Invited review: Associations between variables of routine herd data and dairy cattle welfare indicators

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ABSTRACT

As farm animal welfare is high on the political and societal agendas of many countries, considerable pressure exists to establish audit programs in which farm animal welfare is routinely monitored. On-farm assessment of animal welfare, however, is time-consuming and costly. A promising strategy to monitor animal welfare more efficiently is to first estimate the level of animal welfare on a farm based on routine herd data that are available in national databases. It is not currently known which variables of routine herd data (VRHD) are associated with dairy cattle welfare indicators (WI). Our aim was to identify VRHD that are associated with WI in a literature review. The 27 VRHD used in this review included the main types of data that are currently collected in national herd databases of developed countries, and related to identification and registration, management, milk production, and reproduction of dairy herds. The 34 WI used in this review were based on the Welfare Quality Assessment Protocol for Cattle. The search yielded associations in 146 studies. Twenty-three VRHD were associated with 16 WI. The VRHD that related to milk yield, culling, and reproduction were associated with the largest number of WI. Few associations were found for WI that referred to behavioral aspects of animal welfare, nonspecific disease symptoms, or resources-based indicators. For 18 WI, associations with VRHD were not significant (n = 5 WI) or no studies were found that investigated associations with VRHD (n = 13 WI). It was concluded that many VRHD have potential to estimate the level of animal welfare on dairy farms. As strengths of associations were not considered in this review, however, the true value of these VRHD should be further explored. Moreover, associations found at the animal level and in an experimental setting might not appear at the farm level and in common practice and should be investigated. Cross-sectional studies using integrated welfare scores at the farm level are needed to more accurately determine the potential of VRHD to estimate levels of animal welfare on dairy farms.

Key words: dairy cow, animal welfare, herd data, monitoring

INTRODUCTION

As farm animal welfare is high on the political and societal agendas of many countries, considerable pressure exists to establish welfare audit programs in which farm animal welfare is routinely monitored. These programs should be able to attribute a level of animal welfare to farms and eventually lead to improvement of living conditions of farm animals. Programs require the use of on-farm animal welfare assessments, in which a farm is visited and assessed against compliance with a set of animal welfare criteria. In the past decades, various on-farm assessment protocols have been developed; for example, the Animal Needs Index (Bartussek et al., 2000) and the Bristol Welfare Assurance Programme (Leeb et al., 2004). More recently, knowledge of animal welfare experts in Europe has been integrated in the Welfare Quality (WQ) project to develop on-farm assessment protocols for cattle, pigs, and poultry. The WQ protocols use mainly animal-based, validated welfare indicators to assess animal welfare on a farm. Animal-based indicators are increasingly preferred to resource-based indicators because they are more closely linked to the welfare of animals and can measure the actual state of animals, regardless of how they are housed or managed (Webster et al., 2004).

One factor impeding the use of such animal-based protocols in welfare audit programs is that they are time-consuming and expensive (Knierim and Winckler, 2009). Application of the WQ protocol for dairy cattle, for example, takes approximately one day per herd (Welfare Quality, 2009). The number of days needed to visit and assess all dairy farms in a country is equal to the number of farms in that country. A promising strategy to monitor animal welfare more efficiently is to first estimate the level of animal welfare based on national herd databases. Especially in developed countries, herd
data are routinely collected from dairy farms, relating, for example, to identification and registration (I&R), housing, productivity, milk quality, and fertility. An advantage of routine herd data is that they are regularly collected and assembled, providing a continuous, easy, and inexpensive opportunity to estimate the level of animal welfare on farms. It is still unknown, however, which variables of routine herd data (VRHD) are associated with dairy cattle welfare indicators (WI).

Our aim was to identify VRHD that are associated with WI through a literature review.

**MATERIALS AND METHODS**

**VRHD**

The VRHD that were used in this review (Table 1) included the main types of data that are currently collected in a uniform way in national herd databases of developed countries. In many of these countries, VRHD are regularly collected from residential dairy farms through I&R systems, dairy processors, rendering plants, monitoring systems for milk quality, and breeding enterprises. Data are collected at both the animal and the herd level and collection frequency varies depending on the variable. Although not many countries have such a comprehensive national herd database as described in Table 1, inclusion of such a wide range of VRHD offers the possibility to specify associations between VRHD and WI for different national herd databases.

The VRHD in Table 1 are often combined in studies to generate other variables. Combining “insemination date” and “calving date,” for example, can provide a “pregnancy rate at first service” of cows on a farm. Combined VRHD that were included in this review can all be linked to the VRHD that are listed in Table 1.

**Dairy Cattle WI**

We used WI as defined in the Welfare Quality Assessment Protocol for Dairy Cattle (WQ protocol, Welfare Quality, 2009) because these indicators are mainly animal-based and are regarded as sufficiently valid, reliable, and feasible (Knierim and Winckler, 2009). The WI in the WQ protocol are grouped into 12 welfare criteria, which are based on principles of good feeding, good housing, good health, and appropriate behavior (Table 2). A welfare criterion score is calculated at the herd level from scores of one or more WI. For example, a score for “absence of injuries” (criterion 6) is derived from the percentage of moderately and severely lame cows and the percentage of cows with integument alterations (i.e., lesions, swellings, and hairless patches) on a farm. Although most of the WI in the WQ protocol are animal-based, some WI are
Associations Between VRHD and WI

Associations between VRHD and WI were searched using WI in Table 2 as single keywords in the scientific search engines Scopus and ISI Web of Knowledge. If the number of hits exceeded 100, WI were combined with VRHD as keywords in the search engines. With the term “association,” it is emphasized that relationships are not necessarily causal. We focused on direct associations between VRHD and WI. If indicators of dairy cattle welfare, other than the WI in the WQ protocol, were associated with VRHD, they were mentioned only if the indicator was a valid alternative to the WI in the WQ protocol. Water intake of cows, for example, is a valid (but not a feasible) alternative to the resource-based indicators for absence of prolonged thirst that are used in the WQ protocol. As indicators for “thermal comfort” are absent in the WQ protocol, this criterion was not considered in this review. Only significant associations in peer-reviewed publications in English were included in this review. The review was limited to studies focusing on pregnant heifers, lactating and dry cows located in developed countries. We did not differentiate among studies with regard to housing, management, or herd characteristics. Associations on both the animal and herd levels were included.

