The effect of pair housing on dairy calf health, performance, and behavior

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ABSTRACT

Individual housing of dairy calves prevails in Europe and North America despite its negative effects on calf development. One of the main reasons is that farmers find individual housing of calves more practical than group housing. A compromise between practice and welfare could be housing calves in pairs. Therefore, we aimed to compare health, feed intake, growth, and behavior in a novel arena of 22 individually (INDI) and 44 pair-housed calves that were randomly assigned a treatment. Diarrhea and respiratory problems were recorded every day for the period of 49 d. Intake of calf starter and milk were measured every day for the period 48 and 49 d, respectively. Calf body weight gains were calculated as average daily gain. Calves were individually tested in a novel arena at 11 to 18 d, and their behavior was recorded according to an ethogram including 8 behavioral categories. Behavioral categories were first diminished by principal component (PC) analysis. We found that 2 PC explained 66% of the total variation in calf behavior. Movement-related behaviors (activity, play, and crossing the stair) loaded positively on PC1, and PC2 had positive loading on self-grooming and negative loading on exploration. There were no effects of housing on calf health, feed intake, or average daily gain. The INDI calves had higher PC1 scores than pair-housed calves, indicating a rebound effect of movement. Our results are consistent with other studies that found no negative effect of pair housing of calves on their health, feed intake, or growth compared with individually-housed calves. The rebound effect of movement-related behaviors of INDI calves in a novel arena implies that individual housing of calves causes activity deprivation by the second week of age.

Key words: calf health, calf performance, calf behavior, individual versus pair housing

INTRODUCTION

In North America (Vasseur et al., 2010; USDA, 2016) and Europe (Marcé et al., 2010), most dairy calves are housed individually during their early life. However, the accumulated body of evidence shows that social housing of calves is superior to individual housing as it increases feed intake and BW gain, promotes normal social development, and augments cognitive and stress-coping abilities of young calves (reviewed by Costa et al., 2016). Despite these advantages, dairy farmers are reluctant to adopt group housing due to concerns over more difficult handling and health monitoring (Rushen et al., 2008), cross-sucking, aggression (reviewed by Costa et al., 2016), and disease transmission (Webster et al., 1985; Gulliksen et al., 2009; Curtis et al., 2016). Pair housing of calves could be an attractive option for farmers because it combines the benefits of social contact with the practical advantages of easy handling and illness monitoring (Mikuš et al., 2020), as well as limits the number of nose-nose and fecal-oral contacts responsible for the transmission of enteric and respiratory diseases (McGuirk, 2008). Moreover, many of the positive effects of group housing on the behavior and welfare of calves could be also achieved by pair housing. For example, pair-housed calves are less fearful when introduced to an unfamiliar calf (De Paula Vieira et al., 2012; Jensen and Larsen, 2014) or a novel feed (Whalin et al., 2018), perform better in a reversal task (Gailard et al., 2014), are in a more positive affective state (Bučková et al., 2019), and cope with stress after weaning better than individually-housed calves (De Paula Vieira et al., 2010; Bolt et al., 2017). However, pair housing has received less research interest than group housing, leaving some issues unclear.

First, the difference in the health status of individually- and pair-housed calves remains understudied. The 2 most important health problems in dairy calves are diarrhea and respiratory diseases (Calderón-Amor and Gallo, 2020). To date, 5 studies have compared the occurrence of diarrhea (Chua et al., 2002; Jensen and Larsen, 2014; Pempek et al., 2016; Bolt et al., 2017; Liu et al., 2019), and 2 studies have focused on respira-

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tory problems in individually- versus pair-housed calves (Jensen and Larsen, 2014; Bolt et al., 2017).

