorp LP, College Station, TX). The effect size of group housing (pair or group >2 calves) was expressed as the weighted mean difference (**WMD**) for performance and health variables and the standardized mean difference (**SMD**) for behavioral variables. The SMD expresses the effect size in SD units and is generalizable, whereas the WMD expresses the effect size in the same units as the original measurement and is more interpretable (Takeshima et al., 2014). Furthermore, data were classified according to the following covariates: milk allowance per day (low, <6 L/d; medium, 6–9 L/d; high, >9 L/d); weaning age (less than 8 wk old, <53 d; 8 wk old, 53– 63d; more than 8 wk old, >63 d); sex class (female, male, or both male and female); housing type (outdoor or indoor); total space available per calf (m^2) for individual and group housing (<1.5 m^2; 1.5–2.5 m^2; 2.5–3.5 m^2; 3.5–5.0 m^2; 5.0–6.5 m^2; 6.5–7.5 m^2; >7.5 m^2); and group size (2 calves; 3–6 calves; 7–15 calves; complex group with adults).

Weighted Mean Difference and Standardized Mean Difference

The effect size of group housing was evaluated by WMD between individual (control) and group housing systems (pair or group with >2 calves) for performance and health variables. The means of variables for each calf housing system (individual and group) were weighted by the inverse of the variance, according to the method proposed by DerSimonian and Laird (1986) and used as a random effect on the model.

We adopted the methodology of SMD for behavioral variables due to the variation in behavioral observation methodologies among the included studies (e.g., continuous sampling and scan sampling around feeding behavior). Thus, the effect size of group housing for each outcome variable was calculated by SMD. The SMD was calculated using the methods of DerSimonian and Laird (1986) for random effects models, which consider SMD as the difference in mean values between individual and group housing systems, standardized using the SD. Consequently, the SMD data were expressed in SD units (Higgins et al., 2019).

Heterogeneity and Publication Bias

Between-study variance (i.e., heterogeneity of the calf housing systems) was evaluated using both the χ^2 (Q) test of heterogeneity and I^2 statistic, which measures the percentage of variation due to heterogeneity (Higgins et al., 2003). Negative I^2 values were assigned as zero values. The I^2 values were categorized as low (<25%), moderate (25%–50%), and high (>50%) heterogeneity (Higgins et al., 2003). Publication bias was evaluated using the

funnel plot (Light and Pillemer, 1984). An asymmetry test (indicative of publication bias) between the WMD or SMD and SE was carried out according to Egger et al. (1997). We considered a 95% confidence level, and outliers were removed when studentized residuals were outside of the 95% CI (range: −2.5 to 2.5).

Meta-Regression and Subgroup Analysis

Meta-regression analysis was conducted to identify categorical covariates effects. A mixed model was applied to adjust the data in the meta-regression analysis using WMD as the dependent variable, following the model:

$$\Theta_i = \beta + \beta_i x_{ij} + \ldots \beta_{ip} x_{ip} + \mu_i,$$

where Θ_i is the true effect of the group housing system in the ith explanatory variable; β_i is the overall true effect of the group housing system; x_{ij} is the value of the jth covariate (j = 1, 2, …, p) for the ith explanatory variable; β_{ip} is the change in the true effect size for a unit increase in the jth covariate; and $\mu_i \sim N(0, \tau^2)$. The τ^2 estimates the residual amount of heterogeneity not explained by the covariate (Viechtbauer and Cheung, 2010).

The restricted maximum likelihood estimate approach was used to estimate the between-study variance (Tau-squared = τ^2), as it is less likely to underestimate or produce biased estimates of variance than the moment estimator calculation of (τ^2), which is commonly used in DerSimonian and Laird random effects meta-analysis (Thompson and Sharp, 1999; Viechtbauer, 2005).

Tests of the null hypothesis for the covariate coefficients were obtained from the multiparameter Wald test (Harbord and Higgins, 2008). The adjusted R^2 for the model represents the proportion of between-study variance (heterogeneity) explained by the covariates (Harbord and Higgins, 2008; Viechtbauer and Cheung, 2010).

The criteria to analyze a dependent variable on meta-regression were as follows: (1) $P \leq 0.05$ for the heterogeneity test; (2) $P \geq 0.05$ for the funnel plot; (3) no observations with values for studentized residuals out of the range −2.5 to 2.5 (outliers); and (4) high heterogeneity (I^2 statistic >50%). The WMD or SMD was evaluated by subgroup analysis when the categorical covariates were significant at $P \leq 0.10$ (meta-regression analysis).

