# TECHNICAL NOTE: Development of a pressure sensor-based system for measuring rumination time in pre-weaned dairy calves[1]

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**ABSTRACT:** The pressure-based noseband sensor system (**RWS**: RumiWatch System; ITIN + HOCH GmbH Feeding Technology, Liestal, Switzerland) has recently been validated for the measurement of rumination time in mature cows. We aimed in this study at developing a similar pressure-based system for monitoring rumination in young dairy calves. To this end, a vegetable oil–filled silicon tube with a built-in pressure sensor (outer diameter 5.7 mm, length 38 cm) was attached to the noseband of a calf halter. In contrast to the RWS developed for mature cows, the accelerometer, the battery, the data logger, and the SD card of the RWS were integrated into 1 box to reduce the weight of the RWS to 0.35 kg. The box was attached to the halter so that it was located behind the right ear of the calf. Ten pre-weaned German Holstein calves (49–106 kg BW and 33–63 days of age) were equipped with the RWS. Calves were milk-fed thrice a day and offered hay and commercial starter for ad libitum intake. In parallel, animals were monitored by a video camera connected to a video recorder for 12 h. Two independent observers assessed the video records to obtain a reliable gold standard for the evaluation of the newly developed RWS. Data obtained by either RWS or visual video observation were processed as min rumination per h, yielding a total of 120 pairs of values (12 pairs per animal) for regression analysis. Assessment of 2 independent observers were highly correlated ($r$ = 0.99). Results indicated relatively low random error between results obtained from the RWS (on y-axis) and video observations (on x-axis) ($R^2$ = 0.82). However, the intercept of the regression line (y = 7.70 + 0.64 x) was significantly different from zero ($P$ < 0.01) and the 95% confidence interval of the slope (0.79–0.94) did not include the value of 1. This translates to a significant systemic error resulting in overestimation of rumination time which is attributable to nutritive and nonnutritive oral activities that almost exclusively lasted for up to 10 min. Exclusion of false positive rumination signals lasting less than 10 or 5 consecutive min from the analysis reduced the random and systemic errors of the model ($R^2$ = 0.86 and 0.93, respectively). We conclude that the newly developed RWS can be used to provide accurate measurement of rumination time in young calves. However, an extra programmed algorithm in the evaluation software is recommended to make the system more user-friendly for measurements on calves.

**Keywords:** dairy calf, rumination time, RumiWatch System



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## INTRODUCTION

Measuring rumination behavior in calves is of great importance for monitoring rumen development and roughage intake as well as calf health and well-being. Rumination is absent in newborn calves and its development is critical for stabilizing rumen fermentation and the development of normal rumen function (Swanson and Harris, 1958; Baldwin et al., 2004). Rumination time is positively correlated with dry feed intake (Swanson and Harris, 1958) and dry feed intake is directly linked with calf growth and future milk production (Gelsinger et al., 2016). In addition, a reduction in rumination time is considered as an indicator of anxiety in cattle (Borderas et al., 2008) and associated with increases in serum cortisol levels under stressful situations (Bristow and Holmes, 2007).

Traditional methods of measuring rumination by direct observation are very laborious and time consuming (Beauchemin et al., 1989; Elischer et al., 2013). Therefore, developing and validating automated equipment for monitoring rumination in calves are warranted. Various systems have been developed and validated for automatically measuring feeding behavior of adults cows among which are pressure transducer (Ruuska et al., 2016; Rombach et al., 2018), electrical switches (Luginbuhl et al., 1987), and electrical deformation sensors (Beauchemin et al., 1989). However, reports on the application of rumination loggers for the measurement of rumination time in dairy calves are rare. Hill et al. (2017) evaluated an ear-attached movement sensor, optimized for mature dairy cows, to record rumination in calves and reported very high precision of the device in 6-wk-old calves ($R^2 = 0.91$) but not in 4-wk-old calves ($R^2 < 0.30$). They speculated that correct ear placement of the device, presence of face flies around the calf, improper weight of the sensor for the calves, differences in jaw movement pattern between calves and adult cows and suckling behavior might have contributed to poor precision of the device. Burfeind et al. (2011) have also evaluated an automated system based on sounds (Hi-Tag electronic rumination monitoring system) to measure rumination in calves. Although the system provides a reasonable measure of rumination time in dairy cows, they reported that the algorithm had high variability for calves under 9 mo of age. Therefore, it seems that further studies are needed to introduce and validate electronic devices for the measurement of rumination behavior in calves.