Second, current knowledge on the effect of individual versus pair housing on feed intake and growth is inconclusive. Some studies have found improved solid feed or milk intake in pair-housed calves (De Paula Vieira et al., 2010; Costa et al., 2015; Jensen et al., 2015; Pempek et al., 2016; Whalin et al., 2018), but others have found no improvement (Chua et al., 2002; De Paula Vieira et al., 2010; Pempek et al., 2013; Bolt et al., 2017; Liu et al., 2019). Several investigations have documented improved growth in pair-housed calves (Costa et al., 2015; Jensen et al., 2015; Pempek et al., 2016), but many others were unable to find a positive effect (Chua et al., 2002; Hänninen et al., 2005; De Paula Vieira et al., 2010; Bolt et al., 2017; Whalin et al., 2018; Liu et al., 2019). Further research on preweaning feed intake and growth of individually and pair-housed calves is needed because different aspects of calf body growth (e.g., daily gain, hip height) affect various facets of future dairy cow performance, such as milk yield and longevity (Van De Stroet et al., 2016).

Third, there is evidence that individually-housed calves react with higher expression of movement-related behaviors (e.g., locomotor play) and fear-related behaviors (e.g., defecation or exploration) when given access to a novel, more spacious arena than pair-housed calves (Jensen, 2001; De Paula Vieira et al., 2012). This evidence suggests that individual housing makes calves spatially and socially deprived. Nevertheless, conflicting results have been published on the duration of short-term individual housing (lasting from several days to 1 wk) to cause spatial and social deprivation (Jensen, 2001; Sisto and Friend, 2001). Therefore, in the present study, we compared the health, feed intake, growth, as well as reactivity to novelty in individually versus pair-housed calves. Specifically, we aimed at testing whether there are significant differences between individually and pair-housed calves in (1) the occurrence of diarrhea and respiratory problems across 7 wk of the differential housing, (2) milk consumption, calf starter consumption, and weight gain over the same period, and (3) calf behavior in a novel arena after 7 d of differential housing.

MATERIALS AND METHODS

Animals

The experiment was carried out at the Institute of Animal Science's experimental farm Netluky in Prague, Czech Republic, from June 2017 to August 2018. The study was approved by the Institutional Animal Care and Use Committee of the Institute of Animal Sci-

ence. In total, 66 Holstein female calves were used. They were separated from their mothers within 12 h of birth and were kept individually until they entered the experiment at the age of 2 to 15 d. Then, 22 calves were randomly assigned to individual housing (**INDI**) and 44 calves to pair housing (**PH**). The INDI calves were kept in standard individual pens (1.4 × 2.6 m), and PH calves were kept in double-sized pens (2.8 × 2.6 m). The pens were bedded with straw. All calves had head-to-head contact with 0 to 3 calves (depending on the occupation of the barn) in neighboring pens through a metal fence. They were given free access to water and calf starter as soon as they were separated from their mothers. In the first week of the experiment, calves were fed 7 L of milk per day (3.5 L at 0600 h and 3.5 L at 1800 h) via teat-buckets. In the second week, the amount of milk was increased to 8 L per day (2 L at 0600 h, 4 L at 1200 h, and 2 L at 1800 h). In the same week, INDI calves and 1 calf from each pair began training for a cognitive judgment bias task (Bučková et al., 2019). From the third to the seventh week of the experiment, calves were given free access to hay and, for the purposes of the cognitive judgment bias task, a special milk-feeding regimen. Thus, 10 L of milk per day was divided into 3 meals per day: 2.5, 3, or 3.5 L at 0600 h (with the exact amount depending on how early in the day the training started), 4 L during performance in the cognitive judgment bias task, and the remainder to 10 L at 1800 h. Once each calf had completed the cognitive judgment bias task at age 54.08 ± 5.35 d (mean $\pm$ SD), it was fed 3.5 L of milk at 0600 h, 3 L at 1200 h, and 3.5 L at 1800 h. The length of the whole experimental period was 49 d.

One INDI calf was excluded from the experiment due to illness and consuming approximately 50% of the daily milk volume. Two calves (1 INDI and 1 PH calf) displayed diarrhea for most of the observed period, and thus we only used their health data. As the PH calf showing a high occurrence of diarrhea probably did not provide adequate social housing, we also discarded the feed intake and growth data from its social partner. Thus, the majority of the final data set was taken from 21 INDI and 42 PH calves.