RESULTS

Systematic Analysis of the Included Studies

In total, 47 peer-reviewed articles published between 1979 and 2023 were included in this review, of which 22 presented more than one study, resulting in 81 studies. From these, 57 studies from 34 articles were included in the meta-analysis. Figure 1 presents the number of articles screened, assessed for eligibility, included, and excluded in this review.

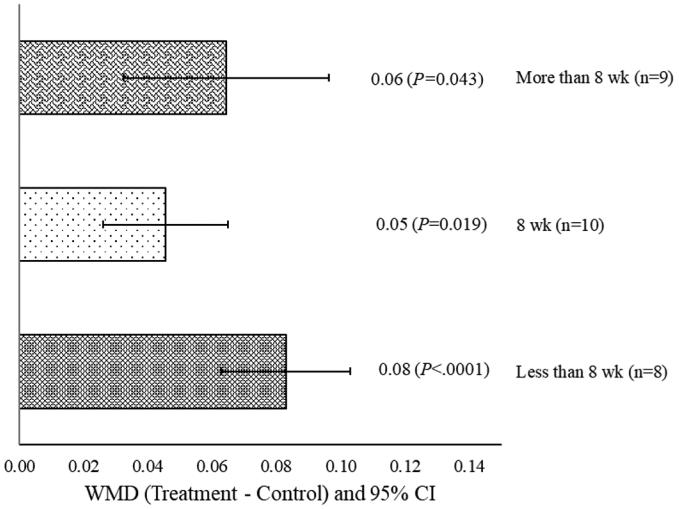

Figure 2. Subgroup (weaning age covariate) analysis effects of group housing on calves' ADG. WMD = weighted mean differences between group-housed and individually housed calves.

The main characteristics of the studies included in our review are presented in Supplemental Table S1 (see Notes). In summary, of the 81 studies that met our selection criteria, 47 investigated the effect of paired housing in comparison to individual housing systems, 65 studies were carried out in indoor systems, 40 were performed in pens with a total space ranging from 1.5 to 2.5 m^2/calf, 38 evaluated only female calves, 41 studies fed the calves between 6 and 9 L of milk/d, and 39 studies evaluated calves weaned at 8 wk old. Regarding the evaluated variables, 43 studies reported performance outcomes, 40 reported feed intake outcomes, 21 reported health outcomes, and 64 reported behavior outcomes, with 34 of them involving behavioral tests. Note that a single study may encompass multiple outcomes.

Calves' Performance, Feed Intake, and Health Parameters

A total of 27 eligible articles reporting results of 57 studies were included in the meta-analyses to evaluate the effect of group housing on calf performance (29 studies), feed intake (14 studies), and health parameters (8 studies). The meta-analysis outcomes are shown in Table 2. Group-housed calves presented a higher concentrate intake (P = 0.021), a greater ADG (P = 0.001), and were heavier at weaning (P = 0.037) compared with individually housed calves. In contrast, there was no effect (P > 0.05) of the housing system on health parameters analyzed in the studies. Unfortu-

nately, no robust health outcomes (such as mortality, diarrhea frequency, respiratory disease) were able to be quantitatively analyzed.

Although no variable showed publication bias ($P < 0.05$) through the funnel plot asymmetry test (Table 2), a moderate heterogeneity (I^2 statistic of 25%–50%) was observed in weaning weight and low heterogeneity (I^2 statistic <25%; Table 2) for the variables blood glucose, blood nitrogen urea, and tumor necrosis factor. The variables that fully met the points of the meta-regression criteria (see the "Meta-Regression and Subgroup Analysis" section) were ADG and concentrate intake. The results of the meta-regression analysis are presented in Table 3.

Five covariates (weaning age, sex class, rearing type, total area per calf, and group size) met the subgroup analysis criteria for ADG. Group housing affected the ADG of the calves for all weaning age categories (Figure 2). Studies that evaluated calves weaned at up to 8 wk old (n = 9) found an increase of 0.06 kg/d for group-housed calves. Group-housed calves weaned at 8 wk old (n = 10) had an increase of 0.05 kg/d ($P = 0.019$), and for calves weaned at more than 8 wk old (n = 9), there was an increase of 0.08 kg/d ($P < 0.001$). Studies that evaluated only female calves (n = 9) found a significant increase in ADG of 0.07 kg/d (95% CI: 0.03, 0.11). In contrast, the studies that evaluated only male calves or males and females together did not find a group housing effect in ADG (Figure 3A).

