Supplementary Materials to

Cow characteristics associated with the variation in number of contacts between dairy cows. *Journal of Dairy Science*

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This pdf was updated 2023-02-02.
The order and the numbering of the Supplementary Materials have been updated as follows:

- Supplementary Material 1 is now named Supplementary Material 3
- Supplementary Material 3 is now named Supplementary Material 1
- The order of the Supplementary Materials in the document is updated according to the revised numbering

Supplementary Material 1

We inspected heatmaps of the FA data for one day (2020-10-18) and for both farms to investigate any apparent shifts in the data. Additionally, we also tracked a subset of individuals and inspected heatmaps of their positions to be able to exclude any apparent shifts in the data.

1. We examined the individual heatmap for randomly selected 20 cows from Farm A (10 from G1 and 10 cows from G2) and 20 from Farm B.
2. We examined the heatmaps for these individuals as groups.
3. We examined the heatmap for all the cows included in our study.

Figure S1 (below) shows the heatmaps of two individuals from Farm A and two from Farm B as examples. The black dots plot the trajectory of the individuals, and the heatmap overlays the trajectory. In total, the positions of 20 cows in each farm were inspected individually. Figure S2 shows the heatmap of these selected individuals as a group. Figure S3 shows the heatmap of all the individuals (163 cows from Farm A, 201 cows from Farm B, at 2020-10-18).

We used Figure S1 to observe potential data shifts in the cubicle areas. When individuals spend a long time in the resting area, we can see the position data spread around the single cubicle. However, the spread is still inside the resting area and show similar mean error distance as the performance tags. Thus, we could not find any apparent data shift in the resting area that will affect our social network analysis. Figure S3 gives more general information on data quality. The feeding area showed narrow and high-density areas over the metal bars of the feeding bank. The resting area showed a clear boundary of the beds' layout. Therefore, we could not find apparent shifts in the data given the blueprints of the farms.

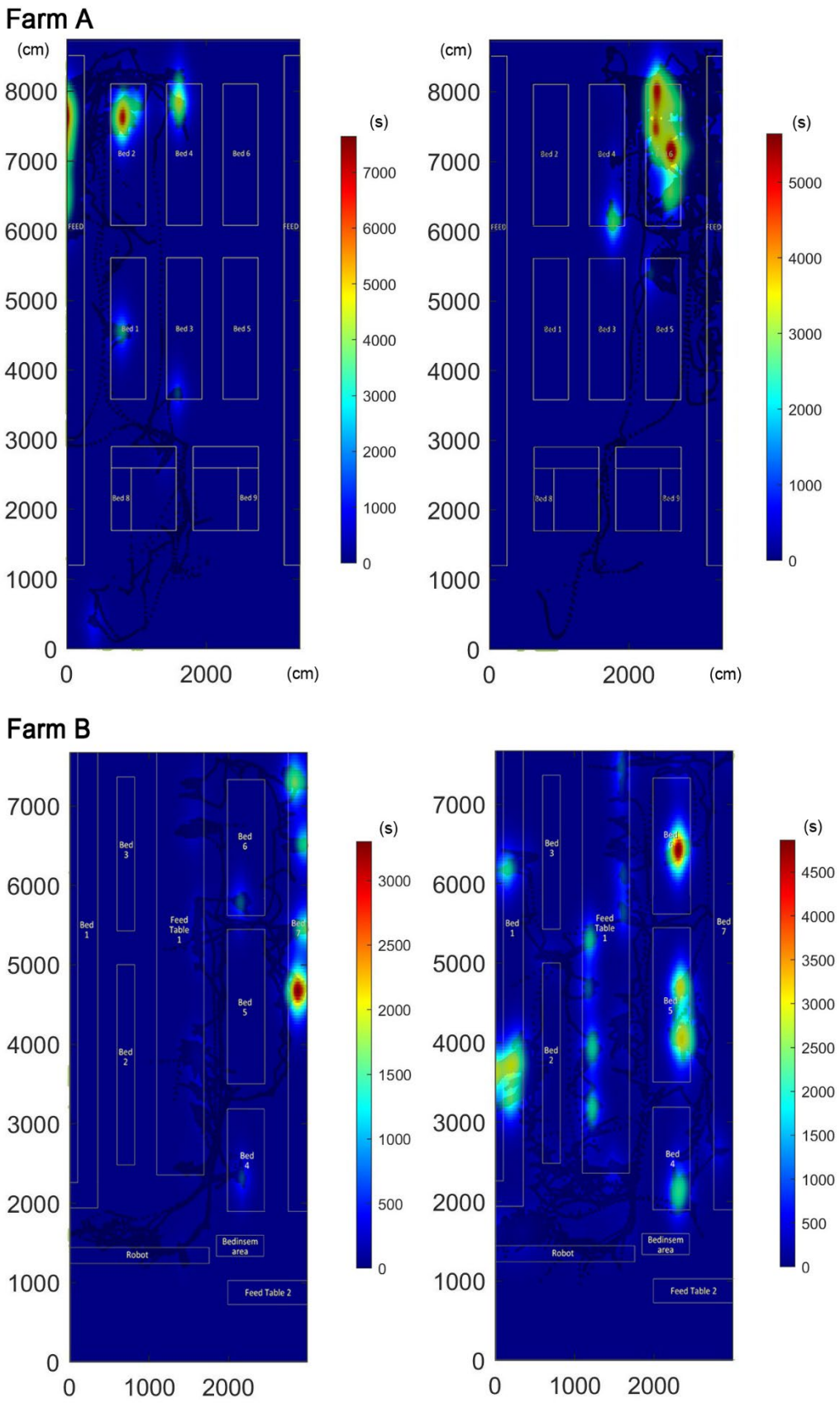

Figure S1. The heatmaps of two example individuals from Farm A and two from Farm B. The black dots plot the trajectory of the individuals, and the heatmap overlays the trajectory. The layouts of the barns are shown in the figure using white outlines.