Data Sampling and Analysis

Health. The assessment of calf health was based on the Welfare Quality Assessment protocol for cattle (Welfare Quality, 2009). We chose the health parameters relevant for calf morbidity on our farm: diarrhea, coughing, ocular discharge, nasal discharge, and hampered respiration. Occurrence of the health state parameters was recorded by a trained researcher once per day for the period of 49 d. It was not possible to blind the

researcher to the housing treatment because calf health was assessed in their home pens. The health state of the calves was also monitored by a farm staff and treated by a veterinarian if the farm manager considered it is a need. The occurrence of diarrhea was quantified as the number of days when present. Coughing, ocular discharge, nasal discharge, and hampered respiration occurred infrequently; therefore, their occurrences were combined into a variable termed “frequency of respiratory problems.” This variable was calculated as follows. Each day was given a score between 0 and 4, depending on how many of the 4 specific problems were noted in the calf. For instance, if the calf had both coughing and hampered respiration, that day received a score of 2 to the frequency of respiratory problems. Subsequently, the scores were summed over the whole period of 49 d.

To investigate the effect of housing on calf health, 2 separate mixed linear models with compound symmetry covariance structure were run, with the dependent variables being the number of diarrhea days and the frequency of respiratory problems, respectively. Housing treatment (categorical variable, INDI: $n = 21$, PH: $n = 44$) and calf age on the first day of the experiment (continuous variable, 2–15 d) were included as fixed effects. Pen was included as a random effect to account for possible nonindependence of paired calves within the same pen. Plots of predicted values against residuals and distribution histograms of residuals were visually inspected to check the homoscedasticity and normality assumptions of all the mixed linear models and the analysis of covariance models in the study.

Feed Intake and Growth. Starter consumption was measured once per day around 1800 h for the period of 48 d. Mean starter consumption was calculated for PH calves because it was not possible to monitor it individually. Therefore, we included data for only 1 calf from each pair in the statistical analysis. Milk consumption was measured for all calves after each feeding during the period of 49 d. Consumption of hay and water were not measured. The calves were weighed on the first day of the experiment and again after 48 to 51 d. The number of days between the first and the second weighing was used to calculate an ADG for each calf. The calves' starter and milk consumption were compared based on the amount consumed for 48 and 49 d, respectively (INDI: $n = 20$, PH: $n = 42$ for milk and 21 for starter). Calf growth was compared based on ADG (INDI: $n = 18$, PH: $n = 42$; 2 out of 20 INDI calves were excluded because of missing values). Mixed models were applied with feed intake, milk intake, and ADG as dependent variables, housing treatment and calf initial age as fixed factors, and pen as a random factor.

Behavior in a Novel Arena. All INDI calves and 1 focal calf from each pair were tested in a novel arena located at the end of the calf barn exactly 7 d after they entered the differential housing. One calf from the PH treatment group was too fearful during the novel arena test and not suitable for the subsequent cognitive judgment bias task (Bučková et al., 2019), so it was replaced by its social partner. Data from both tested calves were included in the analyses. The size of the arena was $2.8 \text{ m} \times 4.2 \text{ m}$, its walls were nontransparent, and the concrete floor was not bedded. There was a stair that divided the arena into a smaller ($2.8 \times 1.4 \text{ m}$) and a larger section ($2.8 \times 2.8 \text{ m}$). The calves were led into the arena by a researcher and left alone for 11 min. Calf behavior was video recorded and assessed from the videoclips by a trained observer blind to the housing treatment (Supplemental Video S1; https://figshare.com/articles/media/Calf_behavior_in_a_novel_arena_test/13280363; Bučková et al., 2020b). We observed activity, presence of the calf in the larger part of the arena, crossing the stair, exploration, play, self-grooming, freezing, and urination and defecation. The definitions of observed behaviors are given in Table 1. The focal period of 11 min was divided into 15-s sampling intervals, resulting in all behavioral variables being quantitative and ranging between 0 (when the behavior was not present in any sampling interval) and 44 (when the behavior was present in all intervals). All behaviors were observed by one-zero sampling (i.e., the behavior being present at any time during the 15-s interval; Altmann, 1974), except for activity and presence of the calf in the larger part of the arena which were observed by instantaneous sampling (i.e., present at the exact moment of the interval break; Altmann, 1974). To ensure the behavioral observations would be repeatable, the first 5 min of each videoclip was assessed by an independent trained researcher blind to the housing treatment to calculate interobserver reliability. We also calculated intra-observer reliability for each observer, so each observer assessed the first 5 min of all videos twice. Both inter- and intra-observer reliability were calculated using Pearson correlation coefficient. High positive correlations were achieved for all behaviors ($r > 0.7$). Principal component analysis [PCA; run as proc factor in SAS 9.4 (SAS Institute) with varimax orthogonal rotation] was used to examine the correlation matrix between the behavioral variables and to condense correlated measures into principal components (PC). The PC are linear combinations of the original variables that reflect latent underlying dimensions revealed in the correlation matrix. Before PCA, the play and self-grooming variables were square-root transformed to remove skewness in their distribution.

