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1 INTERPRETIVE SUMMARY

2

3 Nearly all dairy cattle are housed indoors, at least for some part of their life. Keeping cows
4 indoors allows farmers to meet the nutritional needs of high yielding individuals and provide
5 protection from predators. However, it also confronts cows and calves with a wide range of
6 environmental challenges such as restricted movement and exposure to loud aversive sounds.
7 Here we review recent evidence of the effect of environmental enrichment on the welfare of
8 dairy cattle kept indoors. This is accompanied by an assessment of the practicality of different
9 enrichment options, considering the divergent needs of calves and cows separately.

10 **Environmental enrichment of dairy cows and calves in indoor housing**

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19 ABSTRACT

20 In recent years, there has been an increase in the number of farmers who choose to keep their
21 cows indoors throughout the year. Indoor housing of cows allows farmers to provide high
22 yielding individuals with a nutritionally balanced diet fit for their needs, and it has important
23 welfare benefits for both cows and their calves, such as protection from predators, parasites and
24 exposure to extreme weather conditions. However, it also confronts cows and calves with a wide
25 range of environmental challenges. These include abiotic environmental sources of stress (e.g.
26 exposure to loud and aversive sound) and confinement-specific stressors (e.g. restricted
27 movement and maintenance in abnormal social groups). Cows and calves that live indoors are
28 also faced with the challenge of occupying long periods of time with a limited range of possible
29 behavioural patterns. Environmental enrichment can improve biological functioning (measured
30 as increased lifetime reproductive success, increased inclusive fitness or a correlate of these such
31 as improved health), help animals to cope with stressors in their surroundings, prevent
32 frustration, increase the fulfillment of behavioural needs, and promote more positive affective
33 states. Here we review recent findings on the effect of social, occupational, physical, sensory and
34 nutritional enrichment on dairy cows and calves, and we assess the appropriateness and
35 practicality of implementing different enrichment practices in commercial dairy farms. Some of
36 the enrichment methods reviewed here may also be applied to those more extensive cattle raising
37 systems, where similar challenges occur.

38

39 Key words: Social enrichment, Zero grazing, Animal welfare, Low resilience behaviours

40

41 1. INTRODUCTION

42 Nearly all dairy cattle are housed indoors, at least for some part of their life, and in an increasing
43 number of farms, indoor housing is practiced all year round (van Vuuren and van den Pol-van
44 Dasselaar, 2007; Winsten et al., 2010; March et al., 2014). In continuous indoor housing systems
45 (also referred to as "zero grazing" systems), dairy cows are kept throughout the year in tie stall,
46 free stall, or loose housing cowsheds. Access to pasture is either limited or absent. In the past,
47 continuous indoor housing of dairy cows was practised mainly in regions where the climate was
48 unsuitable for growing grass or too harsh for the animal. Nowadays, with the gradual shift
49 towards intensified farming, year round housing is more widely practiced. It was recently
50 estimated that zero grazing housing will become the most prevalent farming practice in North-
51 West European countries such as NW-Germany and Denmark, by the next decade (Reijs et al.,
52 2013). For example, in the Netherlands, the number of dairy cows housed indoors has tripled in
53 the past 10 years (from 10% to 30%; CBS, 2015). In the United States, more than 95% of
54 lactating cows are denied access to pasture (NAHMS, 2010). Other Mediterranean countries,
55 such as Israel, now keep 100% of their dairy cows indoors throughout the year (Israeli dairy
56 farms reform, 1999-2008). The practice of keeping cows indoors for extended periods may also
57 result from environmental regulations aimed at reducing leaching of nitrates and phosphorus into
58 water reserves (for example, the "Nitrates Action Programme" implemented in Northern Ireland
59 from 2007; Nitrates Action Programme and Phosphorus Regulations 2015-2018).

60

61 Keeping animals indoors provides some important welfare benefits for the animals, such as
62 protection from predators and toxic plants, reduced exposure to extreme weather conditions
63 (Schütz et al., 2010) and external and internal parasites, as well as enabling the provision of a

64 nutritionally balanced diet throughout the year (Algers et al., 2009). However, it also confronts
65 animals with a wide range of challenges. These include abiotic environmental sources of stress
66 (e.g. exposure to loud and aversive sounds such as the noise produced by milking facilities,
67 Arnold et al., 2007, 2008; metal-on-metal clanging, Waynert et al., 1999) and confinement-
68 specific stressors that are more likely to be associated with indoor systems (e.g. restricted
69 movement when kept tied in their stall, when isolated at an early stage of life, or maintenance in
70 abnormal social groups, Morgan and Tromborg, 2007). Zero grazing systems, compared to other
71 production systems, are also associated with higher incidence of lameness (Haskell et al., 2006),
72 and increased risk for claw or foot problems, teat trampling, mastitis, metritis, dystocia, ketosis,
73 retained placenta and some bacterial infections (Algers et al., 2009). Once housed, animals are
74 forced to make substantial changes in their time budget (Newberry, 1993). For example, the food
75 searching and eating times of cattle may be reduced to 4 hrs a day, compared to 6-12 hrs on
76 pasture (Gomez and Cook, 2010) such that long periods of time must be occupied with a limited
77 range of possible behavioural patterns (Hughes and Duncan, 1988). Mason and Burn (2011)
78 argued that when the environment is too impoverished (i.e. without appropriate stimuli or
79 substrates) or too small, the ability of the animals to perform natural behaviours and to satisfy
80 their motivations (i.e. to fulfill their behavioural needs) is restricted. Such behavioural restriction
81 may result in frustration. Indicators of frustration in cattle include leg stamping (Cooper et al.,
82 2008; although this can also be associated with attempts to cope with forced standing by
83 alleviating strain on the legs and hoofs), non-nutritive oral behaviour (e.g. tongue rolling,
84 Ishiwata et al., 2007), and an increase in the visible percentage of eye whites (Sandem et al.,
85 2002; although the latter was also associated with fear, Sandem et al., 2004). Persistent
86 frustration is associated with the development of abnormal behaviours. One example is calves'

87 redirected oral behaviour toward pen mates, when fed from a bucket and restricted from
 88 performing suckling behaviour (Mason and Burn, 2011; Ninomiya, 2014).

89
 90 Keeping animals in an environment that meets their proximate needs (“here and now”, Dawkins,
 91 1983, such as feeding, drinking and sleeping) allows them to engage in low resilience behaviours
 92 (also referred to as 'luxury activities', i.e. behaviours that typically decrease when energy
 93 resources are limited or when the cost involved in the activity increases, McFarland, 1999),
 94 which are associated with improved welfare and long term fitness (Held and Spinka, 2011). One
 95 example is play behaviour, which drops out of the animal's behavioural repertoire in times of
 96 challenge (e.g. sickness, hunger, injury, predation risk and thermal stress). In the majority of
 97 cases, the presence of play behaviour is associated with improved welfare, and its disappearance
 98 is a reliable indicator of the transition from positive to poor welfare (Held and Spinka, 2011). In
 99 cattle, other low resilience behaviours include grooming (Borderas et al., 2008; Fogsgaard et al.,
 100 2012; but see also opposing findings by Almeida et al., 2008) and use of automated cow brushes
 101 (Mandel et al., 2013).

102
 103 One strategy that can help animals to cope with stressors in their surroundings, prevent
 104 frustration and increase the fulfillment of behavioural needs is to enrich their environment.
 105 Newberry (1995) defined environmental enrichment as an improvement in the biological
 106 functioning of confined animals resulting from modifications to their environment. Biological
 107 functioning refers to increased fitness (i.e. lifetime reproductive success), increased inclusive
 108 fitness (i.e. indirect fitness, by helping genetically related individuals such as kin to increase their
 109 fitness), or a correlate of both such as improved health. By focusing on the biological functioning

110 of the animal, Newberry (1995) offered a practical and objective way to measure and evaluate
 111 the effect of different environmental enrichment methods on welfare. However, compromised
 112 welfare does not necessarily result *only* from impaired biological functioning (Fraser et al.,
 113 1997). For example, the welfare of bucket-fed calves is not reduced by malnutrition, but by an
 114 unfulfilled need to suckle (Fraser et al., 1997). For the purposes of this review, effective
 115 environmental enrichment will therefore be regarded as modification to the management or
 116 surroundings of the animal that demonstrably improves biological functioning (Newberry,1995),
 117 or other validated measures of welfare (i.e. those measures that are correlated with valenced
 118 experiences, Nicol et al., 2009) over and above what is achieved by following minimum
 119 management standards (e.g. European Union guidelines).

120

121 Although environmental enrichment plays an important role in maintaining the wellbeing of zoo
 122 animals (Shyne, 2006), laboratory animals (Baumans and Van Loo, 2013), and certain livestock
 123 such as pigs (van de Weerd and Day, 2009; see also EU Directive 2008/120/EC), its
 124 implementation on cattle farms is limited and has not coincided with the gradual shift towards
 125 year-round indoor housing and the challenges it places on cows. Considering the global increase
 126 in the number of cows and calves raised in zero-grazing systems, exploring different methods for
 127 meeting their needs (e.g. by enriching their environment) is more relevant today than ever
 128 before.