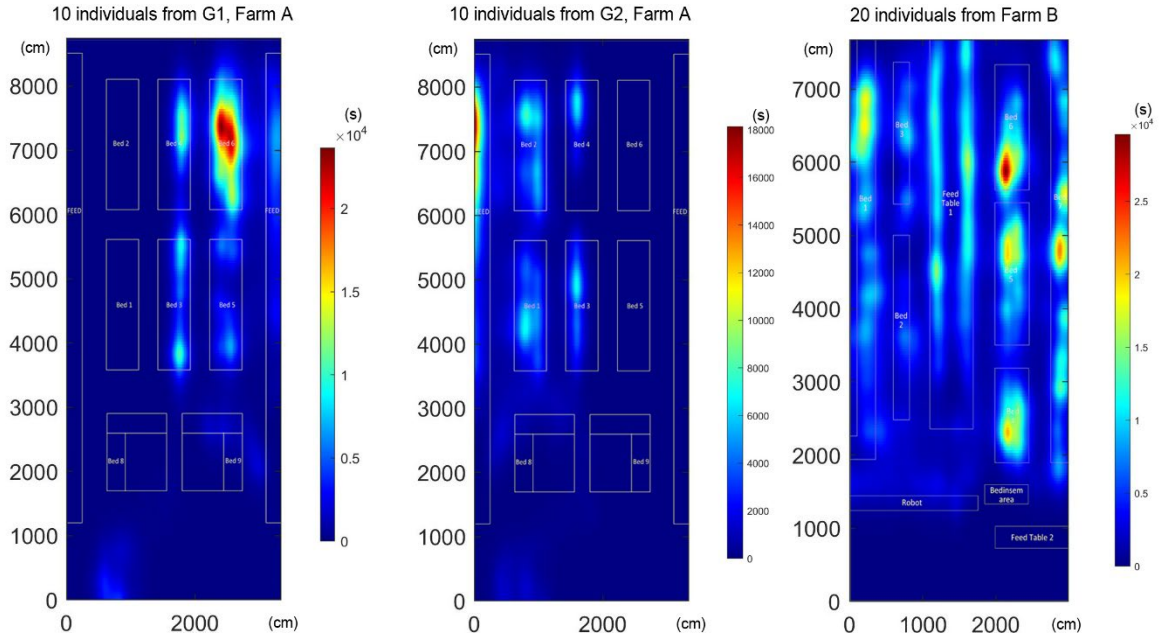

Figure S2. The heatmap of the three groups of cows where the positions of every individual were first inspected individually.

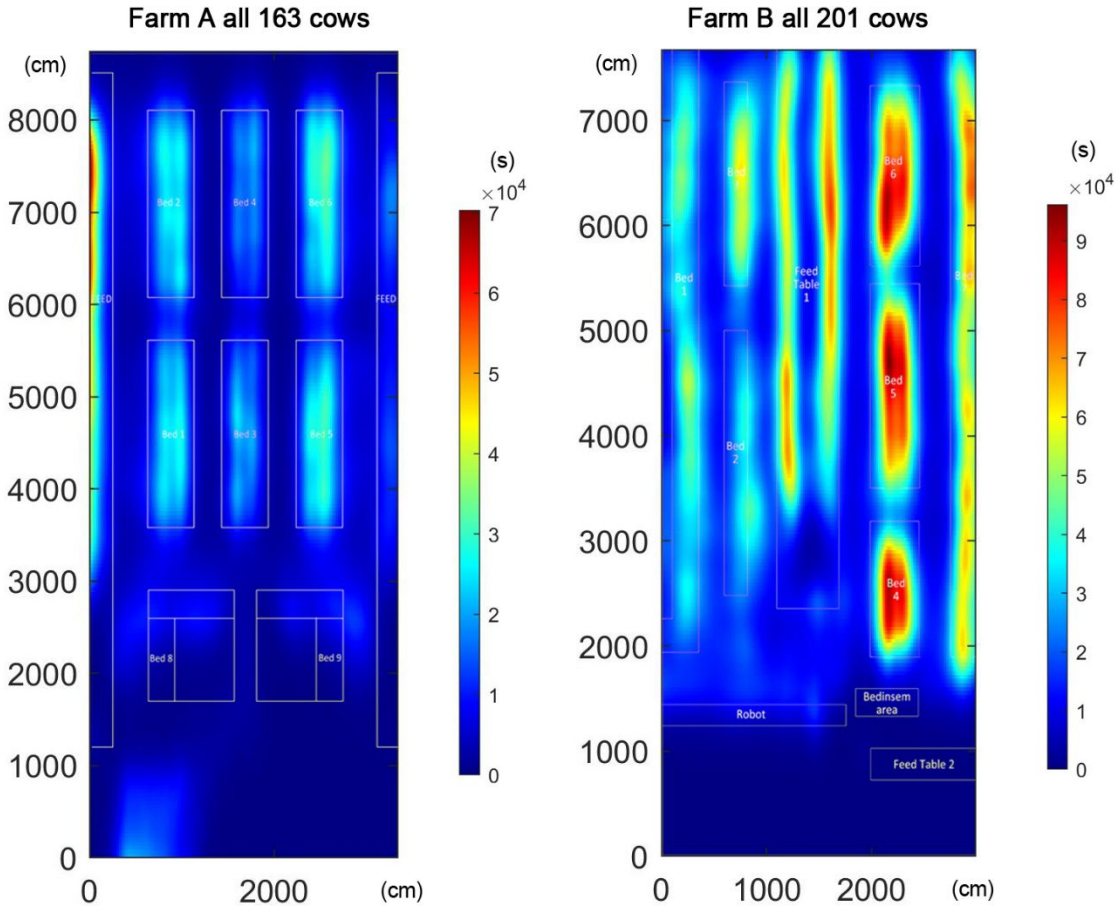

Figure S3. The heatmap using all 163 cows from Farm A and 201 cows from Farm B, on 2020-10-18.

Supplementary Material 2

Description and analysis of the response variables *total duration of contacts*, and *time spent in area*. The same explanatory variables as for the response variable *contact rate* in the main text were used.