As a last step, the number of VRHD associated with one or more WI and the number of WI associated with one or more VRHD were counted. If various VRHD were combined in a variable (e.g., insemination date and calving date are combined in pregnancy rate at first service), all of these VRHD were counted.

Strengths of associations were not considered in this review because studies differ in conditions, association measures, and key parameters. Different types of association measures (e.g., correlation coefficients, odds ratios, hazard ratios, or relative risks) are not always comparable. In addition, various key parameters can be used for one VRHD. For example, studies that investigate the VRHD “milk yield” may use peak milk yield; cumulative 60-, 90-, 270-, or 305-d milk yield; fat- and protein-corrected milk yield; or milk yield acceleration as key parameters, whereas others compare “lower” yielding cows with “higher” yielding cows.

RESULTS

The search yielded associations in 146 studies. The VRHD were either associated or not with WI, or no studies were found that investigated associations between VRHD and WI (Table 3). The following sections describe the VRHD that were associated or not associated with WI. As WI in the WQ protocol are categorized within welfare criteria (Table 2), associations are shown with criteria as main headings and VRHD categories (Table 1) as subheadings.

Absence of Prolonged Hunger

Only a few studies explored associations between VRHD and the percentage of very lean cows at the farm level, whereas many studies associated BCS of individual cows. As the percentage of very lean cows is based on on-farm measurements of BCS of individual cows, associations between VRHD and BCS are relevant and were included in this review. In the WQ protocol, BCS of individual cows is measured at a random moment in lactation, but most studies quantified BCS at specific moments in lactation. We included studies that measured BCS at the time of dry-off (dry-off BCS), BCS at the time of calving (calving BCS), and the lowest BCS over lactation (nadir BCS). Unless mentioned otherwise, the following results represent associations at the animal level, using BCS on a scale of 1 to 5 (Wildman et al., 1982) and classifying cows with BCS <2 as “very lean.” If studies used a different BCS scale, scores were converted according to conversion equations described in Roche et al. (2004).

Prolonged Hunger, I&R, and Management.

Body condition score in lactating cows is affected by age, parity, and the cow’s genotype (Roche et al., 2009). Body condition score was higher in primiparous cows than in second- or third-parity cows (Gallo et al., 1996; Dechow et al., 2001; Friggens and Badsberg, 2007). One study found a negative association between the number of cows in a lactation group and their average BCS (Bowell et al., 2003), but the association with total herd size was not investigated. Cows with a lower dry-off BCS, calving BCS, and nadir BCS were more likely to be culled and had a shorter survival time than cows with higher BCS (Hoedemaker et al., 2009; Machado et al., 2010). At the farm level, the percentage of very lean cows was positively associated with mortality rate of calves (Sandgren et al., 2009).

Prolonged Hunger and Milk Production.

We found studies showing negative associations between BCS and milk yield (e.g., Garnsworthy and Topps, 1982; Treacher et al., 1986; Garnsworthy and Jones, 1987; Domecq et al., 1997b), positive associations (e.g., Domecq et al., 1997b; Markusfeld et al., 1997; Stockdale, 2001), and no associations between BCS and milk yield (e.g., Holter et al., 1990; Ruegg et al., 1992). These contradicting results may be explained by the
Table 2. Welfare principles, criteria, and indicators of Welfare Quality Assessment Protocol for Dairy Cattle (Welfare Quality, 2009)

<table>
<thead>
<tr>
<th>Principle</th>
<th>Criterion</th>
<th>Indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good feeding</td>
<td>1. Absence of prolonged hunger</td>
<td>Percentage of very lean cows&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>2. Absence of prolonged thirst</td>
<td>Number of animals per drinker and/or cm of trough, functioning, water flow and cleanliness of drinkers</td>
</tr>
<tr>
<td>Good housing</td>
<td>3. Comfort around resting</td>
<td>Mean time needed to lie down, percentage of cows colliding with housing equipment, percentage of cows lying partly or completely outside lying area</td>
</tr>
<tr>
<td></td>
<td>3a. Resting behavior</td>
<td>Percentage of cows with dirty lower hind legs, hindquarters, and udder</td>
</tr>
<tr>
<td></td>
<td>3b. Cleanliness</td>
<td>Presence of tethering, number of days per year and hours per day with access to pasture and outdoor loafing area</td>
</tr>
<tr>
<td></td>
<td>4. Thermal comfort</td>
<td>As yet, no indicator is developed</td>
</tr>
<tr>
<td></td>
<td>5. Ease of movement</td>
<td></td>
</tr>
<tr>
<td>Good health</td>
<td>6. Absence of injuries</td>
<td>Percentage of moderately and severely lame&lt;sup&gt;2&lt;/sup&gt; cows</td>
</tr>
<tr>
<td></td>
<td>6a. Lameness</td>
<td>Percentage of cows with hairless patches, percentage of cows with lesions and swellings</td>
</tr>
<tr>
<td></td>
<td>6b. Integument alterations</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7. Absence of disease</td>
<td>Mean number of coughs per cow per hour, percentage of on-farm mortality, percentage of downer cows, percentage of cows with nasal discharge, ocular discharge, hampered respiration, diarrhea, vulvar discharge, dystocia, SCC &gt;400,000 cells/mL</td>
</tr>
<tr>
<td></td>
<td>8. Absence of pain induced by management procedures</td>
<td>Disbudding, dehorning, and tail-docking, and methods and use of anesthetics and analgesics during procedure</td>
</tr>
<tr>
<td>Appropriate behavior</td>
<td>9. Expression of social behaviors</td>
<td>Mean number of head butts and displacements per cow per hour</td>
</tr>
<tr>
<td></td>
<td>10. Expression of other behaviors</td>
<td>Number of days/year and hours/day with access to pasture</td>
</tr>
<tr>
<td></td>
<td>11. Good human-animal relationship</td>
<td>Percentage of cows that can be approached&lt;sup&gt;3&lt;/sup&gt; 0 to 10 cm, &gt;10 to 50 cm, &gt;50 to 100 cm, and &gt;100 cm</td>
</tr>
<tr>
<td></td>
<td>12. Positive emotional state</td>
<td>Scores of 20 terms of the Qualitative Behavior Assessment&lt;sup&gt;4&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>1</sup>The category “very lean” corresponds with a BCS <2 in typical dairy breeds and a BCS <2.5 in typical meat or dual-purpose breeds on a 1 (very lean) to 5 (very fat) point BCS scale (Wildman et al., 1982).

