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To cite this article: Alessio Cecchinato, Mauro Povinelli, Martino Cassandro, Paolo Carnier, Riccardo Dal Zotto & Luigi Gallo (2007) Relations between different objective milking speed recording systems, Italian Journal of Animal Science, 6:2, 195-203, DOI: [10.4081/ijas.2007.195](https://doi.org/10.4081/ijas.2007.195)

To link to this article: <https://doi.org/10.4081/ijas.2007.195>



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Published online: 01 Mar 2016.



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Relations between different objective milking speed recording systems

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Paper received October 20, 2006; accepted January 27, 2007

ABSTRACT

This study aimed to analyse the sources of variation of milking speed assessed through automatic computerised devices included in milking machines, to study the relationships between this trait and milking speed assessed through stopwatch and to develop statistical procedures useful for converting automatic device milking time into stopwatch milking time in order to obtain a fast, simple and cheap collection of milking time records for genetic evaluation purposes.

A total of 571 records of stopwatch milking time (SMT), device milking time (DMT) and milk yield at milking were collected in 23 herds of the Trentino Alto Adige region in Italy equipped with two types of automatic milking devices. After log-transformation of SMT (lnSMT) and DMT (lnDMT) and a preliminary analysis of sources of variation of lnDMT, dataset was partitioned into two mutually exclusive subsets: a calibration one, used for statistical analysis, and a validation one, used as test set to validate the prediction models. This procedure was replicated 6 times in order to repeat the cross validation accordingly. Three conversion models have been compared, based on different combinations of the effects of lnDMT, milking device and herd within milking device on lnSMT. Solutions of the models have been applied for each replicate to the validation dataset for estimating lnSMT and the soundness of conversion equations have been evaluated considering the correlation between estimated and actual lnSMT and bias and precision of estimates. Milking time assessed through different procedures resulted in differences between methods for both mean and distribution, and these suggested the need of developing statistical procedures aimed to the conversion of DMT into SMT before their use in sire evaluation. The soundness of the models tended to slightly increase with the increase in the number of effects considered. The correlation between estimated and actual SMT was in the range of 0.80 to 0.86, the estimated bias was close to 0 for all models and the precision, i.e. the average standard deviation of the difference between estimated and actual SMT, in the range of 8-9% of the mean of actual SMT. In conclusion, conversion equations proposed for joining the two sources of information performed satisfactorily, giving rise to SMT accurate estimates, which were not distorted and fairly precise. The use of such equations can support the integration of automatically acquired milking time records into breeding schemes, which is advisable for increasing the number of sires progeny tested and the accuracy of breeding values estimated.

Key words: Dairy cattle, Milking speed, Electronic milking devices.

RIASSUNTO

RELAZIONI TRA SISTEMI DI CONTROLLO OGGETTIVI DELLA MUNGIBILITÀ

Questa ricerca è finalizzata ad analizzare le fonti di variazione della velocità di mungitura raccolta in automatico da impianti elettronici, a studiare le relazioni tra questo carattere e la velocità di mungitura misurata da operatore tramite cronometro e a sviluppare procedure statistiche di conversione della velocità di mungitura rilevata con dispositivi elettronici in mungibilità rilevata con cronometro al fine di estendere la raccolta dati di questo carattere con finalità selettive. Lo studio ha interessato complessivamente 571 vacche da latte allevate in 23 aziende del Trentino Alto Adige, per le quali è stata misurata contestualmente la velocità di mungitura con cronometro (SMT, metodo ufficiale in uso per la valutazione dei tori Bruni nel Consorzio Superbrown) e con dispositivi elettronici inseriti nell'impianto di mungitura (DMT, rilevato con due differenti tipologie di impianti). L'archivio finale è stato diviso in un dataset di calibrazione (471 record), utilizzato per lo sviluppo dei modelli di conversione, e in un dataset di validazione (100 record), utilizzato per valutare la bontà dei modelli di conversione sviluppati. Tale procedura di estrazione è stata replicata sei volte. Dopo la trasformazione logaritmica delle variabili di mungibilità, sono stati comparati per ciascuna replica tre diversi modelli di conversione, basati su differenti combinazioni degli effetti di DMT, impianto di mungitura e allevamento entro impianto di mungitura. Le soluzioni dei modelli sono quindi state applicate alle sei repliche del dataset di validazione per la stima del SMT. La bontà delle equazioni di conversione è stata valutata sulla base delle correlazioni tra SMT stimato e misurato e sull'accuratezza e precisione delle stime ottenute. Sono state riscontrate differenze tra velocità di mungitura rilevate con procedure diverse sia relativamente alla media dei valori che alla distribuzione, fatti che giustificano l'esigenza di procedure di conversione di una misura in un'altra prima del loro impiego nelle valutazioni genetiche. Sebbene la bontà delle equazioni di conversione tendesse ad aumentare con l'aumentare del numero di effetti inclusi nei modelli, in linea generale i risultati ottenuti sono apparsi comparabili; la correlazione tra mungibilità stimata e rilevata è variata tra i modelli da 0,80 a 0,86 il bias è risultato sempre vicino a 0, sottolineando l'assenza di distorsioni delle stime ottenute, e la precisione, ossia la deviazione standard delle differenze tra valori predetti ed osservati, è risultata compresa tra l'8 e il 9% della media del SMT osservato. In conclusione, le equazioni di conversione proposte per integrare le fonti di informazioni provenienti da impianti di mungitura informatizzati hanno dato esiti soddisfacenti, dando origine a stime del SMT accurate, non distorte e adeguatamente precise. L'uso di tali equazioni può facilitare l'integrazione delle informazioni sulla mungibilità acquisite automaticamente di routine in un crescente numero di impianti di mungitura, facilitando il loro impiego a scopi selettivi accanto a record rilevati con altre procedure ufficiali. La possibilità di aumentare il numero di informazioni rilevate con gli impianti automatizzati, acquisibili a basso costo e con poco dispendio di tempo, permetterebbe di incrementare sia il numero di tori valutati per la mungibilità, sia l'accuratezza degli indici genetici ottenuti.