Total duration of contacts is defined as the sum of all durations of contacts during 24 h. Note that these values can be greater than 24 h since there can be multiple simultaneous contacts. Time spent in area is defined as the total time an individual spends during 24 h within the predefined area, either feeding area or resting area as described in the main text

Total duration of contacts

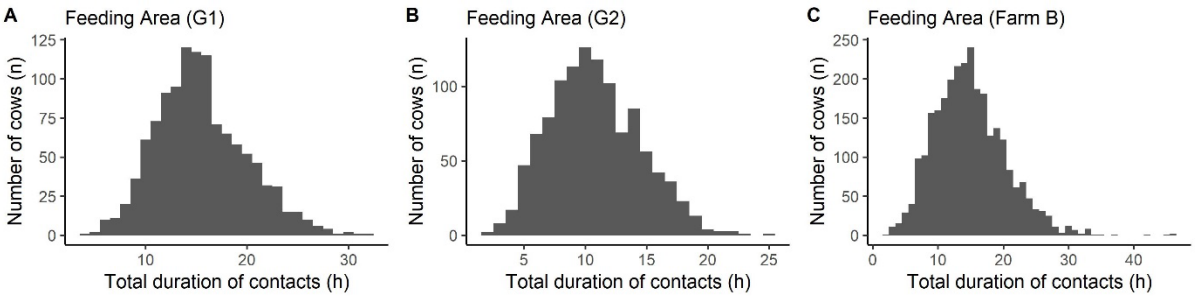

Figure S1. Distribution of the total duration of contacts in the feeding area for all three groups: A) for G1, B) for G2 and C) for Farm B.

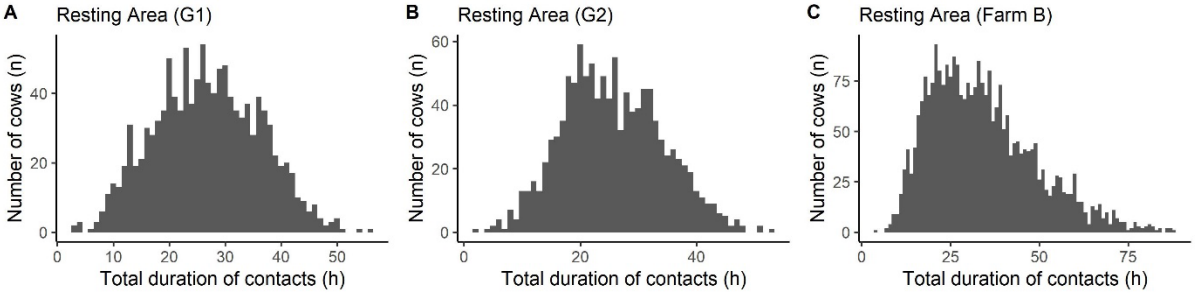

Figure S2. Distribution of the total duration of contacts in the resting area for all three groups: A) for G1, B) for G2 and C) for Farm B.

Table S1. P-values from the ANOVA test for the relation between the total duration of contacts and the individual traits in the feeding and resting area for all groups and farms

	Feeding Area			Resting Area		
	Farm A		Farm B	Farm A		Farm B
Trait	G1 (n = 83)	G2 (n = 80)	(n = 201)	G1 (n = 83)	G2 (n = 80)	(n = 201)
Date	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Parity	< 0.001	0.011	0.052	0.190	0.597	< 0.001
Lactation stage	0.927	0.021	0.013	0.009	0.531	0.639
Breed	0.338	0.015		0.762	0.974	
Pregnancy status	0.550	0.408	0.075	0.002	0.693	0.158
Estrus	0.371		0.493	< 0.001		0.139
Udder Health	0.736	0.080		0.016	0.669	
Claw Health	0.609	0.463		0.724	0.132	

Table S2. Summary of the estimated regression coefficients and significance of the individual traits on the total duration of contacts in the feeding area. Results are shown for G1 and G2 in Farm A and Farm B in a Box-Cox transformed scale. Different characters in subscript represents significantly different values ($p < 0.05$) between the levels for each factor

Feeding Area	Farm A		
Fixed Effects	G1 (n = 83)	G2 (n = 80)	Farm B (n = 201)
	Estimate	Estimate	Estimate
Parity			
1	0_a	0_a	0_a
2	-0.41_b	-0.68_b	$-0.25_{a,b}$
3+	-0.97_c	-0.84_b	-0.37_b
Lactation stage			
Early (7-49 DIM)	0		0_a
Mid (50-179 DIM)	-0.02	0_a	0.46_b
Late (≥180 DIM)	-0.10	-0.65_b	0.66_b
Breed			
Crossbred	0	0_a	
Holstein	-0.13	-0.27_a	
Red Dairy Cattle	-0.22	-0.78_b	
Pregnancy status			
Open	0	0	0
Pregnant	-0.07	0.23	-0.23
Estrus			
Not in estrus	0		0
In estrus	-0.11		-0.08
Udder health			
Low (0 – 130 000 SCC/ml)	0	0	
Mid (130 000 – 300 000 SCC/ml)	0.13	-0.67	
High (>300 000 SCC/ml)	0.05	-0.48	
Claw Health			
No remark	0	0	
Remark	-0.03	0.12	
Residual Std. Dev	0.53	0.80	0.99

Table S3. Summary of the estimated regression coefficients and significance of the individual traits on the total duration of contacts in the resting area. Results are shown for G1 and G2 in Farm A and Farm B in a Box-Cox transformed scale. Different characters in subscript represents significantly different values ($p < 0.05$) between the levels for each factor

Resting Area	Farm A		
Fixed Effects	G1 (n = 83)	G2 (n = 80)	Farm B (n = 201)
	Estimate	Estimate	Estimate
Parity			
1	0	0	0_a
2	-0.27	0.48	0.32_b
3+	1.48	0.75	0.71_c
Lactation stage			
Early (7-49 DIM)	0_a		0
Mid (50-179 DIM)	3.36_b	0	0.11
Late (≥180 DIM)	$2.71_{a,b}$	0.45	0.13
Breed			
Crossbred	0	0	
Holstein	0.27	0.09	
Red Dairy Cattle	-0.55	-0.09	
Pregnancy status			
Open	0_a	0	0
Pregnant	-2.28_b	0.28	0.11
Estrus			
Not in estrus	0_a		0
In estrus	-1.92_b		-0.10
Udder health			
Low (0 – 130 000 SCC/ml)	0_a	0	
Mid (130 000 – 300 000 SCC/ml)	-3.42_b	0.73	
High (>300 000 SCC/ml)	$-0.92_{a,b}$	0.45	
Claw Health			
No remark	0	0	
Remark	-0.31	-1.15	
Residual Std. Dev	3.11	2.34	0.60