129

130 This review has two aims; firstly, we will review recent evidence of the effect of environmental
 131 enrichment on the welfare of dairy cattle kept indoors. Secondly, this will be accompanied by an

132 assessment of the practicality of different enrichment options, considering the divergent needs of
 133 calves, heifers and cows separately when appropriate.

134

135 2. ENVIRONMENTAL ENRICHMENT

136 Bloomsmith et al. (1991) defined five categories of environmental enrichment; social,
 137 occupational, physical, sensory and nutritional. Each category may contribute to the welfare of
 138 the animal in a different way. For example, social enrichment may fill the need of calves for a
 139 companion and help them to cope better with stressors in their surroundings (de Paula Vieira et
 140 al., 2012), whereas physical enrichment in the form of providing a cow with a secluded area in
 141 an individual maternity pen may fulfill its need to hide when calving or when sick (Proudfoot et
 142 al., 2014a,b). When considering the contribution of each category to the welfare of the animal, it
 143 is important to note that: 1) The mechanism that underlies each category of enrichment, and each
 144 method of enrichment, can be multi-factorial (e.g. dam-rearing involves both social and
 145 nutritional factors, Kalber and Barth, 2014). 2) Each enrichment type can have both short- and
 146 long-term effects (e.g. drinking colostrum and milk ad-libitum is associated with improved
 147 weight gain at an early stage of life, but also aids in gastrointestinal-tract maturation, production
 148 of digestive enzymes and nutrient absorption at a later stage through hormonal factors found in
 149 the colostrum, Bach, 2012). 3) Each enrichment method can contribute differently to the welfare
 150 of the animal, when applied at different stages of the production cycle, as a calf or an adult cow
 151 (e.g the presence of a conspecific is associated with improved cognitive development in calves,
 152 Gaillard et al., 2014; but also with reduced stress during social isolation in cows, Kikusui et al.,
 153 2006). 4) The contribution of each category to the welfare of the animal can be explained by
 154 more than one mechanism (reduced stress expressed by calves that were raised in pairs,

155 compared to singly reared calves, can be explained both by improved cognitive development,
 156 which allows better learning abilities but also by the mere presence of a conspecific (social
 157 buffering)). 5) Some enrichment methods are limited to a certain time window (e.g. the effect of
 158 early social housing on cognitive development, Gillard et al., 2014). The examples mentioned
 159 above, and others, will be discussed in more details throughout the text and will serve as the first
 160 step towards developing a conceptual framework for enriching the environment of dairy cows.
 161 Such a framework could allow better understanding of cattle needs and improve the
 162 implementation of enrichment practices in dairy farms.

163

164 **2.1 Social Enrichment**

165 Social enrichment is defined as the provision of access to direct or indirect (visual, olfactory,
 166 auditory) contact with conspecifics (other individuals of the same species) or humans
 167 (Bloomsmit et al., 1991).

168

169 On most North American and European dairy farms, calves are separated from their mothers
 170 within 24 hours of birth (Algers et al., 2009; but see also dam and foster rearing in organic
 171 farming, Kalber and Barth, 2014). Separating the dyad is stressful for both the dam and her calf
 172 and followed by behavioural (e.g. increased calling and activity; Weary and Chua, 2000; Flower
 173 and Weary, 2003) and emotional (i.e calves: cognitive bias test; Daros et al., 2014) responses.
 174 When carried out within 24 hours of birth, the process is accompanied by a weaker behavioural
 175 response compared to separation at a later stage (i.e. two weeks after birth; Flower and Weary,
 176 2001; but see Hudson and Mullord, 1977 for behavioural distress following 5 minutes of calf-
 177 dam contact, and Johnsen et al., 2015 for the formation of cow-calf bond without nursing). Early

178 separation is also done for economic (e.g. use of sources of nutrition that are cheaper than
179 feeding calves' with their mother's milk, such as milk replacers or 'waste' milk that cannot be
180 sold) and management reasons (e.g. close monitoring of calves health and food consumption;
181 minimizing the transmission of Johne's disease, Collins et al., 2010, and faster milk-let-down
182 speed, Kilgour and Dalton 1984). Following separation from the dam, calves are kept in single
183 housing, pair housing or in group housing (three calves or more).

184

185 ***2.1.1 Contact with Conspecifics***

186 ***Calves.*** In farms that practice single housing, calves are reared individually in pens or hutches
187 for two to eight weeks, mainly with the aim of decreasing the risk of horizontal disease
188 transmission, but also for helping farmers to monitor calf milk intake and health. The association
189 between group housing and morbidity is affected by the size of the group, with calves kept in
190 large groups (i.e. 7 or more) being at higher risk of disease (Losinger and Heinrichs, 1997, Wells
191 et al., 1997; Svensson et al. 2003, Svensson et al., 2006; Svensson and Liberg, 2006). A tradeoff
192 between single housing and group housing is pair housing, where physical contact is limited to
193 only one other calf, and the risk of pathogen transmission is limited. A recent study compared the
194 effect of different levels of social contact on calf health ranging from strict isolation in single
195 housing to full physical contact in pair housing, but found no effect of degree of social contact on
196 the level of the 5 most common pathogens present in Danish calf feces, or on the development of
197 serum antibodies against the three most common respiratory pathogens (Jensen and Larsen,
198 2014). However, in indoor environments with poor ventilation and drainage, keeping calves in
199 small groups (i.e. three calves per pen) or in pairs may increase the risk of respiratory disease,
200 compared to individual rearing (Cobb et al., 2014). Acknowledging the contribution of physical

201 contact to disease transmission, pair housing can be considered a tradeoff between individual
 202 rearing and group housing, which allows calves to engage in social contact, while limiting
 203 disease transmission.

204

205 The need of calves for social contact with their peers is present from the first week of life
 206 (Wood-Gush et al., 1984). When given the option, they are more motivated to get access to full
 207 physical contact with their conspecifics, compared to only head contact through metal bars
 208 (Holm et al., 2002). Calves raised with full social contact (either from birth or 3 weeks of age)
 209 will establish stronger bonds with their group members, compared to calves raised with limited
 210 contact (Duve and Jensen, 2011). The bonds that calves develop at an early stage will affect their
 211 social preferences as adults (Sato et al., 1993; Færevik et al., 2006; Raussi et al., 2010; Gygax et
 212 al., 2010).

213

214 Physical contact with conspecifics from an early age affects calf development; individually
 215 housed calves, compared to paired housed ones, spend less time at the feeder, visit it less
 216 frequently and start ingesting concentrate from computerized starter feeder at a later stage (de
 217 Paula Vieira et al., 2010, see also Warnick et al., 1977 and Hepola et al., 2006). Individual
 218 rearing also reduces calves' social skills and their ability to cope with environmental stressors
 219 (de Paula Vieira et al., 2012; Jensen and Weary, 2013). They are also more fearful of unfamiliar
 220 calves (Jensen and Larsen, 2014; de Paula Vieira et al., 2012), have a higher heart rate during
 221 confrontation (Jensen et al., 1997), struggle more when restrained for blood sampling (Duve et
 222 al., 2012) and vocalize more when weaned from milk (de Paula Vieira et al., 2010). The reduced
 223 vocal response of pair-housed calves when weaned is suggested to reflect the effect of social

224 buffering (i.e. the alleviation of stress responses attributed to the presence of a conspecific, Edgar
225 et al., 2015), which can help modulate or down regulate the impact of stressors on the
226 homeostasis of the recipient (for a recent review, see Rault, 2012). Indeed, calves that were
227 isolated with no companion for a period of 20 minutes, were found to vocalize more, show less
228 locomotor activity and explore the pen less, compared to those that were isolated with a
229 companion, particularly a familiar companion (Færevik et al., 2006). Social isolation at an early
230 stage seems to also affect calf behaviour later on in life. Broom and Leaver (1978) studied the
231 effect of prolonged social isolation (8 months) on calves' behaviour at the age of 8 months and
232 20 months. In both age groups, individually housed calves spent more time alone and had a
233 lower social rank once introduced into a new group, compared to grouped housed calves.

234

235 An additional mechanism to social buffering that can affect the behaviour of calves raised in
236 isolation is impaired cognitive development. Individually reared calves achieved poorer
237 performance in a colour discrimination reversal learning task than calves reared in pairs (Gaillard
238 et al., 2014). The socially reared calves appeared to be more flexible in their response to change
239 in routine management and housing, an ability that was previously associated with improved
240 welfare (Wechsler and Lea., 2007). One implication is that socially-reared animals may be more
241 competent in interacting with new technologies, such as robotic milking equipment and
242 automated feeders. Indeed, de Paula Vieira et al. (2010) showed that calves raised individually
243 were slower at learning to use a computerized starter feeder compared to calves raised in pairs.
244 Therefore, the reduced learning ability associated with individual rearing may result from a
245 cognitive impairment or emotional deficiency (or both). Raising calves in pairs or small groups

246 fulfills their need for social contact with conspecifics from an early age, help to develop
 247 cognitive skills, social skills, and reduce stress-associated reactions.