Parole chiave: Vacche da latte, Velocità di mungitura, Dispositivi elettronici di mungitura.

Introduction

In modern dairy farming interest toward functional traits is increasing because of their influence on the farmer's net profit, mainly due to their impact on production costs (Boettcher, 2005). As a consequence, selection programs increasingly include functional traits in their breeding aims. Among these, milking speed (MS) or milking time or milkability is of great relevance both for management and for udder

health of dairy farms (Boettcher *et al.*, 1998; Zwald *et al.*, 2005).

Milking speed is defined as the cow's capacity to give completely and in a short time the milk produced by the udder gland (Dodenhoff *et al.*, 1999; Ordloff, 2001). Increased MS is associated with decreased milking labour time, which represents an important expense in the harvest of milk; this aspect assumes a remarkable importance in a market with stabilisation or reduction in prices of milk (Sölkner, 2002).

For selection purposes, MS can be assessed through different methods: linear scores based on a subjective evaluation of MS (Cassandro *et al.*, 1999; Soresen *et al.*, 2000); objective measurements using specific devices such as electronic flowmeters (Bagnato *et al.*, 1998; Dodenhoff *et al.*, 1999) or a chronometer (Roger *et al.*, 1991; Boettcher *et al.*, 1997).

The flowmeter is adaptable on different milking machines and can give several types of information about the shape of milk releasing curves (Bagnato *et al.*, 1998); however, it is time consuming to install, requires the presence of a technician, and does not seem, therefore, suitable for a wide recording of large numbers of cows and herds.

In recent years in the Trentino Alto Adige region, the stopwatch has been used for assessing the MS of Italian Brown Swiss daughters of the most interesting proven and young bulls. Similarly, the stopwatch is the official recording system in some European regions, such as Bavaria (Germany) and Baden-Wuerttemberg (Austria), and it is approved by ICAR (ICAR, 2005) for the national genetic evaluation of MS (Dodenhoff *et al.*, 1999). The stopwatch is easier to use and less time consuming than the flowmeter, but the presence of a technician during milking is required as well.

In order to increase the number of recorded cows with positive influence on genetic progress is increasing interest in the use of information acquired through computerised devices. Such data could be integrated within the MS database assembled using a stopwatch or flowmeter, provided the relationships between information coming from different sources are known.

Therefore, this study aimed to analyse the sources of variation of MS assessed

through automatic computerised devices included in milking machines and to develop statistical procedures useful for implementing automatically acquired MS information into bull testing schemes currently running for Brown Swiss cattle herded in the Trentino Alto Adige region.

Material and methods

Sources of the data

This study was carried out on 23 dairy herds located in the provinces of Trento and Bolzano; seven herds were provided with the Westfalia® and 16 with the De Laval® computerised milking device.