We found an increase of 0.13 kg/d (95% CI: 0.03, 0.22) in group-housed calves in 9 studies that evaluated calves reared in a pen with an area of less than 1.5 m^2/calf (Supplemental Figure S1, see Notes). However, there was no significant increase in ADG in other pen area categories. Paired housed calves had a higher ADG (0.06 kg/d; $P < 0.0001$) than individually raised calves and groups of 3 to 6 calves presented an increase of 0.03 kg/d ($P < 0.0001$; Figure 3B).

Calf Behavioral Parameters

Fourteen eligible articles including 22 studies were included in the meta-analyses evaluating the effect of group housing on calf behavioral parameters. The parameters included in the meta-analysis were lying, standing, self-grooming, feeding, playing, interacting with pen, and consuming milk (refer to description in Supplemental Table S2, see Notes). Group-housed calves displayed a higher occurrence of feeding ($P = 0.0036$) and playing ($P = 0.042$) behaviors in comparison to individually housed calves. Conversely, individually housed calves demonstrated an increase in self-grooming frequency ($P = 0.028$). However, housing did not influence ($P > 0.05$) lying, standing, and consuming milk (Table 4). The low number of studies that evaluated other behaviors (e.g., ruminating, exploring, non-nutritive sucking) made the meta-analysis not possible.

The only variable that showed a significant meta-regression as SMD was lying behavior on the rearing type parameter (indoor or outdoor; Table 3), but we found no significant housing effects for lying time in subgroup analysis for studies that raised calves indoors ($P = 0.826$) or outdoors ($P = 0.277$; refer to Supplemental Figure S2, see Notes).

Behavior and Cognitive Test Parameters

A total of 18 eligible articles reporting 32 studies were included in the evaluation of the effect of group housing on calf behavioral and cognitive parameters in tests. The tests used in the studies were novel object (n = 8 studies), human approach (n = 7 studies), novel environment (n = 7 studies), social test (n = 5 studies), food neophobia (n = 2 studies), and reversal learning (n = 3 studies); 29 studies did not present the required outcomes (SE or SD) or did not have enough studies with similar outcomes to be considered in the meta-analysis. The outcomes of the behavioral and cognitive tests are shown in Figure 4. In summary, group-housed calves showed higher vocalization frequency (SMD 0.47; CI: 0.09 to 0.85) and lower human touching time (SMD −0.90; CI: −1.39 to 0.41) compared with individual housing.

DISCUSSION

A key finding of this study is that early group housing has a positive impact on the welfare of dairy calves during the preweaning period. Grouped-housed calves exhibited higher concentrate intake, ADG, and weaning weight than calves housed individually. The main criticism associated with raising calves in groups is the potential increase in disease risk and transmission (Marcé et al., 2010; Cobb et al., 2014; Mahendran et al., 2022). Health parameters (e.g., occurrence of diseases) was reported in the included studies in various formats, making it difficult to apply meta-analysis to this outcome. However, some studies presented blood parameters that we considered as health indicators; nonetheless, we did not find significant differences in these variables. Furthermore, as group-housed calves can engage in social interactions (e.g., play and social learning), it is not surprising that we found an increase in playing and feeding behavior frequencies. In addition, calves also exhibited a lower frequency of self-grooming, which can be related to a reduction in stress responses. Thus, if we consider these results as indicators of welfare, we conclude that early group housing positively affects calf welfare.

Table 3. Meta-regression of the effect of group housing for dependent variables with weighted mean differences (WMD; ADG, concentrate intake) and variables with standardized mean differences (SMD; lying behavior) evaluated in the studies included in this review

Dependent variable (WMD or SMD)	Meta-regression parameters (*P*-value)[1]							
	Weaning age	Sex class	Milk allowance	Rearing type	Total area/calf	Group size	Adjusted R^2, %[2]	n[3]
Average daily gain, kg/d	0.42 (0.016)	−0.21 (0.002)	−0.03 (0.623)	0.31 (0.099)	0.19 (0.02)	0.09 (0.10)	99.99	27
Concentrate intake, kg/d	−0.04 (0.301)	−0.06 (0.547)	0.03 (0.992)	NA	0.15 (0.462)	NA	99.98	10
Lying	0.17 (0.942)	0.62 (0.659)	0.46 (0.735)	1.39 (0.044)	−0.89 (0.255)	−0.05 (0.954)	30.22	17

[1]Meta-regression parameters: weaning age (<8 wk; 8 wk; >8 wk); sex class (female; male; female and male); milk allowance (high; medium; low); rearing type (indoor; outdoor); total area per calf (<2 m^2; 2–4 m^2; > 4 m^2); group size (pair or group >2 calves). NA = not applicable; few studies evaluated in comparison between parameters.