Table 1. Definitions of calf's behavior in the novel arena test (Altmann, 1974; Stěhulová et al., 2008; Welfare Quality, 2009; Wagner et al., 2012; Graunke et al., 2013)

Behavior	Definition
Activity	Maximally 3 legs touch the ground, forward movement
Crossing the stair	Crossing the stair by one leg (at least)
Presence of the calf in larger part	Calf's legs are in the larger part of the experimental arena
Exploration	Sniffing and licking the wall or the floor of the novel arena
Play	Run, head shake, buck-kick, turn
Self-grooming	Licking or scratching its own body
Freezing	Calf is tense and standing motionless
Urination and defecation	Calf is urinating or defecating

The variables of freezing and urination and defecation had nonnormal distributions with median value at 0 (i.e., >50% of the calves never performed them), and thus were excluded from PCA. The PC with eigenvalues above 1 were retained for further analysis. Loadings higher or equal to 0.5 were deemed to be high loadings. To investigate the effect of INDI ($n = 20$) versus PH ($n = 23$) treatment on behavior in the novel arena, analysis of covariance models with the PC as dependent variables, housing treatment (INDI, PH) as the fixed effect, and the age of each calf on the testing day (which varied between 11 and 18 d) as a covariate were run in SAS 9.4 (proc glm). As there was only 1 calf observed in the arena from each pair, there was no need to include pen as a random variable into the models. The variables excluded from PCA due to non-normal distribution (freezing and urination and defecation) were transformed to binary variables (yes vs. no) indicating whether the calf performed the behavior at least once, and Fisher exact tests were run to examine whether they differed between the 2 treatments.

RESULTS

Health

There was no significant effect of housing treatment (INDI: $n = 21$, PH: $n = 44$) on number of days when diarrhea was present ($F_{1,41} = 0.01$, $P = 0.94$; Figure 1) or the frequency of respiratory problems ($F_{1,41} = 1.54$, $P = 0.22$; Figure 1). Calf age on the first day of the experiment did not significantly affect respiratory problems ($F_{1,21} = 0.63$, $P = 0.44$), but it did affect diarrhea, with calves coming into the experiment at younger age suffering from diarrhea on a larger number of days ($F_{1,21} = 8.63$, $P = 0.008$).

Feed Intake and Growth

There was no significant effect of housing treatment (INDI: $n = 20$, PH: $n = 21$) on calf starter consumption ($F_{1,38} = 0.32$, $P = 0.57$; Figure 2). Calf age on the

first day of the experiment did not significantly affect starter consumption ($F_{1,38} = 0.84$, $P = 0.36$). There was no significant effect of housing treatment (INDI: $n = 21$, PH: $n = 42$) on calf milk consumption ($F_{1,39} = 1.32$, $P = 0.26$; Figure 3), but calves that were older when entering the experiment consumed more milk over the subsequent 49 d ($F_{1,20} = 9.21$, $P = 0.007$). We found no significant effect of housing treatment (INDI: $n = 18$, PH: $n = 42$) on the ADG of calves ($F_{1,37} = 0.00$, $P = 0.95$; Figure 4), but older calves on the first day of the experiment had higher ADG ($F_{1,20} = 4.20$, $P = 0.05$).