248

249 Pair housing also has economic benefits. Rearing calves in pairs requires less space than
 250 individual housing, which can be used for spacing the pens further apart (i.e. lowering the
 251 chance of horizontal disease transmission), and for increasing the living area for each pair to
 252 allow greater comfort and encourage play behaviour. For example, in order to raise 10 calves in
 253 isolation (0.9*1.8m per calf, with 1 meter space between pens), farmers need an area which is 18
 254 meters wide. In the same area, using pair-housing pens, farmers can increase the living space of
 255 each calf by more than 35% (1.35*1.8m per calf instead of 0.9*1.8m) and the distance between
 256 pens by more than 10% to minimize further the risk of diseases transmission. Housing calves in
 257 pairs however, requires adjustment to the feeding method to minimize food competition and
 258 decrease cross-sucking behaviour (addressed below under nutritional enrichment).

259

260 Although pair housing is a promising rearing solution that balances calf health and social needs,
 261 some fundamental questions regarding the timing of its implementation still remain open. Other
 262 questions concern the implications of dyad separation at a later stage of life (i.e. for either short
 263 periods of time, e.g. for a husbandry procedure or for long periods of time, such as when kept in
 264 different feeding groups). Breaking a social bond between two calves raised together from the
 265 first day of life (and prevented from maternal contact) may prove to be as stressful as breaking
 266 the bond between a calf and its dam bonded for a similar amount of time. To our knowledge,
 267 these questions have not been addressed yet and demand further investigation. Better
 268 understanding of calf social needs (i.e. especially in early life, when kept in isolation) will allow

269 us to integrate more carefully their basic health and functioning, affective states and natural
270 living (Fraser, 2008).

271

272 A more natural rearing method that is little practiced in intensified dairy farms, is to keep calves
273 with their dams following parturition. Dam reared calves are either kept with restricted or full
274 contact with their dam/foster cow and often have access to other calves and adult cows. The
275 length of the rearing period may vary from days to months according to farm management.

276 Calves reared with their dam, compared to calves housed in groups and fed from an automatic
277 feeder, express less abnormal oral behaviour (e.g. cross suckling). Interestingly, low cross
278 suckling rate was documented in both restricted (i.e. twice a day for 15 minutes each) and
279 unrestricted contact with the dam (Roth et al., 2009; Hillmann et al., 2012). Dam-reared calves
280 also struggle less when restrained for blood sampling compared to those housed singly or in pair
281 (Duve et al., 2012). When submitted to an isolation test, calves that have been reared with their
282 dam show lower increase in salivary cortisol concentrations compared to artificially reared
283 calves after reunion with their dam/group (Wagner et al., 2013). Rearing calves with their
284 dam/foster cow also seems to affect their behaviour later on in life (Le Neindre, 1989; Wagner et
285 al., 2012; 2015). When faced with the challenge of integration into a new group, dam reared
286 heifers (either with restricted or unrestricted contact) express more submissive behaviour
287 associated with longer duration of feeding and earlier lying activity, compared to heifers that
288 were separated from their dam and fed through an automatic feeder (Wagner et al., 2012). In
289 another study, 2.5 year old cows that had permanent access to their dams during the first 12
290 weeks following parturition, expressed lower sympathetic and higher HPA-axis reactivity
291 compared to cows that were fed by an automatic feeder (Wagner et al., 2015). The latter finding

292 suggests that calves reared with their dam develop a reactive coping style later on in life (Wagner
 293 et al., 2015). However, since the efficacy of the coping style (i.e. reactive and proactive) depends
 294 on the situation/environment, the welfare implications of this finding are not yet clear.

295

296 Keeping calves with their dam is regarded to be a natural rearing method that benefits from
 297 better public opinion compared to methods that involve early separation (Ventura et al., 2013).
 298 However, concerns regarding cow health (e.g transmission of Johne's disease through contact of
 299 calves with the feces of its dam), and impaired milk ejection still exist (Kalber and Barth, 2014).
 300 Indeed, the opponents for this rearing method base their arguments on the possible negative
 301 effect on calf and cow health, as well as the emotional distress that will be caused once the cow-
 302 calf bond is broken later on, and the limited ability of the industry to accommodate cow-calf
 303 pairs (Ventura et al., 2013). In dairy farms, which are free of Johne's disease and can manage the
 304 logistics that are associated with keeping the dyad together (e.g. suitable enclosures, clean and
 305 dry environment), rearing calves with their dam could be an alternative enrichment method to
 306 pair housing that benefits from better public opinion. An alternative option that favors one side
 307 of the calf-dam dyad is to raise calves with a foster cow. The latter is suggested to allow calves
 308 to satisfy their suckling motivation and engage in social contact with adult cows, and may reduce
 309 weaning stress (Kalber and Barth, 2014). However, more knowledge about this system is needed
 310 in order to evaluate its contribution to the welfare of calves and its possible negative effect on the
 311 welfare of the foster cow (e.g. once more than two calves are fed from the same cow).

312

313 **Cows.** Cows are grouped based on their physiological status (lactating/dry) or milk production
 314 status (low vs. high milk yield). As their status changes, they are regrouped and must form

315 relationships with the new group members. This can be stressful. For example, regrouping
316 destabilizes the social dynamic within the group and increases physical competition in the hours
317 and days following regrouping (von Keyserlingk et al., 2008). Indeed, cows that enter a new
318 group experience increased displacements from the feeding area and their eating time, lying
319 time, number of lying bouts and allogrooming events are reduced. In addition, milk production is
320 reduced on the first day after regrouping (von Keyserlingk et al., 2008). Basic husbandry
321 practices, such as reducing the stocking density in the pen (Talebi et al., 2014), using a familiar
322 pen for regrouping the cows (Schirrmann et al., 2011), or other methods such as grouping during
323 the evening hours (compared to mornings, Boyle et al., 2012), can help lessen the negative
324 effects of this procedure.

325

326 The ideal solution to meet the social needs of the cows would be to keep them in stable groups.
327 This would therefore allow them to enjoy the benefits of social companionship, and to benefit
328 from social buffering, enabling better coping with stressors (Gutmann et al., 2015). The efficacy
329 of social buffering depends on the degree of affiliation between the interacting partners (calves:
330 Færevik et al., 2006; cows: Gutmann et al., 2015, for bulls see Mounier et al., 2006). Social
331 buffering in cattle can be achieved via grooming behaviour (i.e. licking), which depends mainly
332 on familiarity and increases with the length of cohabitation (Sato et al., 1991). This behaviour is
333 regarded as a reliable indicator of friendship (Boissy et al., 2007), and seems to be independent
334 of social dominance, as solicitation occurs both from dominant and subordinate cows (Sato et al.,
335 1991; Val-Laillet et al, 2009). In addition to helping cows to stay clean (i.e. remove parasites,
336 Guillot, 1981), it is suggested that this behaviour induces a "physiological calming effect"
337 (Laister et al., 2011) and helps to resolve conflicts (Val-Laillet et al., 2009). Licking behaviour in

338 cows reduces the heart rate of the receiver (Laister et al., 2011), and was found to be directed
339 more towards lame cows compared to non-lame cows kept at the same stall (Galindo and Broom,
340 2002). These findings suggest that licking behaviour may have a role in alleviating discomfort
341 (Galindo and Broom, 2002). In cases where grouping is necessary, an intermediate solution
342 could be to regroup cows in the company of familiar conspecifics in order to promote such
343 affiliative interactions (Bøe and Færevik, 2003). Heifers that are introduced to a herd with a
344 familiar conspecific (i.e. in pairs) face significantly less agonistic interactions compared to singly
345 introduced heifers (7.19 h^{-1} vs. 3.79 h^{-1} , Neisen et al., 2009) and integrate faster into the herd
346 (Gygax et al., 2009). Heifers that are introduced to a new group in pairs show greater
347 resemblance between their time budget and the time budget of other cows in the herd (e.g. time
348 spent in the lying areas and feeding areas), compared to heifers that were introduced singly
349 (Gygax et al., 2009, for increased lying times of heifers integrated in pairs compared to singly
350 introduced heifers, see also O'Connell et al., 2008).

351

352 ***2.1.2 Contact with Humans***

353 When kept indoors, cows rely on humans for almost every aspect of their lives. The interaction
354 with humans is at times, inevitable, and varies between farms according to management policy,
355 the size of the herd and the level of automation in the farm. Daily interaction with humans has a
356 significant effect on cows' behaviour and productivity (Hemsworth, 2003). Humans can evoke
357 fear in animals by virtue of their relative size, and their propensity for quick or unpredictable
358 movements (Rushen et al., 1999). For example, the use of negative interactions by stock people
359 (i.e. slaps, pushes, or hits with the hand or an object such as a plastic pipe) are negatively
360 correlated with milk yield, protein, and fat, as well as with increased flight distance of cows (i.e.

361 the percentage of cows approaching within 1 m of an experimenter in a standard test; Hemsworth
362 et al., 2000). However, in order for a cow to experience a negative interaction with a human,
363 engaging intentionally in negative handling is not mandatory. Several of the routine husbandry
364 procedures practiced in dairy farms are intrusive by nature and can be aversive to cows, causing
365 pain and/or stress (Pilz et al., 2012). For example, artificial impregnation of cows involves a
366 series of intrusive procedures, which starts with the artificial insemination itself (i.e. including
367 both rectal and vaginal intrusions) and continues with routine pregnancy examinations that
368 involve rectal examination. Following an aversive treatment, dairy cows and calves learn to
369 avoid the specific handler and place associated with the aversive experience (“learned aversion”,
370 Taylor and Davis, 1998, de Passillé et al. 1996; Rushen et al., 1998). By practicing positive
371 handling from an early age, farmers can both help their animals to reduce stress responses during
372 aversive experiences (in the case of artificial insemination, positive interactions by stockpersons
373 was found to be positively correlated with conception rates, Hemsworth et al., 2000) and induce
374 positive affective states promoting positive welfare in the farm (Ellingsen et al., 2014; Proctor
375 and Carder, 2014; 2015a,b).