[2]Adjusted R^2 = proportion of the between-study variance (heterogeneity) explained by the covariate.

[3]Number of comparisons between individual and group housing systems.

Performance

Our findings showed that group-housed calves have higher ADG, feed intake, and weaning weight than individually housed calves. Recent studies have also found growth advantages for heifers that were pair-housed or group-housed during preweaning period (Clein et al., 2024; Riesgraf et al., 2024). The ADG responses to housing systems were highly heterogeneous (76%); in the meta-regression analysis, we found that weaning age, sex class, and pen area were the main sources of heterogeneity. We found no effect of the covariate milk allowance on the ADG. Most of the studies fed the calves a medium quantity of milk per day (range: 6 to 9 L), which matches the recommendation of 8 L of the code of practice of Canada (NFACC, 2023). It is known that a high quantity of milk (12 L/d) is associated with weight gain advantages before weaning (Rosenberger et al., 2017); however, only 2 studies included in the meta-analysis offer a high quantity of milk (>9 L/d) to calves. The higher ADG on group housing was found for all weaning ages (before 8 wk old; 8 wk old; and more than 8 wk old). Weaning stands out as a particularly stressful period for dairy calves (Weary et al., 2008). However, there are many advantages associated with delaying the weaning process. Calves weaned later (>8 wk old) have enhanced weight gain (Eckert et al., 2015; Cheema et al., 2016; Omidi-Mirzaei et al., 2018), improved active behaviors (Eckert et al., 2015), and present more robust gastrointestinal development (Eckert et al., 2015; Meale et al., 2017). It is important to note that delayed weaning is necessary when calves receive a higher amount of milk to ensure that they adequately adapt to increased solid feed intake before milk provision is ceased (de Passillé et al., 2011).

Our findings show that group-housed calves have higher ADG when the pen area is <1.5 m^2 per calf, an effect that was not seen with larger pen areas (1.5–2.5 m^2; 2.5–3.5 m^2; 5.0–6.0 m^2; 6.5–7.5 m^2; >7.5 m^2). It is worth noting that we did not compare the ADG between different pen sizes; therefore, our findings do not suggest any negative impact of larger pens on weight gain. Indeed, greater space allowance is positively associated with calves' growth (Tapkı et al., 2006; Calvo-Lorenzo et al., 2016), behavior (Færevik et al., 2008; Jensen and Kyhn, 2000; Sutherland et al., 2014), and welfare (Sánchez-Casanova et al., 2021). Increased space allowance allows calves to express natural behaviors, such as exploring and playing (Whalin et al., 2021).

Table 4. Effects of group housing on behavior parameters found in the studies included in the meta-analysis

Parameter	n[3]	Group housing		Heterogeneity[1]		Funnel test[2]
		$SMD_{Random\ effect}$[4] (95% CI)	*P*-value	I^2, %	*P*-value	*P*-value
Lying	17	−0.141 (−0.46, 0.18)	0.393	60.98	0.001	0.138
Standing	14	0.144 (−0.04, 0.33)	0.137	0.00	0.599	0.301
Self-grooming	12	−0.238 (−0.44, −0.03)	0.023	0.00	0.727	0.132
Feeding	7	0.256 (0.01, 0.50)	0.036	0.00	0.797	0.752
Playing	7	0.406 (0.03, 0.78)	0.035	47.49	0.076	0.947
Interacting with pen	5	−0.266 (−0.55, 0.01)	0.063	0.00	0.481	0.384
Consuming milk	4	−0.150 (−0.58, 0.29)	0.500	0.00	0.565	0.725

[1]I^2 = proportion of total variation of size effect estimates that is due to heterogeneity; *P*-value to χ^2 (Q) test of heterogeneity.

[2]Egger's regression asymmetry test.

[3]Number of comparisons between individual (control) and group housing.

[4]SMD = standardized mean differences between individual (control) and group housing.

