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Rear shape in 3 dimensions summarized by principal component analysis is a good predictor of body condition score in Holstein dairy cows

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ABSTRACT

Body condition is an indirect estimation of the level of body reserves, and its variation reflects cumulative variation in energy balance. It interacts with reproductive and health performance, which are important to consider in dairy production but not easy to monitor. The commonly used body condition score (BCS) is time consuming, subjective, and not very sensitive. The aim was therefore to develop and validate a method assessing BCS with 3-dimensional (3D) surfaces of the cow's rear. A camera captured 3D shapes 2 m from the floor in a weigh station at the milking parlor exit. The BCS was scored by 3 experts on the same day as 3D imaging. Four anatomical landmarks had to be identified manually on each 3D surface to define a space centered on the cow's rear. A set of 57 3D surfaces from 56 Holstein dairy cows was selected to cover a large BCS range (from 0.5 to 4.75 on a 0 to 5 scale) to calibrate 3D surfaces on BCS. After performing a principal component analysis on this data set, multiple linear regression was fitted on the coordinates of these surfaces in the principal components' space to assess BCS. The validation was performed on 2 external data sets: one with cows used for calibration, but at a different lactation stage, and one with cows not used for calibration. Additionally, 6 cows were scanned once and their surfaces processed 8 times each for repeatability and then these cows were scanned 8 times each the same day for reproducibility. The selected model showed perfect calibration and a good but weaker validation (root mean square error = 0.31 for the data set with cows used for calibration; 0.32 for the data set with cows not used for calibration). Assessing BCS with 3D surfaces was 3 times more repeatable (standard error = 0.075 versus 0.210 for BCS) and 2.8 times more reproducible than manually scored BCS (standard error = 0.103 versus 0.280 for BCS). The prediction error was similar for both validation data sets, indicating that the method is not less efficient for cows not used for calibration. The major part of reproducibility error incorporates repeatability error. An automation of the anatomical landmarks identification is required, first to allow broadband measures of body condition and second to improve repeatability and consequently reproducibility. Assessing BCS using 3D imaging coupled with principal component analysis appears to be a very promising means of improving precision and feasibility of this trait measurement.
Key words: body condition score, 3-dimensional imaging, principal component analysis, precision livestock farming

INTRODUCTION

Body condition assesses body reserves and is often used as an indirect indicator of reproduction and health status in dairy cattle management. Thin or fat cows are commonly known to be less efficient in reproduction with reduced success at first AI, longer calving-to-calving interval, and earlier return to heat cycles (Dechow et al., 2002; Berry et al., 2003). In the same way, body condition is correlated with health status (Ruegg and Milton, 1995), but the strength of this association depends on the disease (Roche and Berry, 2006). Genetic selection enhances the genetic production potential of the dairy herd but weakens its reproductive and health performance. Improving the reproductive and health status of dairy cows while maintaining production is a central issue in dairy husbandry and justifies an increasing interest in body condition phenotyping (Coffey et al., 2003; Pryce and Harris, 2006).

Major concern for selection is the difficulty in achieving accurate, objective, and high-throughput measurement of body condition in dairy cows. Body reserves can be recorded either directly by measuring the quantity of body lipids after slaughtering animals, or indirectly by measuring traits which are highly cor-

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related with lipid levels. Whole-body dissection is time-consuming, cumbersome, expensive, and irreversible for broadband use (Szabo et al., 1999). Assessing body reserves indirectly has been largely analyzed: methods can be precise but time-consuming, expensive, and invasive, such as measuring adipocyte diameter or diffusion space of deuterated water (Waltner et al., 1994). An imaging technique using ultrasonography offers new perspectives for achieving repeatable and noninvasive measures of body reserves, though they are not high-throughput methods (Schröder and Staufenbiel, 2006). On the farm, body condition is usually based on scoring, visually or by palpation, specific anatomic areas according to a chart. Body condition score appears as the cheapest and most practical method, though it suffers from its subjectivity and low reproducibility for an individual monitoring. Small and rapid variations of body condition occur during the first half of lactation in dairy cows. However, these variations are hardly detected because scores for the same cow vary between scorers (Kristensen et al., 2006) and are not sufficiently reproducible (Pryce et al., 2014).