<sup>2</sup>The categories “moderately lame” and “severely lame” correspond to score 3 and scores 4 and 5, respectively, on the 1 (“normal gait”) to 5 (“does not support on one limb or strong reluctance to put weight on limb in two or more limbs”) point scale of the lameness scoring system described in Winckler and Willen (2001).

<sup>3</sup>Avoidance distance is measured by approaching dairy cows from a distance of 2.5 m at the feed bunk and measuring the distance between hand and muzzle at the moment the animal withdraws (Welfare Quality, 2009).

<sup>4</sup>Positive emotional state is measured by quantitative valuation of 20 terms of the Qualitative Behavior Assessment (Rousing and Wemelsfelder, 2006; Wemelsfelder, 2007): active, relaxed, fearful, agitated, calm, content, indifferent, frustrated, friendly, bored, playful, positively occupied, lively, inquisitive, irritable, uneasy, sociable, apathetic, happy, and distressed.
Table 3. Welfare indicators (WI) of the Welfare Quality Assessment Protocol for Dairy Cattle that were associated (n = 16) and WI that were not associated (n = 5) with variables of routine herd data (VRHD), and WI for which no association studies were found (n = 13)

<table>
<thead>
<tr>
<th>Principle</th>
<th>Criterion</th>
<th>WI associated with VRHD</th>
<th>WI not associated with VRHD</th>
<th>No association studies found</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good feeding</td>
<td>1. Absence of prolonged hunger&lt;sup&gt;1&lt;/sup&gt;</td>
<td>Percentage of very lean&lt;sup&gt;1&lt;/sup&gt; cows</td>
<td>Number of animals per</td>
<td>No association studies found</td>
</tr>
<tr>
<td>Good feeding</td>
<td>2. Absence of prolonged thirst</td>
<td></td>
<td>drinker and/or cm of trough, water flow of drinkers</td>
<td></td>
</tr>
<tr>
<td>Good housing</td>
<td>3. Comfort around resting</td>
<td>Percentage of cows with dirty lower hind legs, hindquarters, and/or udder</td>
<td>Mean time needed to lie down</td>
<td>Percentage of cows colliding with housing equipment, percentage of cows lying partly/ completely outside lying area,</td>
</tr>
<tr>
<td>Good housing</td>
<td>4. Thermal comfort</td>
<td>No indicators available</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Good housing</td>
<td>5. Ease of movement</td>
<td>Presence of tethering, number of days/year and hours/day with access to pasture</td>
<td></td>
<td>Number of days and hours/day with access to outdoor loafing area</td>
</tr>
<tr>
<td>Good health</td>
<td>6. Absence of injuries</td>
<td>Percentage of moderately and/or severely lame&lt;sup&gt;2&lt;/sup&gt; cows, percentage of cows with hairless patches, lesions, and/or swellings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Good health</td>
<td>7. Absence of disease</td>
<td>Percentage of on-farm mortality, dystocia, SCC &gt;400,000 cells/mL, diarrhea, percentage of downer cows, vulvar discharge, hampered respiration</td>
<td></td>
<td>Mean number of coughs per cow per hour, percentage of cows with nasal discharge, ocular discharge</td>
</tr>
<tr>
<td>Good health</td>
<td>8. Absence of pain induced by management procedures</td>
<td></td>
<td>Tail-docking, use of anesthetics during tail-docking</td>
<td>Disbudding, dehorning, methods and use of anesthetics and/or analgesics during procedure</td>
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<td>Appropriate behavior</td>
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<td>Mean number of head butts and displacements per cow per hour</td>
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<tr>
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Nonlinear character of the association between BCS and milk yield (Roche et al., 2009). Various studies found a positive association between BCS and milk yield up to an optimum BCS, but a negative association thereafter (Bourchier et al., 1987; Waltner et al., 1993; Berry et al., 2007; Roche et al., 2007a). The association was nonlinear before the optimum BCS: the lower the BCS, the faster milk yield decreased. In the following results, we focus on studies assuming such a positive, nonlinear association between BCS and milk yield. These studies associated BCS with milk yield, using peak milk yield, cumulative 60-, 90-, 270-, and 305-d milk yield, and milk yield acceleration as key parameters.