Behavior in a Novel Arena

The first 2 PC had eigenvalues of 2.67 and 1.29 and explained 65.9% of total variation in calf behavior (PC1 = 44.5%, PC2 = 21.4%). Loadings of variables on the 2 components are depicted in Figure 5. Behaviors related to active movement in the arena (activity, play, crossing the stair, and, to a lesser extent, exploration)

Figure 1. The effect of individual (INDI) versus pair housing (PH) on the number of days with diarrhea and on the frequency of respiratory problems over a 49-d period. The boxplots depict median, interquartile range, and data range. Blue boxes: INDI calves ($n = 21$). Red boxes: PH calves ($n = 44$). Red and blue circles represent extreme values.

Figure 2. The effect of individual (INDI) versus pair housing (PH) on starter consumption. The boxplots depict median, interquartile range, and data range. Blue boxes: INDI calves (n = 20). Red boxes: PH calves (n = 21).

loaded positively on PC1 (Figure 5), and time spent in the larger part of the arena loaded negatively on it. The PC2 had positive loading on self-grooming and negative on exploration. Housing treatment affected PC1 significantly ($F_{1,40} = 6.20$, $P = 0.02$; estimate $\pm$ SEM = 0.73 ± 0.29 ; INDI: n = 20; PH: n = 23), with INDI calves being more active in the arena than PH calves (Figure 6). The PC2 was not affected by treatment ($F_{1,40} = 0.80$, $P = 0.38$; estimate $\pm$ SEM = -0.28 ± 0.31 ; INDI: n = 20; PH: n = 23). Neither of the

Figure 3. The effect of individual (INDI) versus pair housing (PH) on milk consumption. The boxplots depict median, interquartile range, and data range. Blue boxes: INDI calves (n = 20). Red boxes: PH calves (n = 42). Red and blue circles represent extreme values.

Figure 4. The effect of individual (INDI) versus pair housing (PH) on growth. The boxplots depict median, interquartile range, and data range. Blue boxes: INDI calves (n = 18). Red boxes: PH calves (n = 42). Red and blue circles represent extreme values.

2 variables excluded from PCA and tested separately (freezing or urination and defecation) differed between PH (n = 23) and INDI (n = 20) calves (2-tailed Fisher exact tests, $P > 0.10$).

Figure 5. Loadings of the behaviors included in the principal component analysis on the first 2 principal components (PC1 and PC2).

DISCUSSION

Health

Our finding that the occurrence of diarrhea did not differ significantly between INDI and PH calves is consistent with 4 other studies (Chua et al., 2002; Jensen and Larsen, 2014; Pempek et al., 2016; Bolt et al., 2017) and partially in contrast with Liu et al. (2019), who found an increase in the occurrence of diarrhea in pair-housed calves during wk 3. As discussed by the authors of the latter study, there is not enough evidence to support a diarrhea-increasing effect of pair housing, and thus the higher incidence of diarrhea in pair housing during wk 3 was likely due to low immunity to infection of calves aged from 2 to 4 wk and individual differences (Liu et al., 2019). Our finding, that diarrhea occurred more often in calves entering the experiment at earlier ages agrees with this well-established fact found in previous studies (Uetake, 2013; Cho and Yoon, 2014). Our result that occurrence of respiratory problems in INDI and PH calves did not differ significantly is consistent with both studies that focused on this issue thus far (Jensen and Larsen, 2014; Bolt et al., 2017). Taken together, it seems that pair housing of calves does not exacerbate diarrhea and respiratory problems compared with individual housing.