376

377 *Calves*. In calves, positive handling at 4 weeks of age (e.g. moving slowly and calmly around in
378 the pen, speaking in a quiet and calm voice and encouraging interactions including pats and
379 scratches) affects approach behaviour towards familiar handlers, compared to negative handling
380 (e.g. fast movements, speaking with a harsh voice and creating noise with different tools, such as
381 a plastic bottle with rattling stones in it ;Schütz et al., 2012). However, the impact of handling
382 quality at an early age may be overshadowed by the amount of human contact at a later stage
383 (after 3 months, Schütz et al., 2012). When test calves (handled negatively and positively) were

384 compared with a control group reared routinely on-farm (i.e. without any particular handling
385 treatment), the latter showed greater avoidance behaviour than both positively and negatively
386 handled calves, demonstrating the importance of both quality and quantity of handling. In a
387 more recent study, gentle interactions on group-housed dairy calves during the first 14 days of
388 life were associated with smaller avoidance distances from a familiar person before and after
389 weaning (i.e. 86.2 ± 5.1 days old), and with higher average daily gain (up to 7%, depending on
390 milk provision, Lürzel et al., 2015). In beef cattle, gentle interactions (i.e. 120 min of touching
391 over 6 days within 4 weeks of life) were associated with less fearful behaviour towards humans
392 (i.e. smaller avoidance distances) and less stress-related behaviour at the abattoir at the age of 10
393 months (i.e. less avoidance behaviour in the stunning box and a tendency for lower cortisol
394 concentrations in the blood taken during exsanguination, Probst et al., 2012). Positive handling is
395 also associated with more positive mood, as assessed by qualitative behaviour assessment (QBA,
396 Ellingsen et al., 2014). In their study, Ellingsen et al. (2014) characterized the behaviour of
397 stockpersons and portrayed the body language of the dairy calves that were under their care. The
398 stockpersons who handled their calves patiently, and petted and calmly talked to them during
399 handling, were rated by respondents to be more 'friendly' and 'content'. By contrast, stockpersons
400 with a nervous handling style, or who were dominating and aggressive had calves that were
401 perceived as in a more negative mood (Ellingsen et al., 2014). However, the extent to which
402 these QBA labels reflect real underlying mood states needs to be validated using more direct
403 measurements of animal behaviour and physiological state (e.g. Mendl et al. 2010). The effect of
404 brushing calves by humans will be reviewed under sensory enrichment.

405

406 **Cows.** In cows, a high percentage of positive interactions (talking quietly, petting and touching)
 407 and a low percentage of negative interactions (forceful use of stick or hand, shouting and
 408 impatient talk) are associated with reduced avoidance of handlers in the milking parlor
 409 (Waiblinger et al., 2002). Waiblinger et al. (2004) found that the stress response to an aversive
 410 veterinary procedure could be reduced by positive handling prior to, and gentle interactions
 411 during the procedure. In this study, positive handling included feeding cows a small amount of
 412 concentrate out of the hand, stroking them at the neck and head as long as they accepted it, and
 413 speaking to them in a soothing way for several minutes during 10 days distributed over a 4 week
 414 period. Gentle interactions applied during an aversive veterinary procedure consisted of stroking
 415 the cows at the neck and head and speaking to them in a soothing way. The authors found that
 416 cows previously handled in a positive way had a lower heart rate and kicked less when isolated
 417 for the procedure. In addition, cows that were calmed down during the procedure itself (i.e.
 418 gentle interaction) expressed less restless behaviour (e.g. head shaking and tail flicking). The
 419 success of "calming down" the animals however, differed between handlers (Waiblinger et al.,
 420 2004; for additional evidence of the effects of positive and negative handling, see Rushen et al.,
 421 2001; Lensink et al., 2001; Waiblinger et al., 2006; Breuer et al. 2000 and Hemsworth et al.
 422 2000; but see also Pajor et al., 2003 and Stewart et al. 2013 for limited or no effect of previous
 423 handling). Brushing by humans can also lower stress levels in times of isolation and will be
 424 discussed later under tactile enrichment.

425

426 **2.2 Occupational Enrichment**

427 Occupational enrichment encompasses both enrichment that encourages exercise and
428 psychological (also referred to as cognitive) enrichment (e.g. devices that provide animals with
429 control or opportunities to use their cognitive abilities, Bloomsmith et al., 1991).

430

431 *2.2.1. Enrichment that Encourages Exercise*

432

433 *Calves.* During early stages of life, calves are raised alone, in pairs or in groups. The space
434 allowance for each calf varies between rearing systems (and stocking density), and has a direct
435 effect on their ability to engage in voluntary physical training (Jensen et al., 1998). Physical
436 training of animals can be achieved through play behaviour, which can be directed at a
437 conspecific, object, conducted alone or in a company (Held and Spinka, 2011). In calves, play
438 behaviour was studied mainly in rearing conditions that allow very limited voluntary movement
439 (i.e. confinement). The motivation to perform locomotor play (i.e. galloping, bucking and
440 kicking, which involves no interaction between individuals) and trotting, was shown to increase
441 with the length of confinement (Jensen, 2001) suggesting that play is a behavioural need. A
442 reduction in play behaviour in young mammals has been proposed as a reliable indicator of the
443 transition from positive to poor welfare (Held and Spinka, 2011). Indeed, play behaviour in
444 calves is shown to decrease when food provision drops (Duve et al, 2012), or when calves are
445 subjected to painful procedures (e.g. hot-iron disbudding, Mintline et al., 2013). Improving the
446 welfare of calves by rearing them in groups is associated with higher rate of play behaviour
447 (Jensen et al., 1998). In a recent study, Valníčková et al. (2015) assessed the effect of social
448 companionship (single vs. group housing) on play behaviour. In this study, housing calves in
449 groups was associated with more spontaneous play behaviour in the pen compared to housing

450 calves individually. In contrast, in an open-field test and during a social test (i.e. encounter with
451 an unfamiliar conspecific), individually housed calves were more playful compared to group
452 housed calves (Valníčková et al., 2015). The lower levels of spontaneous play and the higher
453 rebound effect during the open field test and during the social test (i.e. when calves were exposed
454 to a larger space without or with companion), was suggested as indicating deprived natural levels
455 of play behaviour in individually housed calves (Valníčková et al., 2015). Although the
456 occurrence of play behaviour is generally low, its applicability as a measure of welfare in
457 combination with other indicators is worth investigating further. Additional methods for
458 encouraging exercise (i.e. via play behaviour) will be further addressed under physical
459 enrichment.

460

461 **Cows.** The motivation of cows to engage in physical activity (i.e walk, trot, gallop and jump),
462 has mainly been studied in individuals kept in tie stall barns. Despite increasing criticism, tie
463 stalls are still used throughout the world, with over 70% of dairy farms in Canada (Canadian
464 Dairy Information Centre., 2014), 38% in the United States, 69% in Finland, 78% in Switzerland
465 (Barkema et al., 2015) that tether their cows. In the EU, 20% (lowland) and 80% (upland) of
466 cows are tethered at least during the winter (Veissier et al., 2008). Cows, similarly to calves,
467 show increasing motivation to engage in physical activity as a function of the time they spend in
468 confinement (i.e. tied up, Loberg et al., 2004; Veissier et al., 2008). Daily access to an exercise
469 area (e.g. indoor exercise area, out-door paddock, or preferably pasture) has been shown to revert
470 locomotor activity of tied cows to levels observed in loose-housed cows (Veissier et al. 2008),
471 and provides them with more opportunities to engage in social interactions, explore their
472 environment and groom 'hard to reach' hindquarters (Krohn et al., 1994). In Hérens cows (i.e. a

473 Swiss breed that is highly motivated to engage in dominance interactions), daily access to an
474 exercise yard was associated with lower frequency of agonistic interactions compared to access
475 every 3 days or more (Castro et al., 2011). Likewise, Loberg et al. (2004) found lower levels of
476 aggressive behaviours (i.e. threatening and pushing) in tied cows that had access to an exercise
477 yard once a day, compared to once a week. Engagement in exercise is also associated with
478 positive effects on claw conformation (Loberg et al., 2004), and reduced incidence of lameness
479 (Regula et al., 2004) and of mastitis (Popescu et al., 2013). In farms where tethering is still
480 practiced, daily exercise of more than one hour is recommended as a measure to fulfill, at least to
481 some extent, the motivation of cows to engage in movement (Veissier et al. 2008). For
482 minimizing hock lesions, at least 50 hr per month are recommended (i.e. preferably on pasture to
483 allow the cows to lie down comfortably, Keil et al., 2006). In the latter study, the duration of
484 each exercise period seemed to be particularly important, as increased frequency alone was not
485 found to be beneficial. To our knowledge, the contribution of additional daily exercise to the
486 welfare of cows kept solely in free-stall systems (i.e. which can be crowded, with high traffic
487 areas, and walking surfaces that are very difficult to keep dry and are slippery) has not yet been
488 studied, and its practicality for high yielding dairy cows and for calves should be considered
489 separately.