Up to the optimum BCS, peak milk yield was positively associated with BCS. With lower BCS, differences in peak milk yields were larger. For example, peak milk yields of cows with calving BCS of 2.25 were 5.0 to 5.9 kg higher than yields of cows with calving BCS of 1.25, but yields of cows with calving BCS of 3.75 were only 1.0 to 2.9 kg higher than yields of cows with calving BCS of 2.25 (Bourchier et al., 1987; Roche et al., 2007a, 2009). Similar to peak milk yields, 60-, 90-, 270-, and 305-d cumulative milk yields were positively associated with BCS up to the optimum BCS, and differences in yields were larger with lower BCS (Waltner et al., 1993; Berry et al., 2007; Roche et al., 2007a). Cumulative 90-d FCM yields of cows with calving BCS of 2.0, for example, were 619 kg higher than yields of cows with calving BCS of 1.0, but 90-d FCM yields of cows with calving BCS of 3.0 were only 322 kg higher than yields of cows with calving BCS of 2.0 (Waltner et al., 1993). Except for one study in which calving BCS of primiparous cows was positively associated with milk yield acceleration during the first 15 d of lactation (Domecq et al., 1997b), no other study found an association between BCS and milk yield acceleration.

**Prolonged Hunger and Milk Composition.** Studies showed a positive linear association between nadir BCS and fat, protein, and lactose contents of milk of individual cows. A single unit higher nadir BCS was associated with 0.05 to 0.13% higher fat content, 0.05 to 0.12% higher protein content, and 0.02 to 0.03% higher lactose content in milk (Berry et al., 2007; Roche et al., 2007a). Some studies found no association (Ruegg and Milton, 1995), whereas others found a nonlinear association between BCS and SCC. In these studies, cows with low BCS showed a higher probability to have an SCC >199,000 cells/mL (Berry et al., 2007; Breen et al., 2009a). At the herd level, the percentage of lean cows was associated with high and low urea content of milk (Sandgren et al., 2009).

**Prolonged Hunger and Reproduction.** Various studies found a nonlinear association between BCS and reproductive performance (Gillund et al., 2001; Pryce et al., 2001; Buckley et al., 2003; Roche et al., 2007b), whereas others found only tendencies (Ruegg and Milton, 1995; Domecq et al., 1997a). Nadir BCS was negatively associated with the postpartum anestrus interval (Buckley et al., 2003; Roche et al., 2007b; Bewley and Schutz, 2008) and positively associated with pregnancy rate at first service and pregnancy at 21, 42, and 84 d after planned start of mating (Buckley et al., 2003; Roche et al., 2007b). A low dry-off BCS and BCS at 10 wk postpartum were associated with a low pregnancy rate at 200 DIM (Hoedemaker et al., 2009; Machado et al., 2010). Averaged BCS over the first 10 wk postpartum was positively associated with pregnancy rate at first service and negatively associated with calving interval (Pryce et al., 2001). In another study, however, percentage of lean cows at the herd level was positively associated with average calving interval and negatively associated with variation in calving interval among cows (Sandgren et al., 2009).

**Absence of Prolonged Thirst**

**Prolonged Thirst and Milk Production.** To our knowledge, the effect of number of animals per drinker and water flow on milk yield was analyzed in only 2 studies (Andersson et al., 1984; Andersson, 1987). Neither number of water bowls nor water flow was associated with milk yield. The effect of water flow, however, was studied for tied cows only, and, despite the low flow rate, the lowest water intake per day was reasonably high (i.e., 77 L). Lactating dairy cows drink approximately 14 to 171 L of water per day (Meyer et al., 2004), depending on milk yield, body weight, diet, and ambient temperature.

Results showed that the number of animals per drinker and water flow were not associated with VRHD. Various other studies, however, associated VRHD with water intake per cow, which is an animal-based indicator of thirst. As water intake has been associated with number of animals per drinker, length of water troughs, and water flow (Andersson et al., 1984; Andersson, 1987; Pinheiro Machado Filho et al., 2004; Teixeira et al., 2006), depending on milk yield, body weight, diet, and ambient temperature, it facilitates an indirect association between WQ indicators of thirst and VRHD.

**Water Intake and VRHD.** Water intake has been associated with milk production and composition. Daily water intake of individual cows was influenced by expected milk yield: high-yielding cows drank more water than low-yielding cows (Meyer et al., 2004; Cardot et al., 2008). Each additional kilogram of milk was associated with an additional demand of drinking water between 0.6 and 2.53 L (Castle and Thomas, 1975; Holter and Urban, 1992; Dahlborn et al., 1998; Meyer et al., 2004; Kramer et al., 2008). This correlation in-
creased with lactation stage (Kramer et al., 2008). In case of insufficient water intake, milk yield decreased (Little and Shaw, 1978; Little et al., 1980; Andersson et al., 1984; Andersson, 1987; Steiger Burgos et al., 2001; Bjerg et al., 2005). When drinking water intake was restricted by 10, 40, or 50% of the normal intake, milk yields decreased after approximately 1 d by 3, 16, and 27% (Little and Shaw, 1978; Little et al., 1980; Steiger Burgos et al., 2001). With regard to milk composition, temporary water restriction was associated with a decreased freezing point of milk and an increased milk fat content (Bjerg et al., 2005). In another study, however, milk fat content did not change significantly when cows were given 50% water restriction, but 3% more urea were excreted in milk (Steiger et al., 2005). In another study, however, increased freezing point of milk and an increased milk fat content (Bjerg et al., 2005). When drinking water intake was restricted by 10, 40, or 50% of the normal intake, milk yields decreased after approximately 1 d by 3, 16, and 27% (Little and Shaw, 1978; Little et al., 1980; Steiger Burgos et al., 2001).

Comfort Around Resting: Resting Behavior

To our knowledge, no studies have associated VRHD with the percentage of cows colliding with housing equipment or the percentage of cows lying partly or completely outside the lying area.

Resting Behavior, I&R, and Management. The time needed for individual cows to lie down was not associated with their parity (Krohn and Munksgaard, 1993). Plesch et al. (2010) found an effect of housing system on mean time needed to lie down, percentage of cows colliding with housing equipment, and percentage of cows lying partly or completely outside lying area, but did not specify differences between deep litter, cubicle housing, and tie-stalls in post hoc analyses. In other studies, time needed to lie down did not differ between cows housed in tie-stalls and loose housing systems (Krohn and Munksgaard, 1993; Jensen, 1999).