The RumiWatch system (**RWS**) has recently been validated for measuring eating, rumination, and drinking behavior in stall-fed (Ruuska et al., 2016) and grazing dairy cows (Rombach et al., 2018). The principle of the measurement is based on an oil-filled silicone tube containing a pressure sensor fastened in a halter over the cow's nose and an accelerometer which is placed at the right side of the muzzle which detects the x-y-z position of the head. The y-axis of the accelerometer is oriented perpendicular to the floor, whereas the x- and z-axes describe the parallel plain of the ground. The weight of the RWS amounts to 2.5 kg and is very robust on mature dairy cows and although it records systematic errors for eating and drinking, results obtained for rumination time have only little random and systemic errors (Ruuska et al., 2016). Thus, we assumed that, the RWS can also be used to measure rumination time of calves after reducing the weight of the system and fitting the halter size to the head of the calf. Therefore, the objectives of the present study were to (1) miniaturize the RWS to the head of a calf and (2) evaluate the accuracy and precision of the miniaturized RWS halter for measuring rumination time of preweaned dairy calves in reference to visual observations on video camera.

## MATERIALS AND METHODS

The experiment was carried out at Tiertechnikum of the Leibniz Institute for Farm Animal Biology (**FBN**), Dummerstorf, Germany. All procedures were approved by the ethics committee of the State Government in Mecklenburg-West Pomerania, Germany (LALLF M-V/TSD/7221.3–1.1–074/12). A vegetable oil–filled silicon tube with a built-in pressure sensor (outer diameter 5.7 mm, length 38 cm) was attached to the noseband of a calf halter. In contrast to the RWS developed for mature cows (Ruuska et al., 2016), the accelerometer, the battery, the data logger, and the SD card of the RWS were integrated into 1 box to reduce the weight of the RWS to 0.35 kg. The box was attached to the halter so that it was located behind the right ear (Fig. 1). This location should protect the box from external percussions and not hinder the calf during drinking. The data logger registered the pressure at a frequency of 10 signals per second (10 Hz). The battery is able to last for a maximum of 100 d and the halter has to be removed at least once a week for data transfer from the SD card to the computer using a USB cable. Data recorded by the RWS were converted to a mean of 1 min and transferred to an Excel file using RWS converter software (version 0.7.3.2; ITIN + HOCH GmbH Feeding Technology, Liestal, Switzerland), which

**Figure 1.** The RumiWatch System (RWS; ITIN + HOCH GmbH Feeding Technology, Liestal, Switzerland) composed of a halter with a noseband sensor comprising of an oil-filled silicon tube reaching from the left to the right side of the nose and the right cheek to end up in the pressure sensor (1). Behind the right ear, a box comprising the accelerometer, the battery, the data logger, and a SD card was fixed to the halter (2). Data recorded by the device are converted to an Excel file using the corresponding evaluation software (version 0.7.3.2).

was originally developed for mature cows. The software is based on a generic algorithm converting jaw movements and the head position into rumination, eating, and drinking events with 1 min resolution. Rumination was classified as "1" in the excel file.