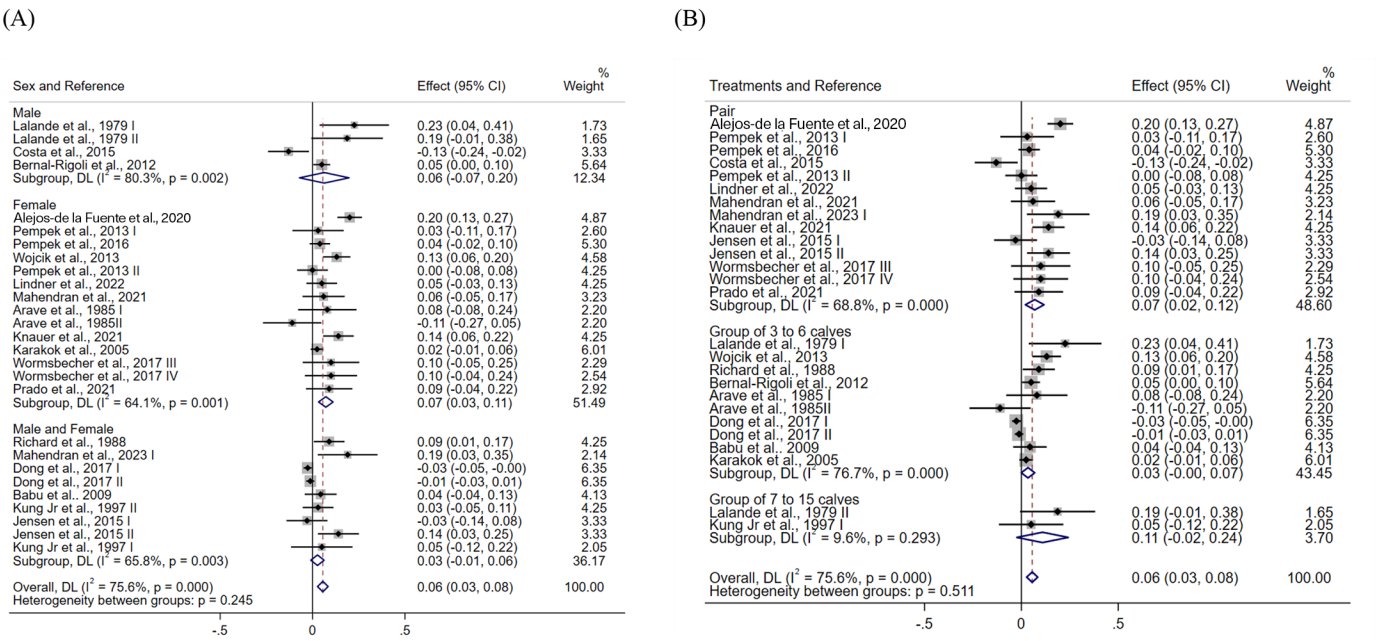

Figure 3. Forest plot with the subgroup analysis of the effects of (A) sex class (male, female, and male and female) and (B) group size (pair, 3–6 calves, and 8–12 calves) on the ADG parameter (Effect = weighted mean difference [WMD]). The x-axis shows the effect size of the WMD. Diamonds to the left of the solid line represent a reduction in the measure, whereas diamonds to the right of the line indicate an increase. Each diamond represents the mean size effect for that study, and the diamond's size reflects the study's relative weighting to the overall size effect estimate, with larger diamonds representing greater weight. The lines connected to the diamond represent the upper and lower 95% CI for the group housing effect. The dotted vertical line represents the overall estimated effect size. The diamond at the bottom represents the mean response across the studies, and the solid vertical line represents a mean difference of zero or no effect. Roman numerals were added to each reference to distinguish multiple studies originating from the same article. Note: weights and between-subgroup heterogeneity tests are from the random effects model. References: Lalande et al. (1979); Arave et al. (1985); Richard et al. (1988); Kung Jr. et al. (1997); Karakok et al. (2005); Babu et al. (2009); Bernal-Rigoli et al. (2012); Pempek et al. (2013, 2016); Wojcik et al. (2013); Costa et al. (2015); Jensen et al. (2015); Dong et al. (2017); Wormsbecher et al. (2017); Alejos-de la Fuente et al. (2020); Knauer et al. (2021); Prado et al. (2021); Mahendran et al. (2021, 2023); Lindner et al. (2022).

Thus, adequate space provision is a key aspect of calf rearing to ensure good growth and welfare. Despite the absence of recommended space allowances for dairy calves across many countries, the European Commission advocates for a minimum requirement of 3 m^2 per calf (AHAW et al., 2023).