Cleanliness

Cleanliness, I& R, and Management. Parity was positively associated with dirty lower hind legs, hindquarter, and udder in individual cows (Reneau et al., 2005). During winter, cows in conventional farming systems were dirtier than cows in certified organic farming systems (Ellis et al., 2007). Mortality of calves up to 90 d old was higher in herds with more dirty cows (Sandgren et al., 2009).

Cleanliness and Milk Production. Days in milk was positively associated with dirty lower hind legs and hindquarter in individual cows (Ward et al., 2002; Reneau et al., 2005), but cows were dirtier during lactation than in the dry period (Ward et al., 2002; Ellis et al., 2007). According to one study, cows with high and average milk yield were dirtier than low-yielding cows (Ellis et al., 2007). Another study, however, found no association between cow cleanliness scores and milk yield (Fregonesi and Leaver, 2001).

Cleanliness and Milk Composition. Bulk tank milk SCC was positively associated with a higher percentage of dirty cows in the herd, especially in organic farms (Ellis et al., 2007). Individual cow SCC was also positively associated with dirty lower hind legs and udder (Schreiner and Ruegg, 2003; Reneau et al., 2005), although one study showed opposite results (Breen et al., 2009a). Individual cow SCC was not associated with dirty hindquarters (Reneau et al., 2005). Reneau et al. (2005) studied associations between cleanliness and high bulk tank milk SCC among herds with mastitis problems caused by environmental pathogens. In these herds, a 1-point change in herd mean cleanliness score [composite udder-hind limbs score on a 1 (clean) to 5 (dirty) scale] was positively associated with a 40,000 to 50,000 cells/mL change in bulk tank milk SCC. Ellis et al. (2007) found an association between cow cleanliness and major mastitis pathogens (Streptococcus uberis and Staphylococcus aureus) in bulk tank milk, but not with Bactococcus counts and clinical mastitis incidence. In other studies, contagious and environmental mastitis pathogens were associated with dirty udders but not with dirty lower hind legs (Schreiner and Ruegg, 2003; Breen et al., 2009b).

Thermal Comfort

As indicators of thermal comfort are absent in the WQ protocol, this criterion was not considered in this review.

Ease of Movement

Presence of tethering is a variable in the WQ protocol (Table 2) as well as in the list of VRHD (Table 1). Hence, presence of tethering can be directly monitored by VRHD. Access to pasture is also a variable in the list of VRHD, but is dichotomous (yes/no); the VRHD stands for a minimum number of days per year and hours per day, but not for the exact number of days per year and hours per day with access to pasture. For associations between VRHD and the exact number of days per year and hours per day with access to pasture, see paragraph about Expression of Other Behaviors. Number of days per year and hours per day with access to an outdoor loafing area are not variables in VRHD. No studies were found that investigated associations between access to an outdoor loafing area and VRHD.

Absence of Injuries: Lameness

Lameness and I&R. A higher age and parity of cows was associated with lameness (Rowlands et al., 2009a).
yield compared with healthy cows (Rajala-Schultz and Gröhn, 1999; Warnick et al., 2001; Bicalho et al., 2008; Archer et al., 2010). In preceding lactations, however, lame cows showed higher milk yields compared with healthy cows (Barkema et al., 1994; Bicalho et al., 2007b, 2008). A lowered milk yield was mainly associated with lameness in second or later parity (Domecq et al., 1997b; Warnick et al., 2001; Hernandez et al., 2002, 2005). Among primiparous cows, variation in average daily milk yield was higher when more cows in a herd were lame (Sandgren et al., 2009). Cows with a milk protein content <3.2 or >3.8% had higher risk of being lame (Dippel et al., 2009). Somatic cell score was not associated with lameness (Mülleder et al., 2007).

**Lameness and Reproduction.** Lower age at first calving was associated with higher lameness prevalence (Rutherford et al., 2009). Another study, however, found no association between age at calving and lameness (Hirst et al., 2002). Lameness was associated with a longer interval between calving and first service, a longer interval from first service to conception, and thus a longer interval between calving and conception (Lucey et al., 1986; Collick et al., 1989; Barkema et al., 1994; Hernandez et al., 2001). Compared with that in healthy cows, the interval between calving and first service was 4 d longer, and the interval calving to conception was 14 to 50 d longer for lame cows (Collick et al., 1989; Hernandez et al., 2005). Pregnancy rate to first service in lame cows was 10% less than in healthy cows, and 0.42 more services were required per conception (Collick et al., 1989). At the herd level, the percentage of lame cows was positively associated with the percentage of cows with late ongoing services (Sandgren et al., 2009). Lame and severely lame cows were at a 15 and 24% lower risk of pregnancy than healthy cows, respectively (Bicalho et al., 2007b).

**Absence of Injuries: Integument Alterations**

**Integument Alterations, I&I, and Management.** Age and parity were positively associated with prevalence, number, and severity of integument alterations per cow (Weary and Taszkun, 2000; Haskell et al., 2006; Rutherford et al., 2008; Kielland et al., 2009), whereas one study found no association (Bicalho et al., 2000). Hairless patches, swellings, and lesions of the hock were more prevalent in conventional than in organic farming systems (Rutherford et al., 2008; Kielland et al., 2009) and more prevalent in tie stalls than in loose housing systems (Osterás et al., 1990; Busato et al., 2000; Regula et al., 2004; Simensen et al., 2010). Access to pasture was positively associated with the percentage of cows with knee swellings (Haskell et al., 2006), whereas other studies found no associations.
between integument alterations and access to pasture, or with herd size (Busato et al., 2000; Kielland et al., 2009).