The length of the halter's neck and muzzle strap was adjustable to different sizes of the calf head and the noseband was fastened in a way that allowed a space of a freely moving finger (1.5 × 3 cm) between the calf nose and the noseband (Fig. 1). Ten halter-trained female German Holstein dairy calves between 33 and 63 d of age (body weight ranging from 49 to 106 kg) were equipped with the RWS and kept individually in a respiration chamber (Derno et al., 2009) to which the animals were adapted before. Calves were bedded on wood shavings, milk-fed thrice a day at 0700, 1300, and 1700 h and had free access to hay, commercial starter (Bergophor Futtermittelfabrik GmbH & Co, Kulmbach, Germany) and water. A video camera (Panasonic wv – BP 100, Lens wv LA210C3 Focal lenght 2.1 mm, Matsushita Electric Industrial Co, Ltd, Osaka, Japan) was placed at the top corner of the chamber (horizontal and vertical distance of 1.70 m relative to feeding bin) and connected to a video recorder to monitor the whole space of the chamber using the software GeoVision GV–650 B (Taipei, Taiwan). The camera registered video clips with 5 min of length each for later evaluation. After installing the RWS to the calf's head, data transmitted in the first 16 h as well as the video records were not considered for analysis to take into account the adaptation of calves to the halter and the chamber. On the day after, from 0600 to 1800 h, data from RWS and video records were used for analysis. To test if human direct observation can provide a reliable gold standard for the evaluation of the RWS, 2 independent observers evaluated video records for 2 periods of 90 min each in the morning and in the afternoon (0900–1030 and 1500–1630 h) for each of 10 calves. The observers recorded rumination time per 90 min yielding 20 pairs of values for correlation analysis. Afterward, one of the observers evaluated the whole video records of the calves for 12 continuous hours (0600–1800 h) to provide data for the evaluation of the RWS. All video clips were evaluated by the use of windows media player 12.0.7601 (2009 Microsoft Corporation) at a rate of 3.5×. Because video clips were 5 min in length, we divided them visually to 5 equal parts on VMP and registered the start and stop time of rumination events accepting an error of about 1 min at each event. On video observation, eating was assigned when the animal was standing at the feeding bin and showing jaw movement with the head moving toward the feed bin and hay basket regularly to pick the feed up. There were jaw movements immediately after eating sessions for very short periods (1 or 2 min) when the calf was no longer beside the feed bin. These activities were considered as chewing the last bite of the feed. The calves were confirmed as playing when they showed jaw movements while pointing the muzzle toward objects such as bars in the chamber for suckling or tongue playing. There were times that the animal exhibited chewing activity while laying down that was interrupted by moving the head toward the ground to pick the wood shaving up which were considered as eating wood shavings. Finally, rumination was confirmed when the calves showed regular jaw movements interrupted by regurgitation and swallow cycles with the head remaining in a constant position. In cases that the calf was laying with the backside toward the camera, rumination was indicated by sudden contraction of the abdominal area followed by the regular movement of the ears. Because video clips were displayed at a faster rate than reality, such ear movements seemed like a vibration of the ears and head of the animal which were easily detectable. There are several reports in the literature that the pattern of the ear movement during rumination is totally different from that during eating or resting and these differences can be used to monitor feeding behavior of cattle (Bikker et al., 2014; Wolfger et al., 2015).

Rumination times recorded by either video observation or the RWS were processed as min of rumination per h during 12 h of monitoring period yielding a total of 120 pairs of values (12 pairs for each of 10 calves) for statistical analysis using SAS software (version 9.4, SAS institute Inc, Cary, NC). To determine interobserver reliability, Pearson coefficient of correlation between data recorded by 2 independent observers were calculated and paired t-test was performed to compare the means between observers. To test the agreement of the rumination time recorded by the RWS and the video observation, regression analysis was performed with RWS results being on y and video observation on x axis. Because the deviation of each individual observation from the regression line was attributable to either animal or unexplained residual, the random coefficient regression model was used (Ruuska et al., 2016):

$$Y_{ij} = B_0 + B_1 X_{ij} + s_i + b_i X_{ij} + e_{ij}$$

where $B_0$ is the overall intercept (fixed effect), $B_1$ is the overall regression coefficient of $Y$ on $X$ (fixed effect), $s_i$ is the random effect of animal $i$ ($i$ = 1, …, $n$), $b_i$ is the random effect of animal $i$ on the regression coefficient of $Y$ on $X$ in animal $i$, $e_{ij}$ is the unexplained residual error, and $j$ is the number of observations for each animal.

Adjusted $Y$ values for the random effect of animal were calculated by adding $Y$ values on the overall regression line and residual between an individual observation $ij$ and $Y$ value on the regression line of animal $i$. Adjusted $Y$ values were then fitted against $X$ values using the REG procedure of SAS (Ruuska et al., 2016). Accordingly, coefficient of determination ($R^2$) was calculated as an indicator of random error and intercept and slope of the regression line represented systemic error. Assuming perfect agreement between RWS and visual observations on the video, the hypothesis was that the slope of the regression line would be 1 and the intercept 0 (Daigle and Siegford, 2014). Deviation of the intercept from 0 was interpreted from the $P$ value of the intercept, whereas the 95% confidence interval was used to interpret the deviation of the slope from 1. To further illustrate the probable systemic error of RWS, the average duration of rumination (RWS and video observation) as h/12 h was tested by paired t-test using procedure TTEST of SAS.