490

491 *2.2.2 Cognitive Enrichment*

492 Recent studies have shown that farm animals are capable of more complex cognitive and
493 emotional responses than previously thought (Broom, 2010). Yet, farm animal housing generally
494 offers less stimulation and fewer opportunities for animals to use their cognitive abilities than
495 those available in the wild (Langbein et al., 2009). Providing animals with more opportunity to

496 use their cognitive abilities has been suggested to be an important component of animal
497 wellbeing (Carlstead and Shepherdson, 2000), however, this key assumption still requires
498 additional supporting evidence. Cognitive enrichment can give animals control over aspects of
499 their environment, and can lead to positive affective states. The majority of empirical work on
500 the effects of providing animals with control over their environment has investigated control
501 over punishment rather than reward (Sambrook and Buchanan-Smith, 1997). However, in recent
502 years, there has been increasing evidence suggesting that the control of positive situations, such
503 as situations that involve anticipation of consummatory reward, improves welfare (Manteuffel et
504 al., 2009; Basset and Buchanan-Smith, 2007).

505

506 Manteuffel et al. (2009) suggested that cognitive enrichment of group-housed animals on
507 commercial farms could be achieved using self-controlled operant learning tasks, and adapting
508 the degree of challenge to the cognitive abilities of each species. The initial stress and frustration
509 which may arise when a challenge is presented to the animal is suggested to be an important
510 feature in the process of cognitive enrichment, as long as the animals possess the skills and
511 resources to effectively solve the problems that they face (Meehan and Mench, 2007).

512 Habituation and "over-experience" however, should be prevented by changing, to some extent,
513 the conditioned discriminatory stimuli or by adding a further conditioned behaviour (e.g. variable
514 or fixed ratio lever pressing) to the initial one. In recent years, an increasing number of studies
515 have explored, both directly and indirectly, the cognitive abilities of cattle (e.g. face perception
516 and recognition, Coulon et al., 2011; spatial memory and decision making, Bailey et al., 1989a,
517 Bailey et al., 1989b; operant conditioning and reversal learning, Vaughan et al., 2014; Webb et
518 al., 2014; Wechsler and Lea 2007; Wredle et al., 2006; reversal learning in calves, Gaillard et al.,

519 2014). Nevertheless, to our knowledge, only Hagen and Broom (2004) specifically explored the
520 effect of cognitive enrichment on cattle behaviour. In this study, heifers were divided into an
521 experimental group, where heifers were conditioned to press an operant panel to open a gate and
522 gain access to a food reward, and a control group, where the gate opened automatically after a
523 delay equal to their matched experimental group partner's latency to open it. Heifers that learned
524 the operant task displayed evidence of greater "excitement" (i.e. higher heart rates and more
525 vigorous movement), compared to control heifers, which received the same reward after
526 spending the same amount of time in the pen. However, it is difficult to infer from this study the
527 valence associated with the higher arousal of the experimental group, and thus whether these
528 heifers indeed experienced enjoyment (contingent on understanding and gaining control over the
529 task) or frustration (Spinka and Wemelsfelder, 2011).

530

531 When planning cognitive enrichment for a group of cows, individual differences arising from
532 age or previous experience must be considered (Manteuffel et al., 2009). Indeed, individual
533 differences can make an enrichment task solvable and rewarding for one group member, and
534 difficult and frustrating for another. Setting the complexity level of a task to the ability of the
535 weakest animal in the group will allow all of the animals in the group to solve the task, but may
536 be too simple and easy for the majority of the group. A more promising solution that has, to our
537 knowledge, not been tested yet in farm animals, would be to adjust the complexity level of the
538 task to each member of the group. A system based on machine learning algorithms could adjust
539 itself to the (changing) lifetime abilities of each individual. This kind of knowledge could be
540 added to the individualized data that is already being collected in an increasing number of dairy

541 farms around the world (e.g. daily milk yield, daily activity or rumination time), and give the
542 farmers a more detailed image of each individual animal kept in the group.

543

544 ***2.3 Physical Enrichment***

545 The complex cognitive abilities of cows should also be considered when designing housing and
546 husbandry systems (Broom, 2010). Physical enrichment includes altering the size or complexity
547 of the animal's enclosure or adding accessories to the enclosure such as objects, substrate, or
548 permanent structures (Bloomsmitth et al., 1991).

549

550 ***Calves.*** Providing animals with access to alternate enclosures (i.e. by dividing space into
551 different functional areas) was suggested to increase opportunities for exploration and patrolling,
552 as well as opportunities for camouflage and hiding (Newberry, 1995). Dividing the space within
553 an enclosure may also be beneficial for decreasing antagonistic interactions between calves.
554 Ninomiya and Sato (2009) compared the rate of agonistic encounters (e.g. head butting, chasing,
555 escaping) between Japanese black calves kept in an enriched pen divided by a wooden wall, with
556 the rate of agonistic encounters between calves kept in a control, not divided pen. Dividing the
557 space in the pen resulted in lower motivation of stronger calves to chase the weaker ones,
558 possibly by preventing eye contact between the animals and forcing them to pass through narrow
559 gaps in order to come into contact with each other (Ninomiya and Sato, 2009). However, since
560 the authors did not control for additional factors, such as the effect of the brush and wood log
561 that were also placed in the enriched cage, the role of the wooden wall in decreasing agonistic
562 behaviour cannot be clearly demonstrated.

563

564 Alternating the physical environment of calves, in addition to reducing agonistic behaviours, can
565 be used to encourage play and related exercise. Providing calves with increased space allowance
566 (i.e. 1.8m× 3.0m compared to 0.9 m × 1.5m) is associated with higher levels of play behaviour
567 (Jensen et al., 2015a). Adding additional stimuli to the enclosure (i.e. provision of fresh bedding)
568 also appears to stimulate the occurrence of this behaviour (Jensen et al., 1998, see also Schütz et
569 al., 2012). Jensen et al. (1998) reported that provision of straw in connection with morning
570 feeding (i.e. when fresh straw was supplied every day after milk feeding), stimulated the largest
571 daily peak in play behaviour. Playing with straw was reported by the authors to resemble ground
572 play, as opposed to object play. Ground play consists in the calf rubbing the head and neck
573 against the ground while kneeling down (Schloeth, 1961). However, since fresh straw was
574 always supplied following morning feeding in Jensen et al. (1998), its effect on play behaviour
575 cannot be fully evaluated, as it is not possible to disentangle time of day effects from the effect
576 of straw. Encouraging play behaviour in calves by the use of other substrates or external objects
577 (e.g. cow brushes and/or balls hanged at a height of 1.3 meters) may prove to be beneficial when
578 social isolation is mandatory (e.g. quarantine, Bulens et al., 2014).

579

580 **Cows.** In zero grazing systems, cowsheds are usually designed to provide constant visual and
581 physical contact between conspecifics. Allowing cows to maintain contact with each other,
582 corresponds, at least to some extent, to their natural need to live in a group. However, in the
583 wild, cows also have the possibility to isolate themselves from the group when they need to, such
584 as the time around calving (Lidfors et al., 1994). The need to isolate oneself from the group
585 seems to be important also for the high yielding cows used today in the industry. Proudfoot et al.
586 (2014a) showed that, when given the opportunity, dairy cows housed in individual maternity

587 pens preferentially used a secluded area to calve. Cows began using the secluded area more than
588 usual during the hour before calving and continued to use it more for the hour after calving. The
589 need to isolate oneself from the group was also documented during times of illness. Proudfoot et
590 al. (2014b) found that cows with high rectal temperature after calving and signs of an infectious
591 disease (mastitis, metritis, pneumonia, or some combinations of these diseases) spent more time
592 in the secluded area compared to healthy cows. Building secluded areas inside the cowshed thus
593 seems to provide cows with the opportunity to express, at least to some extent, their natural need
594 to isolate themselves from the group. Cows should have free access to these secluded areas, as
595 the need for isolation at times of morbidity is not shared by all group members, and not for all
596 morbidity cases (e.g. lame cows, Jensen et al. 2015b). Secluded areas that cows can access freely
597 can be introduced in both loose housing systems (e.g. by installing a "movable" fence that can be
598 folded when the soil needs to be cultivated), and in free stall systems (e.g. by installing dense
599 nets that provide a visual barrier but can still allow air flow). Monitoring the occupation of such
600 areas (i.e. in calving pens, hospital pens and free-access secluded pens) may prove to also be
601 beneficial for farmers, as they could acquire an additional indicator for the wellbeing of their
602 cows and their proximity (i.e. in time) to calving. The need to minimize contact with the group
603 can also appear in low ranking dairy cows at times of high aggression in the shed (feeding time,
604 Haskell et al., 2013). For example, providing access to a loafing area allows low-ranking cows to
605 avoid dominant animals (Haskell et al., 2013). The extent to which summer yards/exercise yards
606 (i.e. adjacent to the cowshed that allow animals to "sun bath") can further contribute to enrich the
607 physical environment of cows should be explored in future studies.