**Integument Alterations and Milk Production and Composition.** Days in milk was associated with integument alterations; cows in late lactation showed more integument alterations of the hock, but fewer integument alterations of the knee and more skin lesions on the neck compared with cows in early lactation (Kielland et al., 2009, 2010). Herds with lower milk yields had more knee swellings than herds with higher yields (Haskell et al., 2006). A hock and teat injury was associated with a decrease of 109 and 155 kg of cumulated milk yield of individual cows, from the day of onset to the day of recovery (Bareille et al., 2003). Other studies, however, found no associations of integument alterations with DIM (Weary and Taszkun, 2000) or with milk yield (Busato et al., 2000). Integument alterations were not associated with SCC of individual cows (Müller et al., 2007). A higher percentage of cows with integument alterations was associated with a lower percentage of cows with high and low urea levels in milk (Sandgren et al., 2009).

**Integument Alterations and Reproduction.** Integument alterations were associated with a lower age of first mating (Rutherford et al., 2008; Kielland et al., 2009). One study found an association between a high percentage of cows with integument alterations and a short calving interval and little variation between cows in calving interval (Sandgren et al., 2009), whereas studies at the cow level found no association with calving interval (Rutherford et al., 2008; Kielland et al., 2009).

**Absence of Disease**

The percentage of cows with a SCC >400,000 cells/mL and the percentage of on-farm mortality are variables in the list of VRHD (i.e., SCC and date of on-farm death of individual cows, Table 1). Associations between these WI and other VRHD, therefore, are not discussed in the following paragraphs.

**Disease, I&R, and Management.** Vulvar discharge was associated with twinning and higher calf mortality (Peeler et al., 1994). Respiratory problems were associated with on-farm mortality (McConnel et al., 2008). Downer cows were most often culled in the start of lactation and were 3.5 times more likely to be culled as healthy cows (Milian-Suazo et al., 1988). In the study of Cox et al. (1986), cows were defined as downer cows when they were nonambulatory for at least 24 h and did not die within 3 d after becoming nonambulatory. Thirty-three percent of the downer cows in this study recovered, 23% were slaughtered, and 44% died or were euthanized on-farm. Currently, the transport of downer cows is prohibited in various countries; therefore, downer cows are less often slaughtered and more often recover or die on-farm. Farms with pasture as the predominant flooring surface in winter had a lower risk of having downer cows (Green et al., 2008). Dystocia occurred more in primiparous cows than in multiparous cows and more often with bull calves than with heifer calves (Lombard et al., 2007). Dystocia was associated with increased death rates (Dematawewa and Berger, 1997) and decreased cow survival (i.e., days from calving to culling or death, Bicalho et al., 2007a), whereas it was not associated with culling until 200 DIM (Tenhagen et al., 2007). Dystocia was also associated with a higher risk of stillbirth and mortality of calves (Martinez et al., 1983; Correa et al., 1993; Peeler et al., 1994; Lombard et al., 2007; Tenhagen et al., 2007). Access to pasture and certified organic farming systems were associated with less dystocia (Bendixen et al., 1986; Bruun et al., 2002; Langford et al., 2009).

**Disease and Milk Production and Composition.** Diarrhea was associated with a 35.6-kg-lower cumulated milk yield from the day of onset to the day of recovery (Bareille et al., 2003). Days in milk was negatively associated with downer cows, and the downer cow syndrome occurred most often in the first day after calving (Cox et al., 1986; Correa et al., 1993). In the study of Cox et al. (1986), 58% of the downer cows became nonambulatory within 1 d and an additional 37% within 100 d after calving. The downer syndrome was associated with high herd milk yields (Cox et al., 1986; Green et al., 2008). Green et al. (2008) found an association between a rolling herd average of >9,090 kg of milk and the risk of having downer cows on a farm. Dystocia was negatively associated with milk yield and fat and protein contents of milk (Djemali et al., 1987; Dematawewa and Berger, 1997; Domecq et al., 1997b; Fourichon et al., 1999; Bareille et al., 2003; Bicalho et al., 2007a), whereas others found no association (Debreyer et al., 1991; Tenhagen et al., 2007). According to Dematawewa and Berger (1997), loss in milk yield and fat and protein contents due to dystocia were highest in cows with lower parity. Dystocia was not associated with SCC (Tenhagen et al., 2007).

**Disease and Reproduction.** One study, which used vulvar discharge as an indicator for postpartum metritis, found an association between vulvar discharge and a lower pregnancy rate and calving in summer (Gautam et al., 2010). Dystocia was associated with decreased conception (Djemali et al., 1987; Dematawewa and Berger, 1997; Bicalho et al., 2007a; Tenhagen et al., 2007) and with a higher number of services in primiparous cows (Dematawewa and Berger, 1997).
Absence of Pain Induced by Management Procedures

The act of tail docking and use of anesthetics in adult cows did not affect milk production (Tom et al., 2002). Although tail docking is generally performed to reduce the risk of mastitis, various studies have found no effect on SCC or bacterial cultures of mastitis (Eicher et al., 2001; Tucker et al., 2001; Schreiner and Ruegg, 2002). No studies were found that investigated associations between VRHD and intact tails in lactating cows or the act of tail docking in calves. Animals can be disbudded when they are less than 3 mo of age and dehorned when they are older. To our knowledge, no studies investigated associations between VRHD and disbudding in calves, dehorning in older animals, or absence of horns in lactating cows.

Results showed no associations between VRHD and disbudding, dehorning, or tail docking. Indirect associations, however, might exist. Docked cows, for example, had higher fly numbers (Eicher et al., 2001), and higher fly numbers were associated with a lower milk yield (Jonsson and Mayer, 1999).