Time spent in area

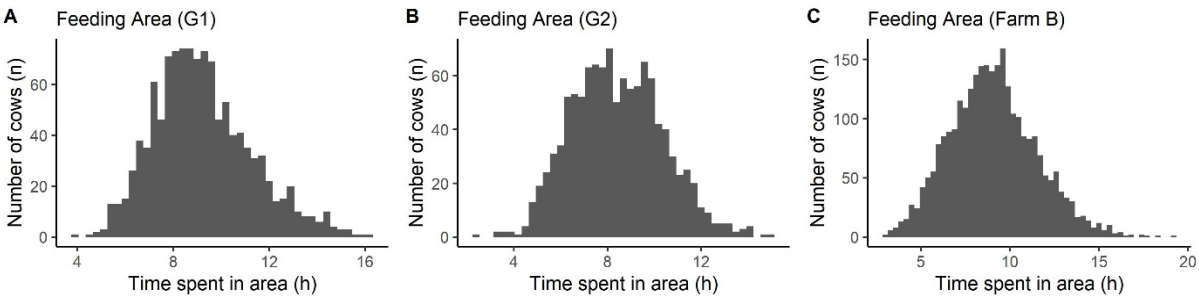

Figure S3. Distribution of the time spent in the feeding area for all three groups: A) for G1, B) for G2 and C) for Farm B.

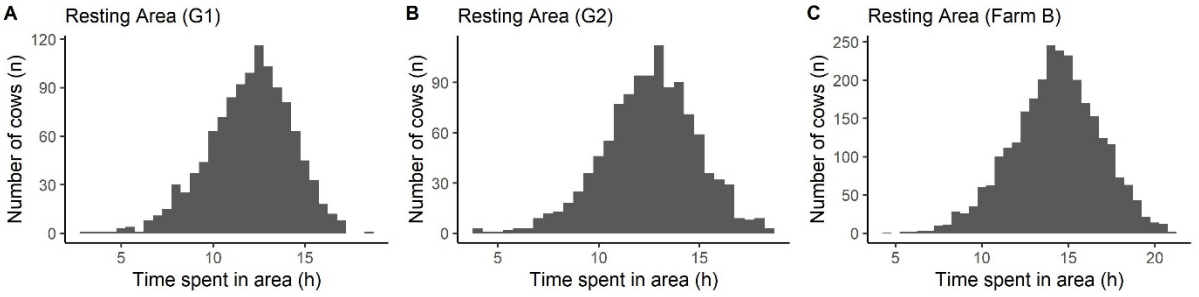

Figure S4. Distribution of the time spent in the resting area for all three groups: A) for G1, B) for G2 and C) for Farm B.

Table S4. P-values from the ANOVA test for the relation between the time spent in area and the individual traits in the feeding and resting area for all groups and farms

	Feeding Area			Resting Area		
	Farm A		Farm B	Farm A		Farm B
Trait	G1 (n = 83)	G2 (n = 80)	(n = 201)	G1 (n = 83)	G2 (n = 80)	(n = 201)
Date	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Parity	0.001	0.006	< 0.001	0.013	0.196	< 0.001
Lactation stage	0.025	0.303	0.934	0.011	0.512	0.801
Breed	0.769	0.215		0.757	0.569	
Pregnancy status	0.139	0.835	0.017	0.490	0.672	0.011
Estrus	0.138		0.382	0.088		0.234
Udder Health	0.775	0.204		0.515	0.177	
Claw Health	0.770	0.558		0.929	0.849	

Table S5. Summary of the estimated regression coefficients and significance of the individual traits on time spent in the feeding area. Results are shown for G1 and G2 in Farm A and Farm B in a Box-Cox transformed scale. Different characters in subscript represents significantly different values ($p < 0.05$) between the levels for each factor

Feeding Area	Farm A		
Fixed Effects	G1 (n = 83)	G2 (n = 80)	Farm B (n=201)
	Estimate	Estimate	Estimate
Parity			
1	0_a	0_a	0_a
2	-0.06_a	-0.46_b	-0.31_b
3+	-0.22_b	-0.63_b	-0.58_b
Lactation stage			
Early (7-49 DIM)	0_a		0
Mid (50-179 DIM)	-0.15_b	0	0.01
Late (≥180 DIM)	-0.23_b	-0.20	0.05
Breed			
Crossbred	0	0	
Holstein	-0.03	-0.25	
Red Dairy Cattle	-0.04	-0.27	
Pregnancy status			
Open	0	0	0_a
Pregnant	-0.06	0.04	-0.23_b
Estrus			
Not in estrus	0		0
In estrus	0.05		0.07
Udder health			
Low (0 – 130 000 SCC/ml)	0	0	
Mid (130 000 – 300 000 SCC/ml)	0.04	-0.40	
High (>300 000 SCC/ml)	0.03	-0.22	
Claw Health			
No remark	0	0	
Remark	-0.02	0.17	
Residual Std. Dev	0.17	0.50	0.66

Table S6. Summary of the estimated regression coefficients and significance of the individual traits on time spent in the resting area. Results are shown for G1 and G2 in Farm A and Farm B in a Box-Cox transformed scale. Different characters in subscript represents significantly different values ($p < 0.05$) between the levels for each factor