For each cow enrolled in the study the following data were recorded:

- stopwatch milking time (SMT), defined as the time interval between the positioning of the last teat cup and the complete removal of the clusters (Meyer *et al.*, 1987) and assessed by a unique operator;
- device milking time (DMT), expressing the time interval between two minimum levels of milk flow from the start to the end of a regular milking session and automatically recorded by the milking device sensor; milk yield (MY) at single milking and dates of birth and of calving, provided by the official milk recording association.

Records from cows with unknown calving dates or from lactations longer than 520 d and irregular milking records, mostly due to abnormal detachment of the milking device, have been removed from the data set prior to statistical analysis.

After editing procedures, a total of 571 records were available for statistical analysis. The log-transformation of SMT (lnSMT) and DMT (lnDMT) were needed to normalize the distribution of frequency before analysis.

Statistical analysis

With the aim of studying the sources of variation of lnDMT, the data set was analysed using the GLM procedure of SAS (1990) according to a linear model which included the fixed effects of class of MY (6 classes with 2 kg-unit increment, being ≤ 8 kg the first and > 18 kg the last class, respectively), milking devices (MD: Westfalia® or De Laval®), herd nested within milking devices (H:MD, 23 herds), and class of calving age (CA: 7 classes with 1 year-unit increment, being ≤ 2 the first and > 9 years the last class, respectively).

Afterwards, the dataset was partitioned into two mutually exclusive subsets, the validation and the calibration set. The former consisted of 100 records randomly selected within each herd from the total database for validating the statistical procedures developed. The validation data set was made up of the remaining 471 records, and it was used for developing the conversion equations. This process has been replicated six times, in order to repeat the cross validation procedure described below.

With the aim of developing models for converting lnDMT in lnSMT, three equations based on (co)variance analysis of lnSMT in function of lnDMT were studied differing by the number of preliminary items of information required and extent of application.

To this purpose, lnSMT from the training data set was analysed according to the models summarized as follows:

$$\text{Model 1: } \ln\text{SMT} = \text{MD} + \text{H:MD} + \ln\text{DMT}$$

$$\text{Model 2: } \ln\text{SMT} = \text{MD} + \ln\text{DMT}$$

$$\text{Model 3: } \ln\text{SMT} = \ln\text{DMT}$$

Where lnSMT = natural logarithm of

stopwatch milking time, MD = milking devices, H:MD = herd nested within milking devices, lnDMT = natural logarithm of device milking time.

Equations developed were applied to each replicate of test data set with the aim of estimating lnSMT (lnSMT_{est}). The soundness of conversion equations was evaluated considering the average correlations between estimated and actual lnSMT and average mean and standard deviation of the difference between estimated and actual lnSMT, which express bias and precision of equations, respectively (Cassandro *et al.*, 1995), for the six replicates performed.

Results and discussion*Descriptive statistics and sources of variation of milking time*

Descriptive statistics of milking time and milk yield traits are given in Table 1.

Device milking time averaged 5.87 minutes and appeared on average lower than SMT of nearly 1 minute. Also standard deviation tended to increase from DMT to SMT; however, as suggested by variation coefficients (33.9 vs 31.1% for DMT and SMT, respectively), variation of milking time was found to be very similar in the two procedures used despite the difference in the average milking times noticed.

The compared frequency distributions of DMT and SMT are shown in Figure 1. Both distributions are slightly asymmetric and exhibit the presence of a longer tail toward longer milking time classes; therefore, milking time traits were log-transformed to better approach the normal distribution of traits before statistical analysis. Moreover, distribution of DMT shows a general shift toward the left of the graph, with higher frequency of fast milked cows when compared to SMT distribution. The differences found between the two procedures are like-

Table 1. Descriptive statistics of milking time and milk yield traits (571 records).

		Mean	SD	Range
Device milking time	min	5.87	1.99	2.05-15.7
Stopwatch milking time	"	6.91	2.15	2.32-18.2
Control milk yield	kg	12.89	4.11	3.4-32.7
Days in milk	d	180	100	5-520
Calving age	years	4.48	2.12	2-14

Table 2. Sources of variation of natural logarithm of device milking time ($R^2=0.44$).

Source of variation	DF	MS	F	P
Milk yield class	5	2.32	35.05	<0.001
Milking devices (MD)	1	2.52	33.89	<0.001
Herd within MD	21	0.16	2.50	<0.01
Calving age class	6	0.15	2.34	<0.05
MSE	537	0.066		

ly to be attributed to dissimilarities in the criteria used by devices or technicians in establishing the beginning and the end of the milking process.

From a methodological point of view, the differences observed between the two procedures justify the need to develop specific statistical procedures aimed to the conversion of DMT into SMT before integrating the information coming from the two sources in a common database.