Although we found that group housing is beneficial for dairy calves, the available information is insufficient to discuss an ideal group size. Lyu et al. (2023) studied groups of 3, 6, and 12 calves, observing no differences in calves' behavior, but better performance outcomes for all group sizes compared with individually reared calves. When comparing pairs and groups of 3 calves to individual calves, Cobb et al. (2014) found that both group sizes exhibited better performance. However, there were no differences in performance and behavior between the paired and group-housed calves. These results indicate that regardless of the addition of 1 or 2 calves to the rearing environment, allowing social companionship for dairy calves has a positive effect on the calves' performance. However, some caution is required to use this outcome, given that the studies included in our review only evaluated group sizes of up to 15 calves. Svensson and Liberg (2006) compared 2 different group sizes (6–9 vs. 12–18 calves) and found that the larger groups presented a higher incidence of respiratory illness and lower growth rates. Furthermore, large groups (>15 calves) can increase competition for feed resources (Jensen, 2004).

Behavior

Group-housed calves showed a higher frequency of playing and a lower frequency of self-grooming compared with individually housed calves. Social facilitation affects calves' behavior (e.g., increased frequencies on feeders [Phillips, 2004; De Paula Vieira et al., 2010; Duve and Jensen, 2012; Miller-Cushon et al., 2014] and increased play behavior [Reinhardt et al., 1978; Jensen et al., 1998; Bertelsen; Jensen, 2019]), increases cognitive capacity (Meagher et al., 2016), and helps calves to be less fearful of novelties (e.g., change of environment; Gaillard et al., 2014). Several factors can also increase the expression of calves' playing behavior, including larger spaces and higher milk allowance (Jensen et al., 1998; Jensen and Kyhn, 2000;