Imaging technologies have recently become more affordable and their image quality and precision justify potential on-farm application. Therefore, few research groups (Ferguson et al., 2006; Bewley et al., 2008; Halachmi et al., 2008, Negretti et al., 2008; Azzaro et al., 2011; Bercovich et al., 2013; Weber et al., 2014) have attempted to automate BCS to achieve a more objective and less time-consuming method. Directly scoring body condition on 2-dimensional (**2D**) images is as efficient as standard BCS, but is still as subjective and labor consuming as the latter (Ferguson et al., 2006). Subsequently developed indirect methods aimed at reducing time and labor consumption of body condition monitoring. The first step was to build an acquisition system capable of acquiring high-quality images at an affordable price and not too sensitive to environmental changes. The second step was to define the information to be extracted from images to be used to assess BCS. Methods developed by Bewley et al. (2008), Halachmi et al. (2008), and Negretti et al. (2008) did not use whole information kept in 2D images but extracted indicators they assumed to be sensitive to BCS variation, such as angles, areas, or 2D shape of the rear.

Instead of using partial characteristics of the shape and keeping the rear shape in the common 2D space, Azzaro et al. (2011) and Bercovich et al. (2013) dealt with whole information kept in the rear shape. Azzaro et al. (2011) used principal component analysis (**PCA**) and Bercovich et al. (2013) compared partial least square regression (**PLSR**) and Fourier descriptors (**FD**). These 3 methods are efficient tools commonly used in shape processing (Vranic and Saupe, 2001; Allen et al., 2003; Zion et al., 2007). Bercovich et al. (2013) concluded that the best method was the model predicting BCS linearly from a few FD. The PCA learning method proposed by Azzaro et al. (2011) performed better on external validation than did methods using partial 2D information (Bewley et al., 2008; Halachmi et al., 2008) and PLSR or FD learning methods (Bercovich et al., 2013). The main reason according to Bercovich et al. (2013) was that they could only focus on the tailhead area, whereas the hooks are important too (Edmonson et al., 1989). These results reflect that it is important to focus on the area going from the hook bones to the pin bones and to work with whole information previously compressed with factor extraction techniques (PCA, PLSR, and FD) rather than using partial indicators.

Dealing with 2D images implies a loss of information that is kept in the third dimension. More recent work assessing body condition with 3D surfaces showed a level of calibration similar to the best calibration observed with 2D methods (Weber et al., 2014).

To enhance the prediction quality of an assumed shape-correlated indicator, using 3D appeared more relevant than using 2D because 3D depicts the most complete information available to analyze the shape's variability. The idea in this project was to work with whole information available to depict a 3D surface to identify the traits of the variation in shapes, which are associated with body condition variability. Therefore, the present study aimed at working closely with imaging experts from 3DOuest (Lannion, France) to develop a method combining the use of 3D shapes of the rear and the reduction of the number of 3D variables using PCA to assess BCS with greater objectivity and higher precision. Moreover, because only a few studies analyzed their method validation, we assessed external validation, repeatability, and reproducibility of the method.

MATERIALS AND METHODS

Experimental System Overview

Data. Data were collected at the INRA-UMR PEGASE experimental dairy station in Méjusseaume, France, between March and July 2013. Cows are milked twice a day and weighed individually and automatically at the milking parlor's exit on a weighing static station (DeLaval France, Elancourt, France).

Surface Acquisition System. The 3D acquisition system was an Xtion PRO Live Motion Sensor (ASUSTek Computer Inc., Taiwan). Ninety pictures are captured in 3 s and stacked to build a 3D surface. The sensor was attached 2 m up from the soil level at weigh station entry and connected to a mechanical