## RESULTS AND DISCUSSION

Calves consumed on average 0.14 kg hay (on DM base) on the experimental day and spent on average 2.46 h ruminating during the 12-h monitoring period on the same day (Table 1). It has been indicated that dietary forage intake is the main determinant of rumination behavior in young calves (Swanson et al., 1958; Borderas et al., 2008; Laarman and Oba, 2011; Castells et al., 2012, 2013; Terré et al., 2013). Terré et al. (2013) demonstrated that provision of forage to pre-weaned calves significantly increased rumination time while NDF content of the starter had no effect on rumination behavior. Borderas et al. (2008) reported that 3-wk-old calves injected with mild doses of lipopolysaccharides reduced their rumination time that was accompanied by a reduction in time spent eating hay but not concentrate.

**Table 1.** Individual data on BW, hay, milk and concentrate intake, rumination time, and correlations between observed and predicted rumination times

| | | | Intake, kg DM/d | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Animal | Age (d) | BW (kg) | Hay[1] | Hay (%BW) | Milk[1] | Concentrate[1] | RT[2], h/12 h | $R_{F0}$[3] | $R_{F10}$ | $R_{F5}$ |
| 1 | 36 | 52 | 0.16 | 0.32 | 0.69 | 0.06 | 3.70 | 0.83 | 0.86 | 0.97 |
| 2 | 40 | 49 | 0.12 | 0.25 | 0.59 | 0.17 | 3.27 | 0.87 | 0.97 | 0.99 |
| 3 | 39 | 53 | 0.08 | 0.15 | 0.70 | 0.05 | 1.78 | 0.73 | 0.93 | 0.94 |
| 4 | 62 | 68 | 0.13 | 0.19 | 0.85 | 0.76 | 1.57 | 0.60 | 0.94 | 0.92 |
| 5 | 62 | 106 | 0.32 | 0.30 | 2.04 | 0.34 | 1.85 | 0.73 | 0.98 | 0.98 |
| 6 | 58 | 75 | 0.17 | 0.22 | 0.99 | 0.70 | 3.22 | 0.85 | 0.93 | 0.98 |
| 7 | 63 | 70 | 0.05 | 0.07 | 0.93 | 0.54 | 1.98 | 0.63 | 0.83 | 0.94 |
| 8 | 53 | 80 | 0.34 | 0.42 | 1.01 | 0.45 | 2.42 | 0.69 | 0.98 | 0.98 |
| 9 | 33 | 63 | 0 | 0 | 1.66 | 0.02 | 2.02 | 0.79 | 0.94 | 0.99 |
| 10 | 36 | 52 | 0.06 | 0.12 | 0.70 | 0.20 | 2.83 | 0.89 | 0.83 | 0.93 |
| Average | 48.2 | 66.8 | 0.14 | 0.20 | 1.02 | 0.33 | 2.46 | 0.76 | 0.92 | 0.96 |

[1]Total amount of milk replacer, hay and concentrate consumed on the video observation day (0001–2400 h).

[2]RT = rumination time observed on video (0600–1800 h).

[3]Concordance correlation coefficient (R) between observed and predicted rumination time (F0 = including raw data of the RWS (no filtering); F10 = excludes rumination events lasting less than 10 min as recoded by the RWS; F5 = excludes rumination events lasting less than five min as recoded by the RWS).

Rumination time has been reported to be positively correlated with dry feed intake in pre-weaned calves (Swanson and Harris, 1958; $r$ = 0.75). However, the correlation between hay intake adjusted for BW and rumination time was not significant in our study (0.34; $P$ = 0.33). One possible explanation is that rumination time was measured for 12 h, whereas hay intake was recorded after 24 h as calves might have ruminated for different times when they were not observed. Another factor can be the differences in age of the calves studied. It has been reported that calf age affects rumination behavior with older calves spending less time ruminating per pound of dry feed ingested (Swanson and Harris, 1958). Furthermore, differences in BW and the level of milk consumption might have also weakened the correlation between hay intake and rumination time (Table 1).