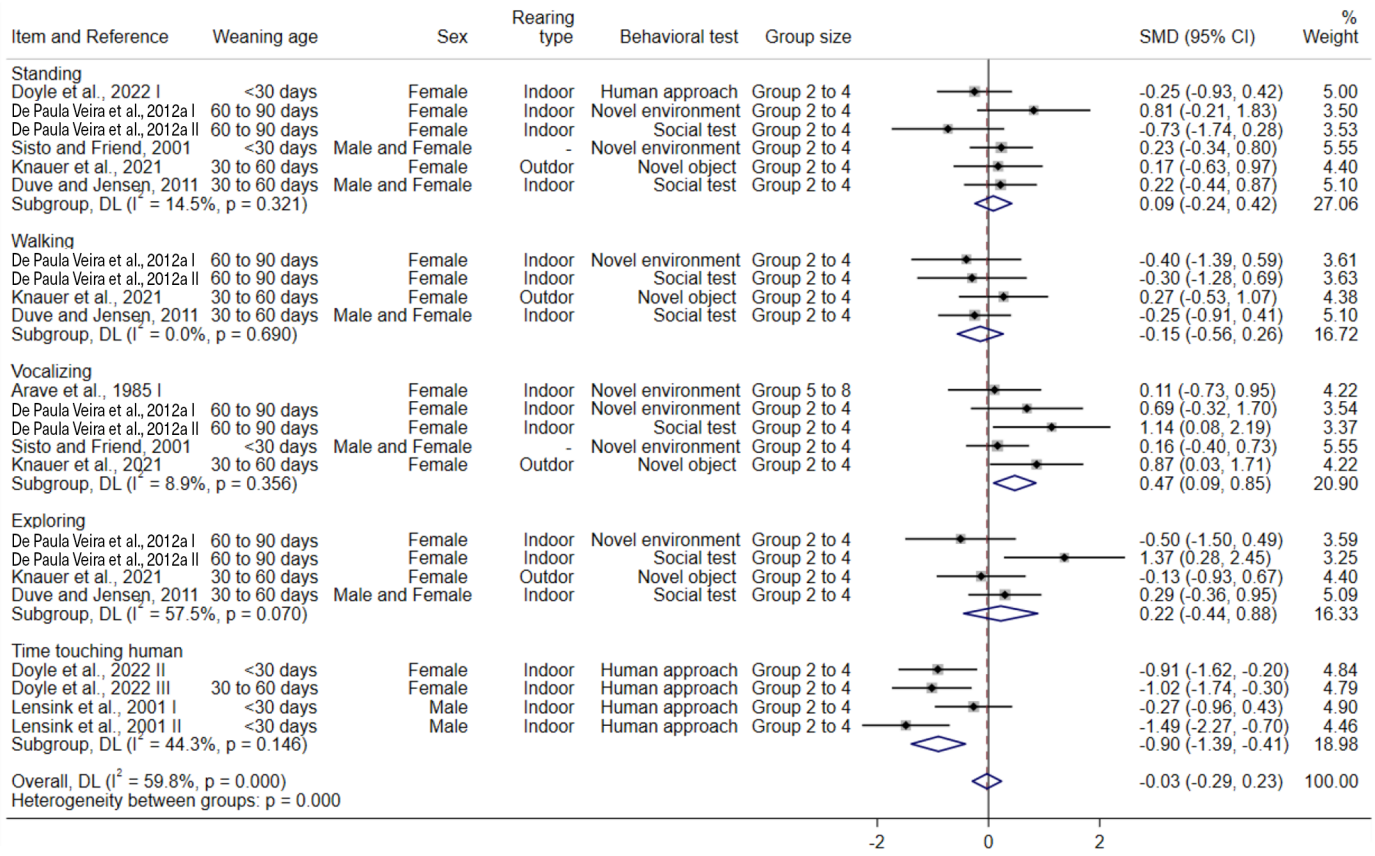

Figure 4. Forest plot with subgroup analysis of the effects of age, sex, housing type, behavioral test, and group size on calves' behavioral test parameters (Effect = standard mean difference [SMD]). The x-axis shows the effects of SMD. Diamonds to the left of the solid line represent a reduction in the measure, whereas diamonds to the right of the line indicate an increase. Each diamond represents the mean size effect for that study, and the diamond's size reflects the study's relative weighting to the overall size effect estimate with larger diamonds representing greater weight. The lines connected to the diamond represent the upper and lower 95% CI for the group housing effect. The dotted vertical line represents the overall size effect estimate. The diamond at the bottom represents the mean response across the studies, and the solid vertical line represents a mean difference of zero or no effect. Note: Weights and between-subgroup heterogeneity tests are from the random effects model. References: Arave et al. (1985); Lensink et al. (2001); Sisto and Friend (2001); Duve and Jensen (2011); De Paula Vieira et al. (2012a); Knauer et al. (2021); Doyle et al. (2022).

Krachun et al., 2010; Jensen et al., 2015). Thus, play behavior is less likely to occur when calves' welfare is compromised (e.g., when they feel pain or are hungry; Spinka et al., 2001; Mintline et al., 2013). In cattle, self-grooming is usually associated with maintaining hygiene (Kohari et al., 2009; Hixson et al., 2018) and is possibly related to stress-coping strategies. The positive relationship between stress and self-grooming has been studied in rats (van Erp et al., 1994; Fernández-Teruel and Estanislau, 2016; Estanislau et al., 2019), but little is known about this relationship in cattle. Lyu et al. (2023) found that individually housed calves exhibit more self-grooming and display increased susceptibility to physiological stressors than group-housed calves. This stress response results is explored in behavioral tests. For example, individual-housed calves have a worse response to novelty than group-housed calves (De Paula Vieira et al. 2012a).

Behavioral Tests

Group-housed calves presented a higher frequency of vocalization than calves individually housed on behavioral tests (novel environment, novel object, and social test). This may suggest that separation from pen mates can be stressful, as calves are highly motivated to seek social contact (De Paula Vieira et al., 2012b; Ede et al., 2022). Vocalization frequency in cattle depends on environmental context and the individual's previous experiences (Green et al., 2020) and can be an indicator of how the animal is interpreting the situation (positive/negative) and their emotional states (Grandin, 1998; Briefer, 2012). For example, early recognition of calves by cows and subsequent vocalization demonstrates the importance of individual recognition in gregarious species to avoid misdirected parenthood and to coordinate social behaviors (Padilla de la Torre et al., 2015, 2016). Furthermore, in

the human approach tests, group-housed calves spend less time interacting with humans than individually housed calves. Mogensen et al. (1999) demonstrated that group housing during the first 3 mo of life does not influence calves' response to repeated human approach tests later in life. Behavior testing has become increasingly used for the assessment of dairy calves' responses in various situations, as it helps to understand calves' cognition and emotional states. For example, prior studies have demonstrated that socially experienced calves are more likely to learn a task than individually housed calves, leading to improved coping skills with novelty (Bernal-Rigoli et al., 2012; Costa et al., 2015; Miller-Cushon and DeVries, 2016). Nevertheless, it is important to acknowledge the limitations of those behavioral tests, given the variability in calf behavior both within and between individuals (Lecorps et al., 2022).