608

609 Enriching the lying area of cows by providing them with a comfortable lying surface (i.e. soft,
610 non-abrasive, clean and dry) was also suggested to be an important factor in enhancing cows'
611 comfort and welfare (Tuytens, 2005, Fregonesi et al., 2007). Bedding materials can vary from
612 organic or mostly organic materials such as straw, saw dust, inorganic (e.g. sand) to synthetic
613 materials such as or mats made of rubber combined with polypropylene and nylon. The
614 preferences of cows can strongly differ depending on the type of bedding (Norrington et al, 2008),
615 quantity of bedding (Jensen et al., 1988), quality of bedding (i.e. whether the lying surface is dry
616 or wet; Fregonesi et al., 2007), on the season (summer and winter, Manninen et al., 2002), and on
617 previous experience (Tucker et al., 2003). However, their preference for some bedding materials
618 may not necessarily fit the long term benefit of the animal. For example, bedding with straw,
619 compared to sand bedding, was associated with increased lying time (straw 749 ± 16 vs. sand
620 678 ± 19 min per day). However, it was also associated with more severe hock lesions and with
621 less improvement in overall foot health (Norrington et al, 2008). The costs of bedding materials can
622 be high in some countries and therefore, lying mats can also be used as a measure to reduce the
623 costs of bedding, by placing small quantities of bedding materials on them (Norrington et al., 2010;
624 for further information on bedding, see review by Tuytens 2005). Other measures that can
625 enrich the physical world of cows, such as placing cow brushes inside the cowshed, will be
626 addressed in the sensory enrichment section.

627

628 ***2.4 Sensory Enrichment***

629 Sensory enrichment is defined as stimulation designed to trigger one or more of an animal's
630 senses; Wells, 2009). The stimulation can be achieved through visual (e.g., television), auditory
631 (e.g. music, vocalizations), or other modalities (e.g., olfactory, tactile, taste; Bloomsmith et al.,

632 1991). As there are very few studies conducted in each subfield of sensory enrichment, we shall
633 discuss both age groups (i.e calves and cows) together.

634

635 *2.4.1 Auditory Enrichment*

636 When considering the use of auditory enrichment, the excellent hearing of cows, compared to
637 humans, should be taken into account. The hearing range of cattle lies between 23 Hz and 35
638 kHz, nearly one octave higher than that of humans (Heffner and Heffner, 1983). Exposing cattle
639 to high pitch sounds was suggested to damage their hearing and affect feeding behaviour (Johns
640 et al., 2015). The environment on commercial dairy farms can be loud and noisy; the sound of
641 metal gates opening and closing, tractors carrying total mixed ration/straw and vacuum operated
642 milking machinery, are only some of the noises that cows are exposed to frequently. Waynert et
643 al (1999) reported that beef heifers exposed to the noise of clanging metal and humans shouting
644 showed higher heart rate and activity than cattle in a quieter environment. Similarly, noise
645 recorded from a commercial milking facility induced fear in dairy heifers and, when given the
646 opportunity, the heifers learned to avoid these noises (Arnold et al., 2008). Although the results
647 of the latter study cannot be generalized to all kinds of milking machinery, and may depend on
648 farm management, they align with the argument that an overall reduction of ambient noise, rather
649 than additional acoustic stimulation, might be more important for the animals themselves (Wells,
650 2009). In accordance with this view, Newberry (1995) emphasized that adding auditory stimuli
651 to an environment that is already noisy may cause more harm than good, especially if the
652 animals have no control over the sound (i.e. such as the ability to move to a quieter location or to
653 switch off the sound).

654

655 On farms, auditory stimuli are used for a variety of tasks, from improving cow traffic in
656 automatic milking systems (Uetake et al., 1997), to training cattle to approach a food source
657 (Wredle et al., 2004). In most cases, the association between the auditory stimulus and cow
658 behaviour is established using classic or operant conditioning. In a recent study, K1Y1C1 et al.
659 (2013) used music as a measure to reduce cows' stress levels during milking. Cows that were
660 played classical music (during the milking period, for a period of 28 weeks), compared to no
661 music, had higher milk let down speed (6.27 ± 0.12 min vs 6.68 ± 0.13 min, respectively).
662 However, since the authors did not control for the effect of classical music on the workers and its
663 possible effect on the handling of cows, nor did they measure stress levels in the cows, the
664 association between classical music and stress levels cannot be clearly determined. If indeed
665 playing classical music in the milking parlor has an indirect effect on the welfare of cows (i.e. by
666 affecting the milkers themselves), an intermediate solution that would reduce ambient noise for
667 cows while enabling farmers to hear music would be the use of earphones.

668

669 In addition to classical music, some studies tested for the effect of more “natural” auditory
670 stimuli, such as playbacks of calf vocalizations, on increased milk yield. Pollock and Hurnik
671 (1978) exposed cows in the milking parlor to playbacks of calf calls. The broadcast of calls
672 started just as the cows entered the milking parlor and ceased when the last teat cup had been
673 placed on the last cow. Milk let down during the first two minutes of milking was higher in the
674 treatment group compared to the control group, which was not exposed to calls (average
675 production of 16 cows = 81.1 ± 0.4 kg vs. 79.7 ± 0.5 kg, respectively). In a more recent study,
676 McCowan et al. (2002) reported an increase of 1-2% in milk yield during the second milking
677 session following playbacks of calf calls. Although the results of these two studies present a

678 positive association between exposure to playbacks of calf vocalizations and milk yield/release,
679 their effect on the emotional state of the cow was not assessed (McCowan et al., 2002). It has
680 been suggested that, similarly as in most other mammals (Manteuffel et al., 2004; Briefer, 2012),
681 vocalizations in cattle may signal the physiological and emotional state of the calling animal
682 (Thomas et al., 2001; Marchant-Forde et al., 2002; Ikeda and Ishii, 2008). Indeed, previous
683 studies have shown that calves vocalize more before feeding time and that calves fed by
684 conventional management (i.e. twice daily for a total of 5 L during 24 h) produce more calls
685 compared to calves fed every 4 hours with 8 L of milk per day (31.4 ± 7.0 vs. 5.0 ± 3.4
686 respectively; Marchant-Forde et al., 2002). The calls used in the two above-mentioned
687 experiments (Pollock and Hurnik, 1978 and McCowan et al, 2002) were produced by calves that
688 were either deprived of food (for 8.5 h, Pollock and Hurnik, 1978) or prior to milk feeding
689 (McCowan et al, 2002). Marchant-Forde et al. (2002) found that cows that were played
690 recordings of calves (i.e. produced in similar conditions - in a commercial farm, under one week
691 of age, before feeding), compared to white noise, had greater heart rate response, increased head
692 movements and ear movements, oriented more toward the speaker and spent less time eating.
693 Since calf call playbacks were played to the cows throughout the milking session in Pollock and
694 Hurnik, (1978) and McCowan et al, (2002) (i.e. playback calls did not stop while milking was in
695 process), a negative emotional reaction in the cows might have been triggered through, possibly,
696 emotional contagion. The appropriateness of using this procedure as a measure to increase milk
697 yield, and its possible influence on the public opinion, should also be weighted into the equation
698 when considering its use.

699

700 ***2.4.2 Visual Enrichment***

701 The visual system of cattle is very sensitive to motion and contrasts of light and dark (Grandin
702 2000). The lateral eye position enables cattle to constantly scan the horizon (up to 330 degrees)
703 for predators, and facilitates other activities, such as sexual (mounting) behaviour (Grandin 2000,
704 Tucker 2009). Visual enrichment, as opposed to auditory and olfactory enrichment, can be
705 simply avoided by the animals when found to be aversive (i.e. by closing their eyelid, or
706 diverting their gaze away), and consequently, controlled (Wells, 2009). However, to the best of
707 our knowledge, very little work has been carried out on the effect of visual enrichment on cattle.
708 Haskell et al. (2013) found no significant effect of access to a view of surrounding fields and
709 farm tracks on the motivation of cows to occupy a loafing area. The authors' interpretation was
710 that a view of the surroundings has little motivational value for cows. However, since the effect
711 of visual access to the surroundings was not assessed during feeding time (i.e. food was placed
712 inside the cowshed), when lying down (i.e. loafing area had concrete flooring which is less
713 favored by cows) or during the evening/night (i.e. observations in this study were conducted only
714 during day light hours), further investigation on this potential enrichment is needed. An
715 additional factor that should be controlled for when assessing the effect of visual surroundings on
716 dairy cattle is the confounding effect of previous experience (discussed above under physical and
717 cognitive enrichment, Tucker et al., 2003; Manteuffel et al., 2009). Piller et al. (1999) studied the
718 effect of mirror-image exposure on heart rate and movement of isolated heifers. The presence of
719 mirrors was associated with reduced heart rate and movement, and had a greater calming effect
720 when placed directly in front of the animal, compared to a reflected side-view. In accordance
721 with these results, Coulon et al. (2011) found that heifers were more attracted to images of
722 familiar conspecifics (i.e. chosen first, explored more, and given more attention) compared to
723 images of unfamiliar conspecifics. If images of conspecifics are indeed treated as representations

724 of the real individuals, they might prove to be beneficial for lowering stress levels during
725 husbandry/medical procedures that require isolation. In a study measuring salivary cortisol and
726 chromogranin A concentrations from three Japanese Black cows, a picture of a companion,
727 compared to a blank picture, tended to decrease, but not significantly, stress response measured
728 after 30 minutes following the start of the isolation. However, two hours later, the opposite effect
729 was observed for salivary cortisol levels (Ninomiya and Sato, 2011). One possible explanation
730 for the time-limited effect of presenting a picture of a companion on lowering stress levels is that
731 frustration might build up over time, because of the inability to eventually engage in contact with
732 the conspecifics (Wells, 2009). More research is needed in order to gain a better understanding
733 of the short term and long term beneficial effects of this tool in lowering stress. It is important to
734 point out that reducing stress responses in cattle can also be achieved by eliminating visual input
735 rather than enriching it. Mitchell et al. (2004) found that preventing beef cattle from seeing by
736 blindfolding them, reduced the amount of struggle and tended to lower heart rate during restraint.
737 We encourage research aimed at a better understanding of the “calming effect” induced by
738 blindfolding and a systematic comparison between these two approaches (i.e. mirror vs.
739 blindfolding).