Resting Area	Farm A		
Fixed Effects	G1 (n = 83)	G2 (n = 80)	Farm B (n = 201)
	Estimate	Estimate	Estimate
Parity			
1	0_a	0	0_a
2	$-3.46_{a,b}$	2.31	2.83_b
3+	$4.09_{a,c}$	3.63	4.32_b
Lactation stage			
Early (7-49 DIM)	0_a		0
Mid (50-179 DIM)	7.88_b	0	0.33
Late (≥180 DIM)	10.21_b	1.29	-0.22
Breed			
Crossbred	0	0	
Holstein	1.64	1.91	
Red Dairy Cattle	1.69	0.58	
Pregnancy status			
Open	0	0	0_a
Pregnant	1.33	-0.82	1.73_b
Estrus			
Not in estrus	0_a		0
In estrus	-2.68_b		-0.67
Udder health			
Low (0 – 130 000 SCC/ml)	0	0	
Mid (130 000 – 300 000 SCC/ml)	-3.41	4.35	
High (>300 000 SCC/ml)	-0.04	2.34	
Claw Health			
No remark	0	0	
Remark	0.76	0.59	
Residual Std. Dev	8.18	5.14	5.01

Supplementary Material 3

Distributions and correlations for the response variable *contact rate* when the distance threshold is changed from 2.5 m to either 1.5 m or 3.0 m, and the threshold for accumulated duration of contacts is changed from 10 minutes to 20 or 30 minutes are presented here.

The primary distance threshold of 2.5 m was chosen as it is approximately one body length and captures pairs of cows when one cow is standing in front of the other. The lower threshold of 1.5 m was chosen as it captures cows very close to each other. The longer threshold distance of 3 m was chosen because it encompasses the outer boundaries of two neighbouring cubicles and therefore captures all possible interactions between neighbouring cows in the cubicle area.

When the time threshold was changed from 10 minutes to 30 minutes for group G1 (Farm A) in the feeding area the correlation was 0.77 (Figure S15 panel A), and among the lowest correlations investigated. (Feeding area group G2 had a slightly lower correlation but several values equal to 0 for the 30-minute threshold caused difficulties in comparing model results since the Box-Cox transformation is not uniquely defined for outcome values equal to 0, see Figure S15 panel B.) In Table S1, the changes in p-values are compared for the two time thresholds. The results show that the same explanatory variables (date and parity) are significant at the 5% significance level, except for lactation stage and estrus where the p-value changed from 0.013 to 0.189 for lactation stage and from 0.002 to 0.069 for estrus.

When the distance threshold was changed from 2.5 m to 1.5 m for group G2 (Farm A) in the resting area the correlation was 0.83 (Figure S4) and among the lowest correlations investigated. In Table S2, the changes in p-values are compared for the two distance thresholds. The results show that the same explanatory variables (date and claw health) are significant at the 5% significance level.

Table S1. P-values from the ANOVA test for the relation between the contact rate and the individual traits in the feeding area for G1 in Farm A, using a 30 min threshold for the accumulated duration of contacts, compared to the results in the main text for a 10 min threshold.

	G1 (n=83) Farm A	
	Feeding Area	
Trait	30 min [a]	10 min
Date	< 0.001	< 0.001
Parity	< 0.001	< 0.001
Lactation stage	0.189	0.013
Breed	0.182	0.468
Pregnancy status	0.951	0.319
Estrus	0.069	0.002
Udder Health	0.847	0.967
Claw Health	0.229	0.109

[a] Two records where the contact rate was equal to zero were removed to enable a Box-Cox transformation.

Table S2. P-values from the ANOVA test for the relation between the contact rate and the individual traits in the resting area for group G2 (Farm A) using a 1.5 m distance threshold, compared to the results in the main text for a 2.5 m distance threshold.

	G2 (n=80) Farm A	
	Resting Area	
Trait	1.5 m [a]	2.5 m
Date	< 0.001	< 0.001
Parity	0.946	0.999
Lactation stage	0.825	0.646
Breed	0.791	0.815
Pregnancy status	0.382	0.583
Estrus		
Udder Health	0.748	0.936
Claw Health	0.034	0.008

[a] One record where the contact rate was equal to zero was removed to enable a Box-Cox transformation.

Distance threshold: 1.5 m

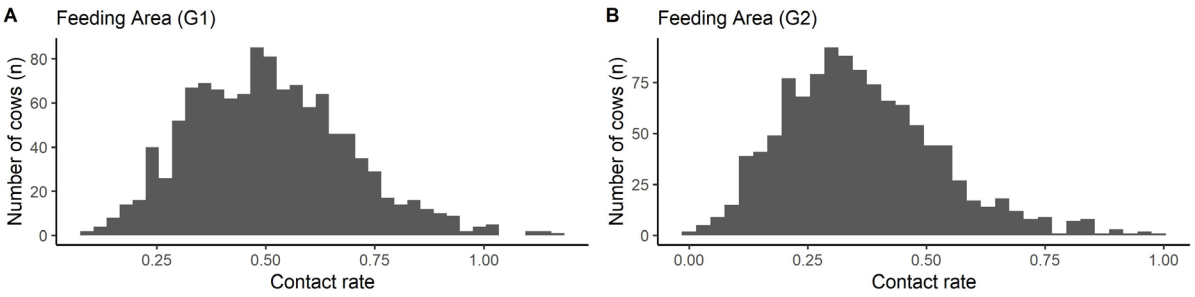

Figure S1. Distribution of the contact rate in the feeding area for the two groups in Farm A, with a distance threshold of 1.5 m: A) for G1, B) for G2.

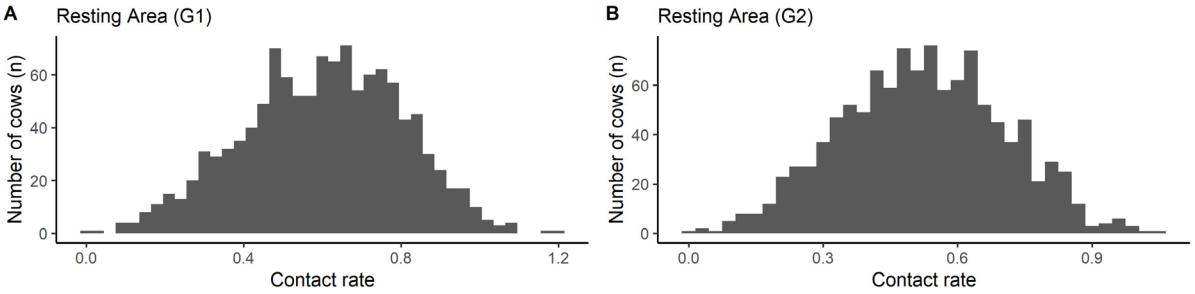

Figure S2. Distribution of the contact rate in the resting area for the two groups in Farm A, with a distance threshold of 1.5 m: A) for G1, B) for G2.