The average of milk production at single milking was 12.9 kg, with a standard deviation of about 4 kg and was comparable to the average production level of the dairy cattle population under the milk recording system in the Trentino Alto Adige region (AIA, 2005). Days in milk and age at calving of controlled cows exhibited a wide variation, thus assuring a good representation of the group of cows sampled.

The relevance of some sources of variation of lnDMT are shown in Table 2. In gen-

eral, all the effects included in the model significantly affected lnDMT and contributed to explain more than 40% of the total variation of the trait.

Milking time appeared significantly different when measured with the De Laval or Westfalia device, but the extent of this difference was very limited (6.63 vs 6.65 minutes, respectively; data not shown in table). Herd also affected lnDMT significantly, probably because of a heterogeneous set of environmental effects mainly linked to the management of the milking procedure. Last, both production level at milking and calving age influenced the MS assessed through milking device; the relevance of these variables in affecting milkability have already been reported by others (Seykora *et al.*, 1985; Boettcher *et al.* 1998).

Conversion models and their validation

The main objective of this study was to develop reliable conversion models able to

predict the stopwatch milking time when device milking time was known. To this purpose, three conversion equations were proposed, and characterized by different degrees of complexity in terms of preliminary information needed and flexibility for a wide application. Effects included in the conversion equations, and the relative P level for each effect are given in Table 3.

The first model considers the effects of both milking device and herd in addition to lnDMT. The solutions of this model, the most complete for the effects taken into account, can only be applied to the herds represented in this sample, which have their own solutions for the herd effect. The second model, which has an intermediate complexity, skips the herd effect. This model could also be run in new herds, provided that they are equipped with the same milking devices taken into account in the present study. In the third model, the simplest, the milking device effect also has been skipped; therefore, this equation could be also used in case of inclusion in the dataset of new herds equipped with

milking device different from those taken into account in this study. In all models the MY and CA effects were not included because, even if they appeared a significant source of variation of milking time, their contribution to the prediction of SMT was negligible and not relevant to the practical use of equations.

As expected, average determination coefficient (R^2) of models developed varied accordingly with the number of effects included in the conversion equations and ranged between 0.84 and 0.75, with a quite small magnitude of standard deviation among replicates.

Some parameters useful for evaluating the soundness of the conversion equations proposed are given in Table 4. In order to avoid any autocorrelation among data, such parameters have been estimated using 100 records independent from data used for developing conversion equations, and this procedure of cross validation has been replicated six times. Therefore, the means and standard deviation of these replicates are reported as validation

Table 3. Probability level of the effects included in the conversion equations of natural logarithm of device milking time (lnDMT) into natural logarithm of stopwatch milking time (lnSMT), regression coefficients of lnDMT on lnSMT (b) and determination coefficients of equations (R^2).

	Model 1	Model 2	Model 3
Probability level:			
- milking device (MD)	<0.001	<0.001	
- herd within MD	<0.05		
- lnDMT	<0.001	<0.001	<0.001
Average b of lnDMT on lnSMT ¹	0.823	0.835	0.805
SD of b	0.007	0.010	0.010
Average R^2 of conversion equations ¹	0.84	0.77	0.75
SD of R^2	0.007	0.007	0.007

¹means of 6 replicates

parameters in Table 4.

The correlation between estimated and actual stopwatch milking time was high for all the models proposed and ranged between 0.80 and 0.86. As can be seen by descriptive statistic reported in Table 4, average estimated lnSMT tended to be close to actual lnSMT, particularly for the most complete model of conversion. Average bias of equations proposed was close to 0 suggesting that the developed models do not tend to overestimate or underestimate the stopwatch milking time. Conversely, standard deviations of estimated lnSMT appeared lower than those observed for actual lnSMT, and tended to slightly decrease with reduction of effects included in the conversion models; therefore, conversion equations proposed tended to sterilise part of the variation of SMT, particularly when the simplest conversion equation is used.

This led to a decreasing precision when passing from model 1 to model 3, due to an increase in the standard deviation of the difference between $\ln\text{SMT}_{\text{est}}$ and $\ln\text{SMT}$;

however, precision obtained from the equation proposed was on the whole comparable and ranged from 8 to 9% of the mean of actual SMT.

Conclusions

Results from this study indicated that milking time recorded through electronic devices implemented into milking machines appeared to be only partially equivalent to milking time recorded with a stopwatch. As the use of automatically recorded information within the Superbrown selection program for Italian Brown cattle reared in the Trentino Alto Adige region, based on stopwatch milking time, is of great interest for increasing the number of controlled cows economically, the adoption of specific statistical procedures able to reliably convert this kind of information seems advisable.