Feed Intake and Growth

We failed to find a significant difference in solid feed intake in the INDI and PH calves. This result is in accordance with some studies (Chua et al., 2002; Pempek et al., 2013; Bolt et al., 2017; Liu et al., 2019), but in contrast with others (De Paula Vieira et al., 2010; Costa et al., 2015; Jensen et al., 2015; Pempek et al., 2016; Whalin et al., 2018) that found increased solid feed intake in pair-housed calves. We also failed to find a significant difference in growth of INDI and PH calves. Our finding is consistent with the results from 6 studies (Chua et al., 2002; Hänninen et al., 2005; De Paula Vieira et al., 2010; Bolt et al., 2017; Whalin et al., 2018; Liu et al., 2019), but in contradiction with others (Costa et al., 2015; Jensen et al., 2015; Pempek et al., 2016) that found improved growth in pair-housed calves. It is not clear why some studies found improved solid feed intake or growth and some did not. Costa et al. (2015) found that pair housing improves solid feed intake and growth when calves are assigned to pairs at age 6 ± 3 d but not at age 43 ± 3 d. However, in all studies that did not find improved solid feed intake or growth in pair-housed calves, calves were introduced to pairs at early age: 0 to 8 d (Chua et al., 2002), 7 d (Hänninen et al., 2005), 5 d (De Paula Vieira et al., 2010), 3 to 9 d (Pempek et al., 2013), 5 d (Bolt et al., 2017; Whalin et al., 2018), 2 d (Liu et al., 2019), and 4 to 11 d (this study). We also carefully looked at the milk-feeding regimen because Jensen et al. (2015) found that pair-housed calves on enhanced milk (9 L until weaning) had a greater concentrate intake and grew better than individually-housed calves and pair-housed calves on standard milk (5 L until weaning). Calves in most of the other studies that found a positive effect of pair housing on solid feed intake or growth were also fed by higher amounts of milk: ad libitum (De Paula Vieira et al., 2010), 8 L (Costa et al., 2015), and 6 to 10 L/d (Whalin et al., 2018). However, the current study and Chua et al. (2002) found no significant effect of pair housing on solid feed intake or growth, despite feeding calves 7 to 10 L of milk per day and ad libitum, respectively. On the contrary, Pempek et al. (2016) fed their calves 3.78 to 4.54 L of milk per day and found a positive effect of pair housing on solid feed intake (even if only in wk 9) and growth. It was previously suggested that social facilitation and social learning may result in higher solid feed intake and improved BW gain in socially-housed calves compared with individually-housed calves (Costa et al., 2016). Based on this, we suggest that this effect could be more pronounced in group-housed calves than in pair-housed calves due to more opportunities for social facilitation and social learning.

Figure 6. Scores of the first 2 principal components (PC1 and PC2) for individual calves. INDI calves: blue dots ($n = 20$); PH calves: red crosses ($n = 23$).

Thus, solid feed intake and growth may be more likely affected by the interaction of other factors (e.g., feeding regimen, amount of milk, providing hay, health state) in pair-housed calves. We encourage more research on the comparison of solid feed intake and growth of individually- and pair-housed calves to clarify this issue.

No study, including our current work, has found a difference in milk consumption with respect to individual and pair housing (Chua et al., 2002; De Paula Vieira et al., 2010; Pempek et al., 2013). Therefore, milk consumption probably holds independently on the housing as well as milk-feeding regimen, which ranged from only 6 L/d in Pempek et al. (2013) to *ad libitum* feeding in Chua et al. (2002). It is important to note that no study to date has found impaired feed intake and growth in pair-housed calves compared with individually-housed calves.

Behavior in a Novel Arena

We recorded behaviors related to movement to find out whether individually-housed calves suffer from a lack of space: activity, play, crossing the stair, and presence of the calf in the larger section of the arena. We also observed fear-related behaviors reflecting the ability of calves to cope with novelty: exploration, self-grooming (displacement behavior in situations of motivational conflict; Herskin et al., 2004), freezing, and urination and defecation. Six of the 8 variables had near-normal distribution and were used for PCA. The first PC explained a large part of total variation in calf behavior with 5 of the 6 variables loading on it. It had high positive loadings for activity, play, and crossing the stair, indicating that the underlying motivational factor for these behaviors was the motivation to actively move in the new pen. Presence of the calf in the larger part of the arena loaded negatively on PC1, probably because it was related to calf hesitance to cross the stair dividing the 2 arena parts. A similar factor underlying various movement-related behaviors was repeatedly detected in PCA analyses of calf behavior in open field situations (de Passillé et al., 1995; Van Reenen et al., 2005; Webb et al., 2015). The INDI calves in our study had higher PC1 values, indicating that individual housing increases the motivation for active movement in a novel arena. Our results are consistent with some previous findings (Raussi et al., 2003; De Paula Vieira et al., 2012; Valníčková et al., 2015). Raussi et al. (2003) found that at the age of 15 wk, individually-housed calves tended to spend more time running and to move from one square to another more frequently than pair-housed calves. De Paula Vieira et al. (2012) found that individually-housed calves at age 65 to 69 d were more active (i.e., spent more time