740

741 ***2.4.3 Olfactory Enrichment***

742 Cattle, compared to humans, have a very sensitive sense of smell. Using their vomeronasal
743 organ, cattle can detect pheromones indicating the reproductive state of their conspecifics or their
744 stress state (via their urine; Terlouw et al., 1998). To our knowledge, there is only one study that
745 assessed the suitability of olfactory enrichment in cattle. Wilson et al. (2002) compared two
746 tactile enrichment devices (e.g. a scratching/rubbing walkway and a movable scratching/rubbing

747 device), two olfactory enriching devices (e.g. a milk-scent releasing device and a lavender-scent
748 releasing device) and a control non-scented device. Their results show that tactile enriching
749 devices were used for a longer duration, more frequently and by a higher percentage of cows
750 compared to the scent devices. Moreover, the initial preference that cows displayed towards the
751 milk and lavender-scent devices over to the non-scented control device decreased over the course
752 of the experiment. The authors concluded that scratching/rubbing devices are better candidates
753 for environmental enrichment than scent devices, as the interest that cows display towards them
754 does not fade over time. A different approach that holds higher biological relevance, and that, to
755 our knowledge, has not been tested yet, is to enrich the scent of cows food ration, either with
756 artificial or natural smell. One possible constraint associated with this idea is the reluctance of
757 ruminants to eat novel food (known as food neophobia; Launchbaugh, 1995), and the possible
758 association of the new smells with new tastes. We will further discuss this limitation in the
759 nutritional enrichment section.

760

761 ***2.4.4 Tactile Enrichment***

762 On pasture, cattle use trees and other inanimate objects to groom themselves. The use of trees for
763 rubbing seems to originate from a different need than grooming behaviour. When trees are
764 available, cattle will use them for scratching different body regions, without spending less time
765 self-grooming and allogrooming than when trees are absent (Kohari et al., 2007). Inside the dairy
766 farm, lacking any trees, dairy cows rub their body and mainly their head and neck on metal gates,
767 fences and water troughs (DeVries et al., 2007). A useful tactile enrichment device that can be
768 placed on the farm and ease grooming behaviour of cows is an automated brush. Automatic
769 brushes allow cattle to groom themselves, particularly in body regions that they find hard to

770 reach otherwise (DeVries et al., 2007), and were shown to be preferred over fixed brushes
771 (Gutmann 2010). In addition to providing the cows with the opportunity to engage in
772 scratching/rubbing behaviour, the brushes are also associated with better body cleanliness and in
773 some situations, improved milk yield (second lactation, Schukken and Young, 2009). Once a
774 brush is installed on the farm, calves, lactating dairy cows, dry cows and breeding bulls (both
775 young and mature), will use it on a daily basis (Georg and Totschek, 2001, Georg et al., 2007;
776 DeVries et al., 2007; Hoyer 2013, Newby et al., 2013; Mandel et al., 2013). The frequency of
777 brush usage varies between cows and housing systems, and was found to be considerably higher
778 (4-7 fold) in studies where cows/bulls were housed individually (Hoyer 2013; Newby et al.,
779 2013), compared to studies where one brush was present for a group of cows (Georg and
780 Totschek, 2001, Georg et al., 2007; DeVries et al., 2007; Mandel et al., 2013). The high usage
781 rates by individually housed cows can be attributed to reduced competition over this resource
782 (Val-Laillet et al., 2008), boredom (Hoyer 2013) or simply the lack of allogrooming possibilities.
783 Another factor that plays an important role in brush utilization is the location of the brush and its
784 distance from the food bunk (Mandel et al., 2013). In addition to its hedonistic character and
785 high utilization rates, brush usage can serve as an interesting tool to measure and identify stress
786 and morbidity in dairy cows (Mandel et al., 2013). Indeed, in this previous paper, we found
787 reduced brush usage under heat load and following intrusive medical procedures (i.e. stress;
788 Mandel et al., 2013). In accordance with this idea, a recent study showed that brush usage is also
789 reduced among steers infected with Bovine Respiratory disease (BRD) on the day of peak illness
790 (i.e. morbidity; Toaff-Rosenstein et al., 2014).

791

792 The need of cows to engage in scratching/rubbing behaviour can also be achieved by brushing
793 them manually. In a recent study, Westerath et al. (2014) examined whether calves judge human
794 brushing as positive. The majority of calves faced with a preference test preferred a compartment
795 with a human that brushed the animals over an empty compartment. The authors mentioned that
796 all calves “leaned against the brush” and “stretched the neck while being brushed”, possibly
797 indicating some kind of perceived pleasure when being brushed. However, the authors emphasis
798 the need to habituate the animals to being brushed, in order for the positive impact of brushing to
799 exceed the fear of novelty or the fear of a contact with humans (as opposed to very rapid
800 adaptation of cows to automated brushes, DeVries et al., 2007). Accordingly, Westerath et al.,
801 (2014) also mention that some of the animals used in their study never habituated to being
802 brushed by the experimenter, implying that this action is not perceived to be positive by all
803 individuals. Hanging manila ropes (i.e. fiber ropes originally used for pathogen sampling) in the
804 yard may also serve as a tactile enrichment device (Stanford et al., 2009). Following a short
805 adaptation period, cattle will lick and nibble the rope on a daily basis (Stanford et al., 2009).
806 Calves and heifers interact more with the rope than mature cows (Stanford et al., 2005; Stanford
807 et al., 2009). However, to our knowledge, the nature of the motivation to engage in this
808 behaviour was not investigated, and its origin should be assessed to control for nutritional
809 deficits/stereotypic origin.

810

811 ***2.5 Nutritional Enrichment***

812 Nutritional enrichment can involve either presenting varied or novel food types, or changing the
813 method of food delivery (Bloomsmith et al., 1991).

814

815 *Calves*. Calves start to suckle milk from their dam within hours of birth (domestic settings:
816 Edwards and Broom, 1982; non-domestic settings: Tucker, 2009). The motivation to suckle at
817 this age is very high, and the frequency of milk intake in dairy calves ranges between 8-12 times
818 a day (dairy calves, Jensen, 2003). Calves kept with their dam can suckle at will, and tend to
819 have frequent suckling bouts during which they ingest small amounts of milk at a time (Kalber
820 and Barth, 2014). In the following weeks, the frequency of milk intake will gradually decrease to
821 3-4 times a day (Jensen, 2003), allowing plant based diet to slowly build up. Natural weaning
822 occurs between 6 months and one year (Newberry and Swanson, 2008). Allowing calves to
823 suckle directly from the teats of their dam/foster cow (i.e. either in a full or restrict contact dam
824 rearing system), has been associated with higher growth rates and reduced cross-sucking
825 behaviour (Roth et al., 2009). However, the higher growth rate associated with dam-rearing
826 could be confounded by a higher milk intake (of natural milk) compared to calves provided with
827 milk replacer (Kalber and Barth, 2014).

828

829 In most intensive farming systems, calves are raised separately from their dam and milk is
830 typically provided via a teat feeder or in a bucket. When fed from a bucket, calves consume a
831 large amount of milk in a very short time (i.e. 2.5 liters in about one minute, compared to 8-12
832 minutes for an average suckling bout from the dam's udder, Loberg and Lidfors, 2001). Feeding
833 calves through an open bucket (i.e. without a nipple) is cheap and easy to maintain, but does not
834 provide calves with the possibility to perform suckling behaviour. Preventing calves from
835 performing suckling behaviour may result in its redirection towards pen objects or peers (i.e.
836 cross-sucking). Although the origin of cross-sucking behaviour is thought to be influenced by
837 multiple factors, such as milk allowance and age of weaning, recent findings show that cross-

838 sucking may reflect individual differences or be the result of habit formation (de Passillé et al.,
839 2011).