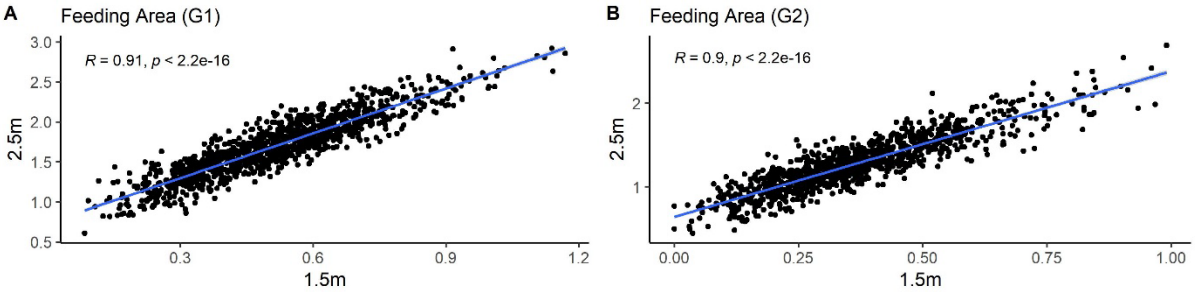

Figure S3. Correlation plot of the contact rate using either a distance threshold of 1.5 m or 2.5 m, in the feeding area: A) for G1, B) for G2.

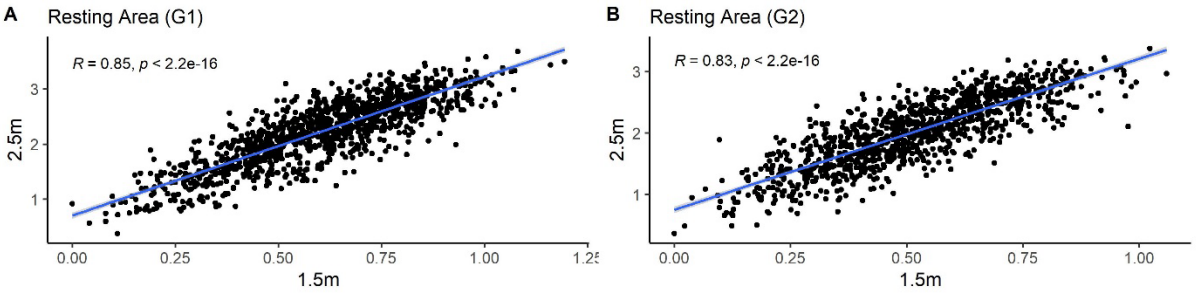

Figure S4. Correlation plot of the contact rate using either a distance threshold of 1.5 m or 2.5 m, in the resting area: A) for G1, B) for G2.

Distance threshold: 3.0 m

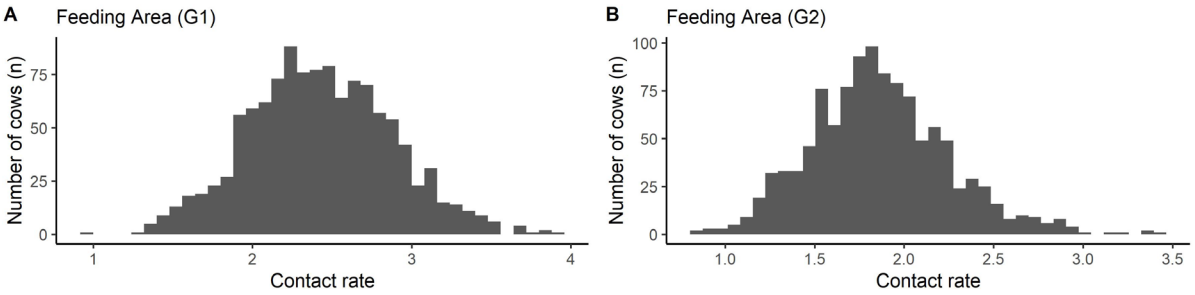

Figure S5. Distribution of the contact rate in the feeding area for the two groups in Farm A, with a distance threshold of 3.0 m: A) for G1, B) for G2.

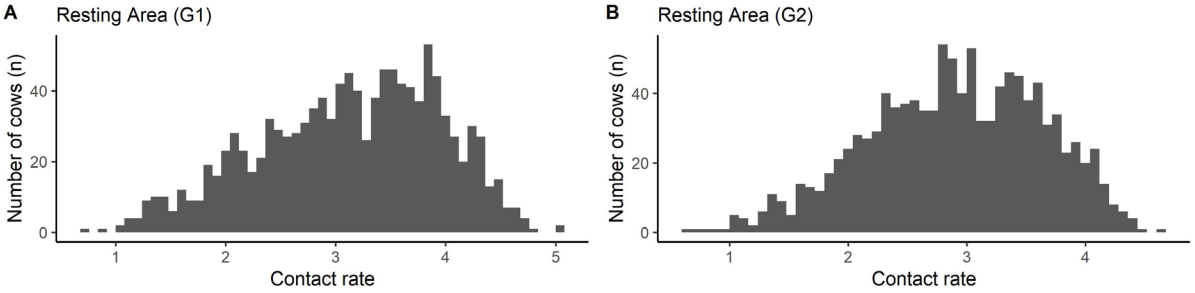

Figure S6. Distribution of the contact rate in the resting area for the two groups in Farm A, with a distance threshold of 3.0 m: A) for G1, B) for G2.