running and less time standing in a novel arena test than pair-housed calves). Valníčková et al. (2015) found that individually-housed calves showed an increased rebound effect of play in wk 2 and 5 in comparison to group-housed calves. Findings of Warnick et al. (1997) are partially in agreement with our results, as they found that 70-d-old individually- and group-housed calves entered similar amounts of squares but did not differ in urination, defecation, or vocalization. However, Jensen and Larsen (2014) did not find any significant effect of housing (in pairs or individually with auditory, tactile, and visual contact) on calf activity measured as number of areas entered and heart rate. Some differences across studies are probably caused by different methodologies (e.g., different age of tested calves or size of arena). We interpret the increased movement-related behaviors of individually-housed calves in a novel arena as a rebound effect (Dawkins, 1988) caused by a lack of stimuli in their home environment. First, individually-housed calves had less absolute space available than pair-housed calves (even though space allowance per individual was the same), and thus might have been movement-deprived (Dellmeier et al., 1985; Tapkı et al., 2006). Second, individually-housed calves did not have full social contact with a conspecific, and consequently may have suffered from deprivation of social behavior such as play (Tapkı, 2007). We do not know if the increased rebound effect in individually-housed calves was caused by a lack of space, social deprivation, or both. Furthermore, the behavior in the novel arena may be affected by social motivation, especially when socially-reared animals are tested individually (Forkman et al., 2007). Thus, the first separation from social partners might have suppressed the play of the pair-housed calves in the arena and contributed to the difference between housing treatments.

In addition to activity-related behaviors, we were also interested in fear-related behaviors of the differently housed calves. In our study, PC2 could be associated with underlying fear motivation because self-grooming (which could be interpreted as a displacement behavior stemming motivational conflict; Herskin et al., 2004) loaded strongly positively on it, and exploration (putative opposite of fear) loaded negatively on it. de Passillé et al. (1995) and Webb et al. (2015) also identified exploration-related PC in their PCA analyses of calf novel arena behaviors. Nevertheless, our study did not reveal any effect of INDI versus PH on PC2. In addition, the housing treatment did not affect the other 2 behaviors that appeared to be related to fear, namely freezing or urinating and defecating. Therefore, our study could not prove any effect of differential housing on fear-related behaviors. A limitation of our study is that we tested calves only once when they had been

in the housing treatments for only 1 wk (because the experimental arena was used for a cognitive judgment bias task immediately after the novel arena test). Thus, the duration of differential housing might have been too short to cause detectable differences in fear reactions to a novel situation.

We previously found that individually-housed calves are in more negative affective states (Bučková et al., 2019), and Raussi et al. (2003) detected increased hypothalamic-pituitary-adrenal axis reactivity in 17-wk-old individually-housed calves compared with pair-housed calves. Collectively, this evidence suggests that dairy calves perceive individual housing negatively and feel deprived from motivated behaviors. The current study documents that these effects may arise after only a single week of early individual housing.

CONCLUSIONS

Our study did not find any differences between individually and pair-housed dairy calves in their health, milk and feed consumption, and growth during the first 8 wk of life. These results, together with previous studies that have largely reported either no difference between the housing systems or a better performance in paired calves, show that pair housing is on par with individual housing in most economically important calf-performance parameters. We also found that calves may be more deprived of movement-related behaviors by the second week of age when housed individually. Based on our findings, we support the growing consensus that pair housing should be preferred to individual housing in dairy farming practice. (The datasets generated during this study are available in Supplemental Table S1; <https://doi.org/10.6084/m9.figshare.13292855.v1>; Bučková et al., 2020a.)

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