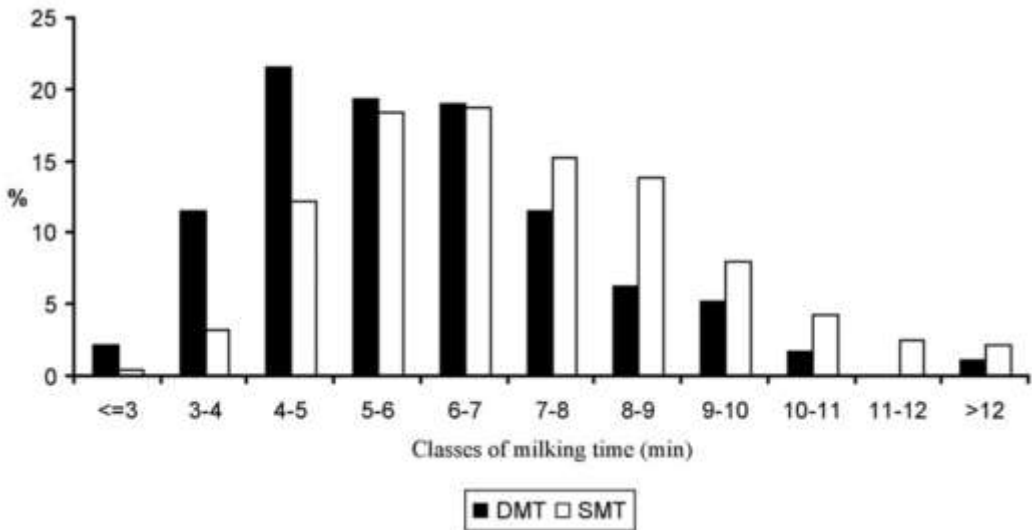
In this study three conversion equations of varying degrees of complexity have been developed and tested, based on DMT and other sources of variation of milkability easy to acquire from official milk recording

Table 4. Correlations between estimated ($\ln\text{SMT}_{\text{est}}$) and actual stopwatch milking time ($\ln\text{SMT}$), descriptive statistics of $\ln\text{SMT}_{\text{est}}$ and $\ln\text{SMT}$, bias (mean of $\ln\text{SMT}_{\text{est}} - \ln\text{SMT}$) and precision (standard deviation of $\ln\text{SMT}_{\text{est}} - \ln\text{SMT}$) of the prediction tests for conversion equations proposed.

	Model 1	Model 2	Model 3
Average correlation between:			
$\ln\text{SMT}_{\text{est}}$ and $\ln\text{SMT}$ ¹	0.86 ± 0.02	0.82 ± 0.02	0.80 ± 0.02
Average $\ln\text{SMT}_{\text{est}}$ ¹	1.906 ± 0.027	1.879 ± 0.025	1.884 ± 0.024
SD of $\ln\text{SMT}_{\text{est}}$	0.265 ± 0.004	0.265 ± 0.004	0.259 ± 0.006
Average $\ln\text{SMT}$ ¹	1.902 ± 0.021	1.902 ± 0.021	1.902 ± 0.021
SD of $\ln\text{SMT}$	0.291 ± 0.016	0.291 ± 0.016	0.291 ± 0.016
Average bias ¹	-0.009 ± 0.038	-0.021 ± 0.011	-0.028 ± 0.018
Average precision ¹	0.151 ± 0.008	0.169 ± 0.008	0.178 ± 0.009

¹means of 6 replicates

Figure 1. Comparison of frequency distributions of device milking time (DMT) and stopwatch milking time (SMT).



databases. In general, the equations proposed proved satisfactory, giving accurate stopwatch time estimates, not substantially distorted and characterised by a fairly good degree of precision. Use of such equations can now allow the Superbrown Consortium to join milking time data automatically acquired by electronic devices along with milking time data recorded with stopwatch by consortium staff. This is expected to increase the number of bull sires progeny tested for milkability and accuracy of breeding values estimated.

Further perspectives of the research will concern the estimation of genetic parameters of the device milking time and of genetic correlations between this trait and stopwatch milking time.

The authors are grateful to Daniele Marcomin for his support in data collection and to Barbara Contiero for her cooperation in statistical analysis.

Conorzio Superbrown of Trento - Bolzano (Italy) is acknowledged for having supported this study.

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