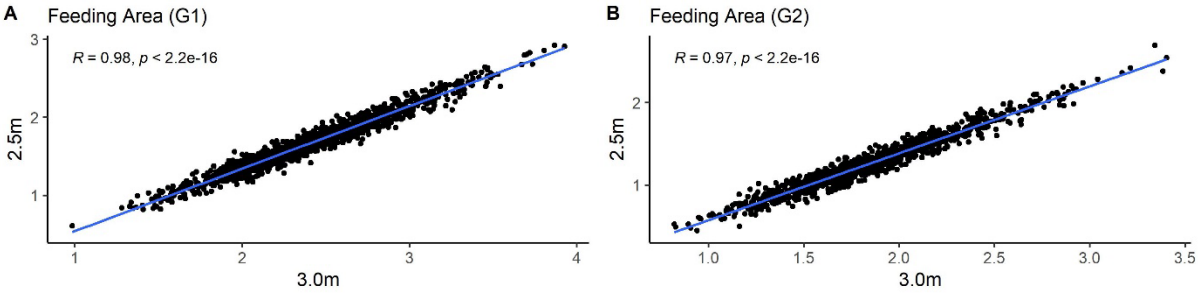

Figure S7. Correlation plot of the contact rate using either a distance threshold of 2.5 m or 3.0 m, in the feeding area: A) for G1, B) for G2.

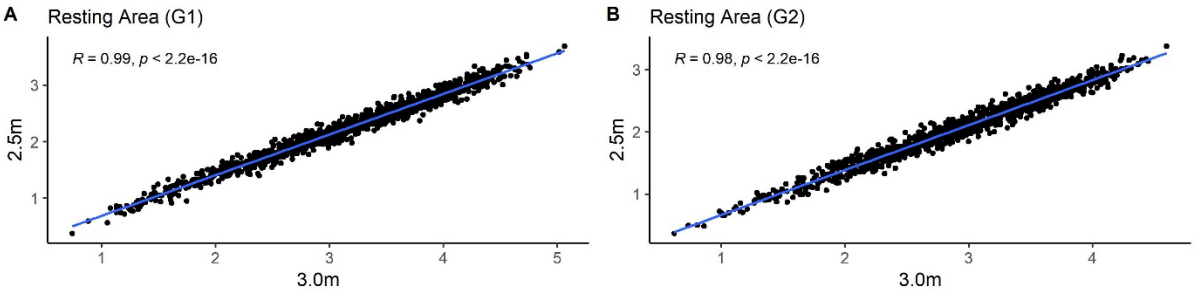

Figure S8. Correlation plot of the contact rate using either a distance threshold of 2.5 m or 3.0 m, in the resting area: A) for G1, B) for G2.

The accumulated duration of contacts: 20 Min

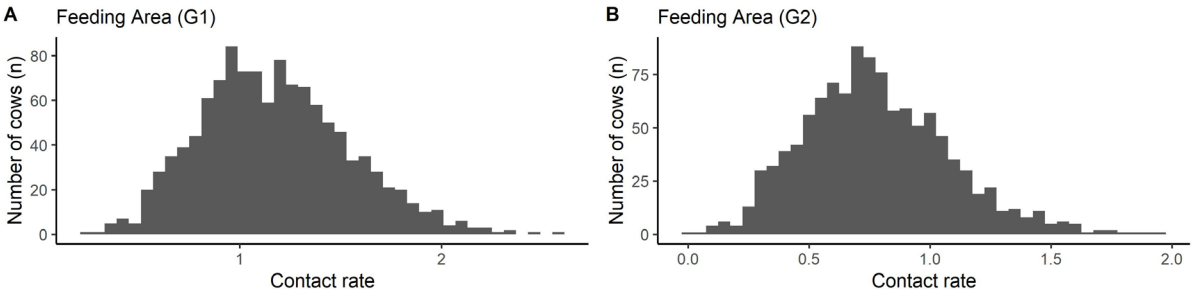

Figure S9. Distribution of the contact rate in the feeding area for the two groups in Farm A, with the accumulated duration of contacts set to 20 Min: A) for G1, B) for G2.

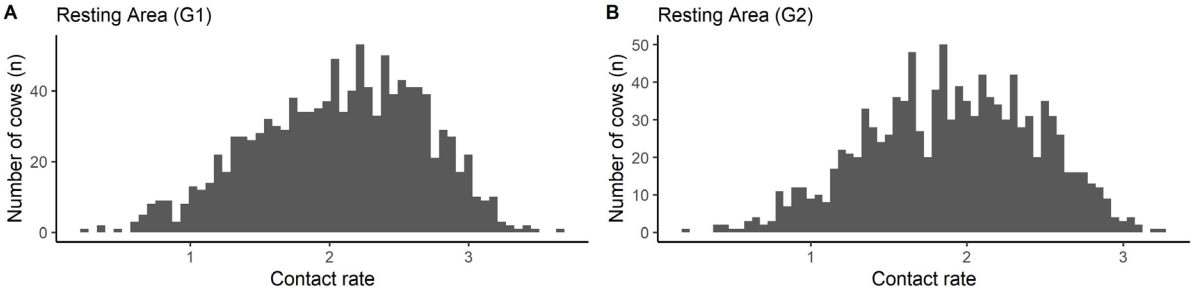

Figure S10. Distribution of the contact rate in the resting area for the two groups in Farm A, with the accumulated duration of contacts set to 20 Min: A) for G1, B) for G2.

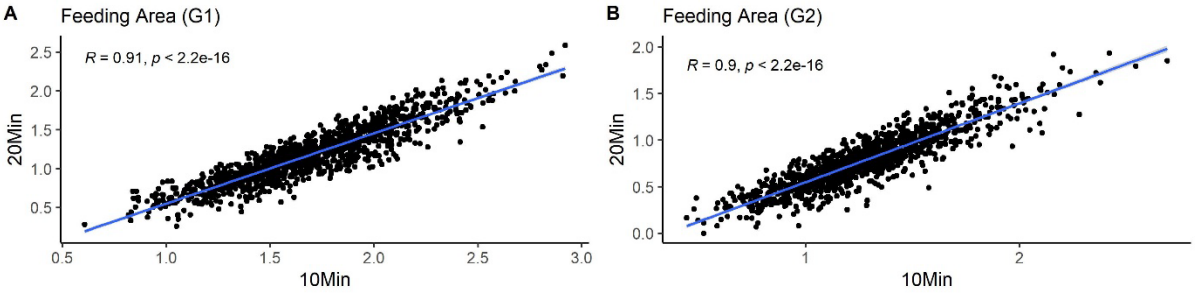

Figure S11. Correlation plot of the contact rate using either an accumulated duration of contacts threshold of 10 Min or 20 Min, in the feeding area: A) for G1, B) for G2.