Assessments of the videos by 2 independent observers were highly correlated ($r$ = 0.99, $n$ = 20; $P$ < 0.01) and the difference between observers was not significant (29.65 ± 2.90 vs. 29.65 ± 2.93 min/90 min; paired t-test; $P$ = 1.00). Minor differences between observers (0, 1, or 2 min in each rumination event) mainly was due to the visual estimates of the start and the end of rumination events by the observers with 1 observer capturing a half minute of rumination and the other recording the following minute as the start of rumination. The same error applies in case of termination of rumination events. Therefore, human direct observation provided a reliable gold standard for the evaluation of the RWS in the present study. Results of the regression analysis of RWS against visual observation along with paired t-test comparison are presented in Table 2. The regression model (Column $M_{F0}$ in Table 2) revealed relatively high correlation between RWS results and video documentation ($R^2$ = 0.82). However, the 95% confidence interval of the slope (0.79–0.94) did not include value 1 and the intercept of the regression line (7.07 ± 0.64) differed significantly from 0. These results indicate a systemic error in RWS overestimating rumination time in calves. This was further confirmed by significantly greater rumination time recorded by RWS than video observations (3.69 vs. 2.46 h/12 h, paired t-test, $P$ < 0.01). Contrary to our results, Ruuska et al. (2016) have reported high accuracy of the RWS measuring rumination time in mature dairy cows. This discrepancy can be attributed to differences in feeding and nonnutritive oral behaviors between calves and mature dairy cows which affect the signaling of the RWS differently. The algorithm used in RWS software to differentiate eating and rumination is based on both, the jaw movements and changes in the head position of mature cows. As far as the head remains in a constant position, jaw movements are classified as rumination by the software which is also applicable to young calves. However, this criteria resulted in some false positive rumination signals (no rumination but detected as such by RWS) in calves in the present work. Dairy calves separated from their dam express nonnutritive oral activities such as sham chewing, licking, suckling or nibbling on objects, or tongue-playing apart from suckling and ingestive chewing (Veissier et al., 2013). These behaviors are considered abnormal, are mostly performed by animals living in

**Table 2.** Comparison of rumination times of 10 dairy calves recorded by the RumiWatch system (RWS; ITIN + HOCH GmbH Feeding Technology, Liestal, Switzerland) and visual observations on a video

| | Approach | | |
|---|---|---|---|
| | $M_{F0}$[1] | $M_{F10}$[2] | $M_{F5}$[3] |
| A) Rumination time, h/12 h | | | |
| RWS | 3.69 ± 0.20 | 2.03 ± 0.20 | 2.43 ± 0.20 |
| Video | 2.46 ± 0.23 | 2.46 ± 0.23 | 2.46 ± 0.23 |
| *P* value[4] | <0.01 | 0.001 | 0.60 |
| B) Linear regression model | | | |
| Slope | 0.87 | 0.88 | 0.93 |
| 95% CI range for slope | 0.79–0.94 | 0.82–0.95 | 0.88–0.98 |
| Intercept (SEM) | 7.70 ± 0.64 | -0.75 ± 0.57 | 0.73 ± 0.40 |
| $R^2$ | 0.82 | 0.86 | 0.93 |
| *P* value[5] | <0.01 | 0.19 | 0.07 |

Data were processed as rumination time (min/h) in 12 one-h periods per each calf yielding a total of 120 pairs of values.

[1]Model includes raw data of the RWS (no filtering).

[2]Model excludes rumination events lasting less than 10 min as recoded by the RWS.

[3]Model excludes rumination events lasting less than five min as recoded by the RWS.

[4]Comparison of rumination times determined by RWS vs. video using paired t-test.

[5]Deviation of the intercept from zero.