Expression of Social Behaviors

Social Behaviors and I&R. Average age and herd size were associated with agonistic interactions (Mülleder et al., 2007), and interactions were doubled when new cows were introduced individually into the herd instead of pairwise (Neisen et al., 2009). Introduction of new cows into a herd was associated with a 2.6-fold increase of displacements in the feeding area (von Keyserlingk et al., 2008). Number of displacements did not differ between parities (Proudfoot et al., 2009).

Social Behaviors and Milk Production and Composition. The dominance rank of cows, based on frequencies of displacements, was associated with individual milk yield (Phillips and Rind, 2002; Val-Laillet et al., 2008), but it was cautioned that, for example, age and parity could be confounded with milk yield. Others, however, found no association between frequency of head butts and displacements and daily milk yield (Andersson et al., 1984; Fregonesi and Leaver, 2001). A higher dominance rank of cows was associated with higher fat content of milk (Andersson et al., 1984). Somatic cell count was not associated with agonistic interactions (Mülleder et al., 2007).

Expression of Other Behaviors

The number of days per year and hours per day with access to pasture is available in the list of VRHD, but as a dichotomous (yes/no) variable ("access to pasture," Table 1). The variable implies that cows have or do not have access to pasture for a minimum number of days per year and hours per day. The exact number of days per year and hours per day, however, is unknown. In the following paragraphs, therefore, we describe associations between VRHD and the total number of days per year and hours per day with access to pasture. As much variety exists in the characteristics of indoor and outdoor housing systems, effects of access to pasture should be interpreted with care (Rushen et al., 2008).

Access to Pasture, I&R, and Management. Obviously, the number of days per year cows spend on pasture largely depends on a farm’s geographic location, due to the length of the grazing season, which varies by climate and soil type. Cows in certified organic farming systems are obliged to have access to pasture. Systems with access to pasture had lower culling rates than zero-grazing systems (Washburn et al., 2002; White et al., 2002), and grazing systems in the United States had less land and fewer cows (Gillespie et al., 2009).

Access to Pasture and Milk Production and Composition. Cows with access to pasture produce less milk per lactation than cows in zero-grazing systems (Rust et al., 1995; Soriano et al., 2001; Washburn et al., 2002; White et al., 2002; Hernandez-Mendo et al., 2007; Gillespie et al., 2009), whereas one study reported higher milk yields with access to pasture (Dillon et al., 2002) and another reported equal milk yields with only overnight access to pasture (Chapinal et al., 2010). One study found higher milk protein content in milk of cows with access to pasture compared with cows with zero-grazing (Dillon et al., 2002), whereas other studies found no difference in milk protein, fat, and lactose contents and SCC (Goldberg et al., 1992; Rust et al., 1995; Soriano et al., 2001; Kennedy et al., 2009). Access to pasture decreased prevalence of streptococci other than Streptococcus agalactiae (Goldberg et al., 1992) and increased conjugated linoleic acid and milk fat C18:1 trans-11 concentration (Khanal et al., 2008). The concentration of conjugated linoleic acid reached its maximum and plateau level after 23 d of access to pasture and declined to the pre-pasture level after 4 d of indoor housing.

Access to Pasture and Reproduction. Access to pasture was not associated with reproductive performance (Washburn et al., 2002; White et al., 2002).

Good Human–Animal Relationship

Avoidance Distance, I&R, and Milk Production. The percentage of cows that could be touched was negatively associated with herd size (Waiblinger et al., 2003). Avoidance distance was not associated with milk yield (Waiblinger et al., 2002). Besides herd
size, no other associations with avoidance distance were found. Various studies, however, found associations between other human–animal relationship tests and milk production and composition and reproduction parameters.

Other Human–Animal Relationship Tests and VRHD. Aversive handling of cows by stockpeople was negatively associated with milk yield and protein and fat content of milk (Seabrook, 1984; Breuer et al., 2000; Hemsworth et al., 2000, 2002; Waiblinger et al., 2002), whereas one study found no association (Munksgaard et al., 2001). The presence of an aversive stockperson increased residual milk by 70% (Rushen et al., 1999). Breuer et al. (2000) suggested that 19% of the variation in milk yield among farms could be ascribed to fear of humans. Flinch, step, and kick responses during milking were negatively associated with milk yield (Breuer et al., 2000; Bertenshaw et al., 2008). The association between approach behavior to a human and milk yield was not significant in one study (Hemsworth et al., 2000) but was positive in another study (Breuer et al., 2000). Approach behavior to a human was positively associated with conception rate at first service (Hemsworth et al., 2000, 2002; Waiblinger et al., 2002). Flight distance was moderately associated with milk yield (Breuer et al., 2000; Bertenshaw et al., 2008).

Positive Emotional State

We found no associations between Qualitative Behavior Assessment scores and VRHD. Nevertheless, the Qualitative Behavior Assessment has been associated with quantitative assessments of social behavior in cattle (Rousing and Wemelsfelder, 2006). Some of these social behavior indicators have been associated with VRHD (see paragraph about Expression of Social Behaviors).

DISCUSSION

The aim of this review was to identify VRHD that were associated with WI. We searched for associations between 27 VRHD and 34 WI. The search yielded associations in 146 studies. For 18 of 34 WI, associations with VRHD were not significant (n = 5 WI) or no studies were found that investigated associations with VRHD (n = 13 WI). Sixteen of 34 WI were associated with VRHD. Almost all VRHD (n = 23) were associated with at least one WI.

The WI in this review were taken from the Welfare Quality Assessment Protocol for Dairy Cattle. If welfare audit programs use other on-farm assessment protocols, the results found in this review might be less useful. Although welfare indicators are often based on the same fundamentals, on-farm assessment protocols may include indicators other than the ones used in this review, which could yield different associations with VRHD. Besides this, we used a wide range of VRHD, whereas not many countries collect all of these VRHD. Potential of VRHD to estimate the animal welfare may vary among different national herd databases.