840

841 The traditional method for treating cross-suckling behaviour is to install a pronged nose-ring or
842 halter on the nose of the suckling calf. Spikes attached to the nose ring/halter provoke avoidance
843 behaviour among group members, and limit their ability to suckle each other. The method was
844 criticized for targeting the signs rather than the cause (Keil et al., 2000). An alternative treatment
845 that deals with the cause itself and gives calves the opportunity to perform suckling behaviour is
846 to place a rubber nipple in the pen. de Passillé and Caza (1997) showed that the occurrence of
847 cross-suckling behaviour is reduced by more than 75% when calves are presented with dry
848 rubber nipples following milk intake from a bucket. However, although the rate of cross-suckling
849 was reduced using this method, it still involves the performance of a functionless behaviour (i.e.
850 sucking a dry rubber teat), which may be referred to as stereotypic (de Passillé et al., 2011). A
851 more promising solution is to provide calves with nutritive feeding nipples (i.e. where milk is
852 being provided through the rubber nipple), which reduces both cross-suckling behaviour (de
853 Passillé, 2001; Jensen and Weary, 2013), and the time spent in non-nutritive suckling (i.e. when
854 milk is finished and the nipples are dry; de Passillé et al., 2011). The nutritive rubber nipple can
855 be connected to a bucket (i.e. teat-bucket) or to a feeder (i.e. teat-feeder), and be used to provide
856 calves with several milk meals a day. Since calves, when suckling from their mothers, tend to
857 switch quarters once milk flow begins to decline (in contrast to piglets which use the same teat;
858 Haley et al., 1998), placing shoulder barriers between feeding stations is encouraged, in order to
859 prevent competition between calves (Jensen et al., 2008). Enriching the environment of a teat-

860 feeder by adding a post-feeding area with non-nutritive rubber teats and a net filled with a hay
861 bale, can also further reduce cross-sucking behaviour (Ude et al., 2011).

862

863 **Cows.** On pasture, dairy cows graze between 6-12 hrs a day, depending on nutrient availability,
864 ingestion speed and competition over food resources (Coffey et al., 1992). However, when kept
865 indoors, feeding time is reduced to 4 hrs a day on average (Gomez and Cook, 2010). This change
866 in feeding time can be explained, at least to some extent, by the highly predictable food location
867 and the easily consumed form in which food is being dispensed in indoor conditions (e.g.
868 fence-line feeding of total mixed ration (TMR); Newberry, 1993; Gomez and Cook, 2010). This
869 form of dispensing food is however associated with increased incidence of agonistic interactions,
870 which is usually not the case on pasture, when the animals are spaced out from each other (Miller
871 and Wood-Gush, 1991). Providing cows with a larger feeding space (1.0 m per cow compared to
872 0.5 m) resulted in at least a 60% increase in space between animals and a 57% reduction in
873 aggressive interactions while feeding (DeVries et al., 2004). This change was associated with
874 increased feeding activity throughout the day, especially during the 90 min after providing fresh
875 feed (an increase of 24%). More importantly, the increase in feeding activity was particularly
876 evident for subordinate cows. When providing extra feeding space per cow is not possible,
877 placing feed barriers (i.e. headlocks) can serve as an intermediate solution that decreases
878 displacements at the feeding bunk by more than 20% (Endres et al., 2005).

879

880 Although keeping cows indoors seems to affect the "naturalness" of their feeding behaviour (i.e.
881 the extent to which a behaviour resembles that performed in more extensive or natural
882 environment), the functionality and adaptiveness of indoor feeding techniques should be

883 emphasized (Newberry, 1995). The demand for high milk yield in intense dairy farming systems
884 places high metabolic demand on dairy cows (Butler and Smith, 1989; Rauw et al., (1998),
885 Oltenacu and Algers (2005), or Veerkamp (2009). Providing cows with easier access to food (i.e.
886 in the form of TMR) reduces the time they need to spend standing in order to feed, and may thus
887 be adaptive in order for cows to cope with the energetic demand placed on them. However, the
888 functionality and adaptiveness of this feeding method for heifers is not clear, as they do not share
889 the same metabolic demands as lactating dairy cows, and are consequently left to occupy longer
890 periods of time with a limited range of possible behavioural patterns. Providing part of the daily
891 food ration through a food net (or a device that forces the animal to engage in food collection -
892 such as pulling the hay from a bundle rather than just picking it up from the floor) may prolong
893 the duration of feeding behaviour and serve as a measure to increase the "naturalness" of calf
894 feeding behaviour. Providing essential resources (such as food) both in their regular form (i.e.
895 feed bunks) and as a reward (i.e. food net), can enrich cows' feeding experience through
896 contrafreeloading (i.e. the phenomenon where an animal will work for a reward in the presence
897 of the same reward available freely; reviewed by Inglis et al., 1997) and may contribute to their
898 welfare. We encourage further investigation of this idea as an enrichment method for heifers.

899

900 Offering animals a wider selection of food types was also suggested to be a potential source of
901 enrichment (Newberry 1995). Bioactive forages for example, are offered to combat
902 gastrointestinal parasites and serve as an alternative to anthelmintic drugs (Hutchings et al.,
903 2003). However, when considering the practicality of this enrichment method, one should also
904 take into account the effect of neophobia towards unfamiliar food (Westerath et al., 2014,
905 although see Costa et al., 2014 for reduced neophobia in calves raised in complex social groups

906 including both calves and cows). Familiarizing the cows with varying types of food (of which
 907 some is regarded to be more rewarding and some less, e.g. concentrate in calves, Westerath et al.,
 908 2014) may prove to be beneficial in decreasing neophobia, but may have an impact on the
 909 bacterial diversity in the rumen, which plays a major role in the productivity and health of cows
 910 (Callaway et al., 2010). In addition, food that is considered to be more rewarding (e.g.
 911 concentrate in calves, Westerath et al., 2014) may increase competition, and render the food
 912 accessible only to more dominant cows. In accordance with this idea, Rioja-Lang et al. (2009)
 913 showed that dairy cows trade-off food quality with proximity to a dominant individual in Y-maze
 914 choice tests. Therefore, enriching the food of farm animals (using familiar food which is
 915 perceived to be more rewarding by the animals) might prove to be more suitable in farms that
 916 dispense food individually (via individual recognition systems), or in farms that install proper
 917 barriers between feeding stations to avoid agonistic behaviour (Arachchige et al., 2014). A
 918 different approach, which to our knowledge has not been tested yet, is to use nutritional
 919 enrichment as a measure to detect lack of sufficient nutrients in the diet. Bell and Sly (1983)
 920 showed that the hedonic characteristics of nutritional enrichment, such as salt-licks, may be
 921 limited to nutrient deficient cattle. However, this idea should be further examined.

922

923 3. CONCLUSION

924 Indoor housing of dairy cows and calves is associated with various challenges for the animals,
 925 such as the constraint to occupy long periods of time with a limited range of behaviour patterns,
 926 as well as maintenance in abnormal social groups (Hughes and Duncan, 1988, Morgan and
 927 Tromborg, 2007). Here, we have reviewed environmental enrichment methods that are aimed at
 928 assisting cattle to cope better with stressors in their environment, prevent frustration and increase

929 the fulfillment of behavioural needs. As animal welfare is considered not only as the absence of
930 stress and harm, but also as the promotion of better affective conditions (Boissy et al. 2007), the
931 implementation of cognitive enrichment that can lead to positive emotions was also discussed.
932 Several of the basic behavioural requirements described here (e.g. social enrichment in the form
933 of contact with conspecifics) are considered as minimal requirements for raising standards for
934 gregarious animals, and in some countries are enshrined under legislative acts (European Union
935 Council Directive 2008/119/EC, Article 3). However, in many other countries, even these basic
936 requirements are not met (Fraser et al., 2013). Enrichment methods aimed at fulfilling other
937 important behavioural needs (e.g. providing cows with a secluded area to calve, or feeding
938 calves with milk through a nipple), have the potential to advance the welfare of dairy cows and
939 calves, but are not yet statutory. Finally, the contribution of enrichment methods that are less
940 biologically relevant (reviewed here under olfactory and auditory enrichment, e.g. classical
941 music, lavender smell) to the wellbeing of cattle is, however, less clear. Newberry (1995) argued
942 that "enrichment attempts will fail if the environmental modifications have little functional
943 significance to the animals, are not sufficiently focused to meet a specific goal, or are based on
944 an incorrect hypothesis regarding the causation and mechanisms underlying a problem". Once
945 these criteria are met, other factors, such as the accessibility of the enrichment device to cows
946 from different hierarchical rankings (and competition over resources), as well as the difficulty of
947 cleaning and disinfecting enclosures and other enrichment materials, should be taken into
948 consideration when assessing the practicality of a specific enrichment device. The benefits of
949 enriching the environment of dairy cows and calves, in terms of improving the physical and
950 mental state of the animals, and in some cases increased productivity, should be weighted in the
951 expected costs of integrating these methods into commercial farms, and may consequently play

952 an important part in increasing the motivation of farmers to adopt these methods. Several of the
953 methods described here, will, with time, be integrated to the minimum raising standards of cattle,
954 whereas others will remain under the scope of enrichment, and continue to pull the field of
955 animal welfare forward, allowing us to deepen our understanding of farm animals and their
956 needs inside the industry. As zero grazing systems gain popularity around the world, more
957 research will be needed to assess their impact on the wellbeing of the animals, and the
958 development of enrichment methods which are better adapted to cows and calves housed indoors
959 will be required.

960

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