inappropriate captive environments (Mason, 1991), and increase by social deprivation (Veissier et al., 1998). Some of these behaviors such as nibbling and biting of substrates probably derive from the normal ontogeny of grazing in pre-ruminants (Veissier et al., 1998) and from an intrinsic need for exploring (Sato and Wood-Guch, 1988). Nonnutritive oral behaviors, therefore, indicate that without the opportunity to graze, in the absence of an appropriate amount of roughage, or in a poorly stimulating living environment such as limited freedom for movement and experience, calves redirect their grazing, ruminating, and exploring behaviors toward inappropriate objects (Leruste et al., 2014). Although we did not measure actual time spent performing nonnutritive oral behaviors in our study, these activities were a main contributor to false positive classifications (43% of total) when evaluated in 5 out of 10 calves over a 12-h period. In agreement with our study, Hill et al. (2017) also speculated that object-suckling behavior of calves has resulted in poor precision of an ear-tag system based on adult cow algorithm for the measurement of rumination in 4-wk-old calves. In addition, dairy calves still lack a well-developed solid feed intake behavior as adult cows show (Miller-Cushon et al., 2015) and therefore their jaw and head movements during eating might have not resembled those of mature cows, resulting in false positive classification by the RWS in this study. Differences in jaw movement pattern between calves and mature cows have also been reported to cause inaccuracies in determining rumination time with an ear-attached movement sensor, originally developed for adult cows, in other studies (Burfeind et al., 2011; Hill et al., 2017). Additionally, we speculate that the positioning of the hay basket has also affected the signaling of the RWS. Calves in the present study received hay in a basket which was attached to the wall of the chamber and thus ate with a horizontally stretched neck and a lifted head. Adult cows, in contrast, eat with bowed neck and ruminate with a straighter head. This speculation was supported with the fact that 48% of total false positive signals corresponded to eating in video records of 5 calves. Therefore, it appears that calf-specific nutritive and nonnutritive oral activities have mostly contributed to false positive rumination signals and overestimation of rumination time in our trial.

Despite above limitations, our modification of the RWS data suggests that the system is still applicable for the measurement of rumination in calves. On the video, we observed that nutritive and nonnutritive oral activities causing false positive rumination signals at the RWS lasted in the majority of the cases less than 5 and in few other cases less than 10 consecutive min. Therefore, we first filtered out rumination events lasting less than 10 min and performed the regression using the $M_{F10}$ model (Table 2). Although the precision and accuracy of the model improved significantly with the new criteria ($M_{F10}$: y = 0.88x; 95% CI of the slope= 0.82–0.95; $R^2$ = 0.86), we detected a risk of underestimation of rumination time with paired t-test analysis (Table 2; $P$ = 0.001). However, when the filter threshold was decreased from 10 to 5 consecutive min, the precision and accuracy of the model was further increased ($M_{F5}$: y = 0.93x; 95% CI of the slope = 0.88–0.98; $R^2$ = 0.93, Table 2). High accuracy of new criteria in determining rumination time is also confirmed by the results of paired t-test comparison ($P$ = 0.60; Table 2). These results are comparable to those reported by Ruuska et al. (2016) evaluating the RWS for measuring of rumination time in adult dairy cows (slope of 0.88; 95% CI = 0.73–1.02 and $R^2$ = 0.93). Therefore, it seems that rumination signals recorded by the RWS lasting less than 5 consecutive min are caused by other activities than real rumination and should be ignored when using the system for calves. This would provide precise and accurate measurement of rumination time in pre-weaned dairy calves for research and practical purposes.

We speculated that there might be anatomical or physiological constraints for the use of the RWS. Therefore, after adjusting to the random effect of animal, the concordance correlation coefficient was calculated between observed and predicted rumination times separately for each calf (Table 1). Results of the analysis revealed relatively high variation in precision of the device among calves before filtering out the data (F0). This variation can be attributed to variation in the number of false positive signals. As described above, eating and nonnutritive oral activities mostly contributed to false positive signals. Although we did not measure actual time spent eating, calves also showed large variation in dry feed intake (Table 1) and nutritional factors have been reported to influence nonnutritive oral behaviors as well (Leruste et al., 2014). After filtering out the data (F10 and F5), however, the variation among individual animals decreased markedly (Table 1). This indicates that variation in nonnutritive oral activities and feed intake behavior are major issues when the device data are not processed according to the criteria defined in our study.

In conclusion, the RWS was relatively free from random error in predicting rumination time

($R^2$ = 0.82). Due to significant systemic errors, however, the software developed for the detection of rumination in mature cows should be used with minor modifications for the measurement of rumination time in calves. Based on our observation in this study, ignoring rumination signals lasting less than 5 consecutive min (in almost all cases being false positive signals) would markedly improve the precision and accuracy of the RWS for the application in dairy calves. Defining extra algorithm in the evaluation software based on our findings is encouraged to make the system more user-friendly.

*Conflict of interest statement.* None declare.

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