Health Parameters

We could not compare robust health outcomes (e.g., occurrence of diseases) in the studies, and no differences were found in the included blood parameters; however, some caution is required in extrapolating our findings from the meta-analysis. First, a lack of standardization and methodology limitations of the included studies may have contributed to the absence of a significant result, and a low number of studies in a metanalysis can lead to a reduced power to detect publication biases (Murad et al., 2018). Furthermore, several studies included in our review (e.g., Wójcik et al., 2013; Cobb et al., 2014; Mahendran et al., 2023) were observational and did not present a quantitative analysis of the health parameters. Although observational studies facilitate the assessment of disease effects more readily than experimental studies and are often more cost-effective, summarizing them using metanalysis models can be a challenge, due to variations in study reporting and designs (Metelli and Chaimani, 2020). Studies about calf housing system usually do not report deaths or discuss mortality, unlike disease-related studies, such as those on respiratory disease in dairy calves (e.g., Buczinski et al., 2021). For example, Costa et al. (2016) found few studies that presented diarrhea and respiratory disease. They concluded that group-housed calves can be kept in good health if the housing is properly managed. Ollivett (2020) showed that group housing is generally linked to higher respiratory disease rates, with larger groups (12–18 calves) having more issues than smaller groups (6–9 calves). Altogether, these findings indicate a need for standardization and more research on the effects of housing type on calf health. More information about the health effects on calves would help in decision-making regarding the housing system. We strongly suggest that new research be carried out with a focus on calf health in group housing systems.

Although cow-calf separation is a growing topic of discussion (Placzek et al., 2021; Sirovica et al., 2022; Hansen et al., 2023), we did not find any eligible study to include in the meta-analysis that compared individually housed calves to calves in contact with an adult cow. Systematic reviews of cow-calf contact have highlighted the lack of consistent evidence in support of early cow-calf separation (Beaver et al., 2019; Meagher et al., 2019). In addition, calves showed an improvement in their health (e.g., lower incidence of diarrhea) and a reduction of sucking and licking pen fixtures and other calves when housed with foster cows (Solarczyk et al., 2023). Despite this being the most natural-like housing type (Whalin et al., 2021), there is still a lack of studies presenting quantitative performance and behavioral outcomes focusing on calves in contact with adult cows. Future studies could also focus on study standardization to facilitate meta-analysis in the field of calf housing. Nevertheless, our findings indicate that group housing is a good improvement for calves' development. Thus, disseminating this information should be a goal to change the dairy industry's current reality.

CONCLUSIONS

Our findings highlight the benefits of early group housing for dairy calves, revealing improvements in performance parameters such as weight gain and weaning weight compared with individual housing during the preweaning period. Crucial factors influencing calf performance include weaning age and space allowance. Regarding behavior outcomes, group-housed calves presented increased active behavior frequencies, such as feeding and playing, as well as reduced self-grooming, possibly related to a less stressful response. In addition, group-housed calves vocalized more and spent less time in contact with a human in behavioral tests. There is a need to disseminate the benefits of group housing apart from individual housing to improve calves' welfare and dairy system sustainability, especially for health outcomes which is the main concern for dairy farmers.

NOTES

Author JPD acknowledges CAPES (Coordination for the Improvement of High Education Personnel, Brasília, Distrito Federal, Brazil) for the scholarship during their master's degree in the Graduate Program in Animal Science (Universidade Estadual Paulista, Botucatu, São Paulo, Brazil). Maria J. Hötzel acknowledges the support from CNPq (National Council for Scientific and Technological Development, Brasília, Distrito Federal, Brazil).

Also, we thank Isabela Patrocinio da Luz (Universidade Estadual Paulista, Botucatu, São Paulo, Brazil) for their help during the article screening and review of the database. Supplemental material for this article is available at https://doi.org/10.17605/OSF.IO/V4PW7. Author contributions are as follows: J. P. Donadio, conception and design of the study; acquisition, analysis, and interpretation of data; original draft preparation. K. T. De-Sousa: conception and design of the study; revising the manuscript critically for important intellectual content. R. N. S. Torres: analysis and interpretation of data; revising the manuscript critically for important intellectual content. T. C. Alves: revising the manuscript critically for important intellectual content. M. J. Hötzel: conception and design of study; revising the manuscript critically for important intellectual content. M. Deniz: conception and design of the study; analysis and interpretation of data; revising the manuscript critically for important intellectual content. No human or animal subjects were used, so this analysis did not require approval by an Institutional Animal Care and Use Committee or Institutional Review Board. The authors have not stated any conflicts of interest.

Nonstandard abbreviations used: NA = not applicable; SMD = standardized mean difference; WMD = weighted mean difference.

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