WI Not Associated

The lack of association with more than half the WI suggests that VRHD may only hold potential in estimating few aspects of animal welfare. This statement, however, requires some moderation. For most of the 18 WI that were not associated, no studies were found that investigated associations with VRHD. Studies may have been absent because associations were not investigated or results may not have been published. Associations between VRHD and these WI remain to be explored. With regard to the other WI that yielded nonsignificant associations with one or more VRHD, no associations were found with these VRHD, but associations with other VRHD were not investigated. Hence, associations between VRHD and the 18 WI that were not associated in this review are largely unknown and require further exploration.

We can propose some plausible reasons why associations between WI and VRHD may be absent. First, few associations were found where WI referred to behavioral instead of physiological aspects of animal welfare (e.g., WI of the criteria comfort around resting, expression of social behaviors, good human–animal relationship, and positive emotional state). On the one hand, this might indicate that VRHD have little potential to identify behavioral problems on farms. On the other hand, studies associating behavioral indicators of animal welfare with VRHD are scarce compared with studies associating physiological indicators of animal welfare with VRHD. Because behavioral indicators are important in the assessment of animal welfare (Dawkins, 2003), it is important that associations between VRHD and behavioral WI are included when VRHD are used to estimate the level of animal welfare on farms. Second, few studies were found where WI referred to nonspecific disease symptoms (e.g., mean number of coughs, hampered respiration, diarrhea, and nasal, ocular, and vulvar discharge). Nonspecific symptoms are symptoms that are not associated with a particular disease but rather with several diseases. These diseases have been associated with VRHD, but studies rarely associate nonspecific symptoms with VRHD directly. Diarrhea, for example, has not been associated with VRHD but is a sign of, for example, clinical salmonellosis in cows. Clinical salmonellosis, in turn, has been associated with...
VRHD (e.g., decreased milk production and abortion; Divers and Peek, 2007). Third, few associations were found for resources-based WI (e.g., WI of criteria 2 and 8, Table 2). Resources-based indicators are those that relate to the environment of the animal, whereas animal-based indicators relate to the state of the animal itself. Resource-based indicators are often favored in on-farm assessment protocols when they are more feasible or reliable than animal-based indicators (Knierim and Winckler, 2009). The fact that some WI in this review were not animal-based might explain their lack of association with VRHD. Water intake, for example, is an animal-based indicator for absence of thirst and, in contrast to number and water flow of drinkers, water intake was associated with VRHD. Presumably, VRHD (e.g., animal productivity) are more closely related to the state of the animal than to its resources. Hence, the use of animal-based indicators in an on-farm assessment protocol could enhance the potential of VRHD to estimate the level of animal welfare on farms.

**VRHD Associated with WI**

Almost all VRHD were associated with WI, which indicates that many VRHD are related to the level of animal welfare on farms. This does not necessarily imply that the potential of VRHD to estimate level of animal welfare on farms is high.

Variables relating to milk yield, culling, and reproduction were associated with the largest number of WI, but using such measures of productivity to monitor animal welfare is controversial (e.g., Main et al., 2003; Whay et al., 2003). Especially when the precise cause of poor animal welfare is unknown, changes or differences in productivity are generally considered to be of little relevance to assess animal welfare. Small changes or structural differences in productivity are found to be associated with many factors besides WI, such as breed or management decisions, and therefore strengths of associations with WI are often low (Müller et al., 2007). It was not possible to consider strengths of associations in this review, because studies differed in conditions, association measures, and key parameters. Strengths of associations are, however, highly important in indicating the true potential of VRHD to estimate levels of animal welfare on farms, and should be included in future research. Large, abrupt changes in productivity may be of greater interest than small changes or structural differences to estimate levels of dairy cattle welfare on farms. A large decrease in individual daily milk yield or a strong increase in individual SCC, for example, does not normally occur in cows with good welfare. Although the exact cause of change may be unknown, animal welfare is likely to be affected in such cases.

A few other factors explain why associations found in this study should be interpreted with care. Many studies that were included in this review concerned experimental designs. Associations can be significant in such an experimental setting but not always in common practice. In addition, we included associations between VRHD and WI at the animal level, whereas welfare assessments are made at the farm level. Associations at the animal level do not, by definition, apply at the farm level. For example, individual cow BCS <1.5 was associated with an SCC >199,000 cells/mL, but this does not necessarily imply that the percentage of cows with BCS <1.5 is associated with a higher bulk tank milk SCC. Extrapolation of associations from the animal to the farm level depends on other risk factors, on-farm prevalence, and variation between farms. Besides this, we included mainly univariate associations between VRHD and WI in this review, but we found that VRHD was frequently associated with more than one WI. The numerous causes and effects of changes in productivity emphasize the multifactorial character of VRHD. Multivariate analyses and integration of WI scores may yield interesting results. In the study of Thomsen et al. (2007), for example, integrated scores at the animal level for lameness, body condition, hock lesions, other cutaneous lesions, vaginal discharge, condition of hair coat, and general condition were associated with various VRHD. Existing aggregation methods (e.g., as developed by Botreau et al., 2007a, b) could be used to integrate WI scores. Cross-sectional studies using integrated welfare scores at the farm level are needed to more accurately determine the value of VRHD to estimate levels of animal welfare on farms.

**CONCLUSIONS**

Twenty-three VRHD were associated with 16 WI. Associations between VRHD and other WI were not significant (n = 5 WI) or no studies were found that investigated associations with VRHD (n = 13 WI). The VRHD that related to milk yield, culling, and reproduction were associated with the largest number of WI. Few associations were found with WI that referred to behavioral aspects of animal welfare, nonspecific disease symptoms, or resources-based indicators. It was concluded that many VRHD are associated with WI, but the true potential of these VRHD to estimate the level of animal welfare on dairy farms should be further explored.
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