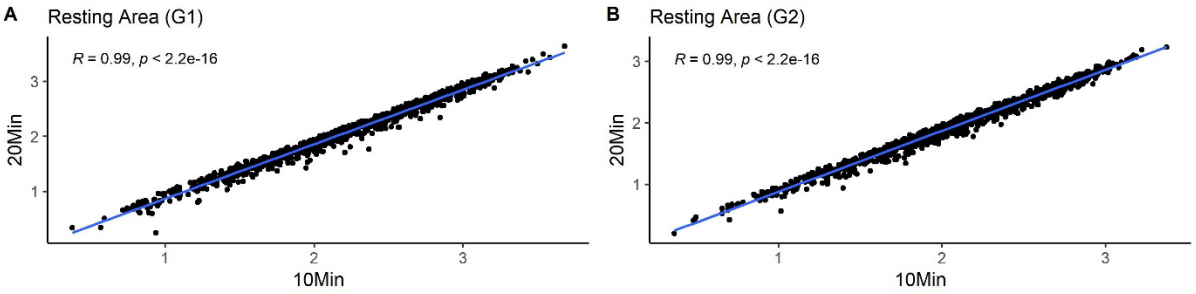

Figure S12. Correlation plot of the contact rate using either an accumulated duration of contacts threshold of 10 Min or 20 Min, in the resting area: A) for G1, B) for G2.

The accumulated duration of contacts: 30 Min

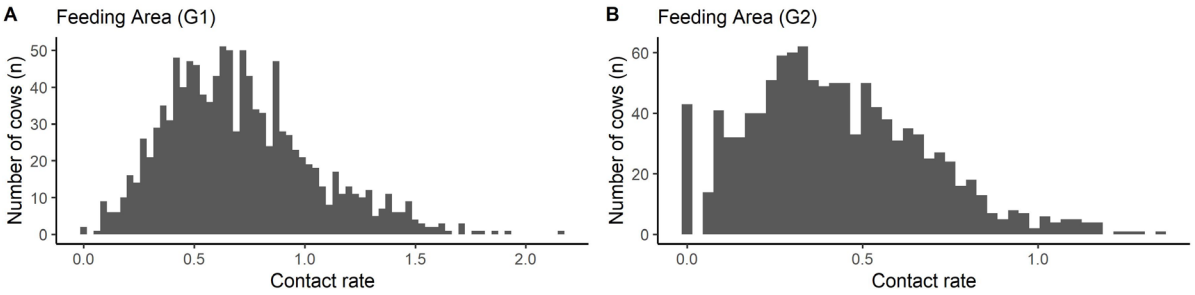

Figure S13. Distribution of the contact rate in the feeding area for the two groups in Farm A, with the accumulated duration of contacts set to 30 Min: A) for G1, B) for G2.

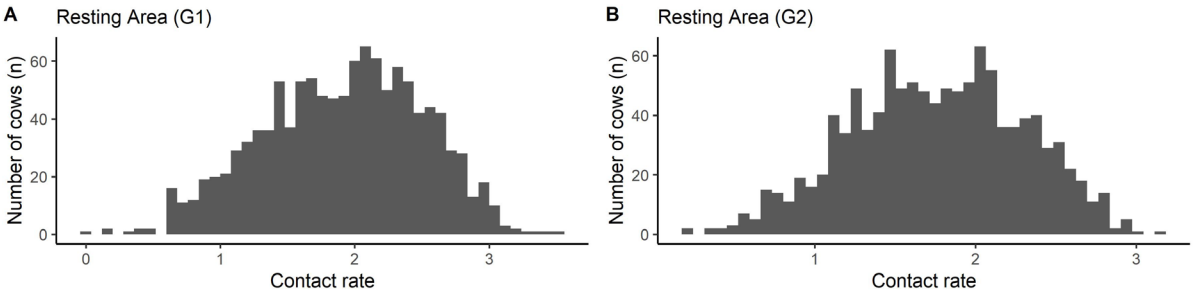

Figure S14. Distribution of the contact rate in the resting area for the two groups in Farm A, with the accumulated duration of contacts set to 30 Min: A) for G1, B) for G2.

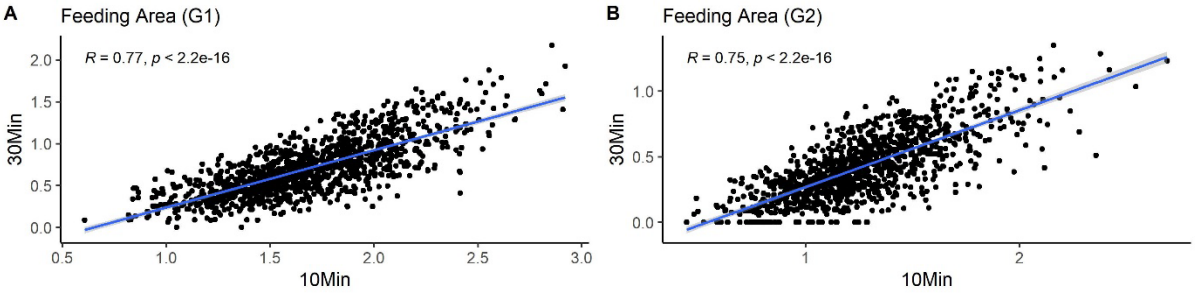

Figure S15. Correlation plot of the contact rate using either an accumulated duration of contacts threshold of 10 Min or 30 Min, in the feeding area: A) for G1, B) for G2.

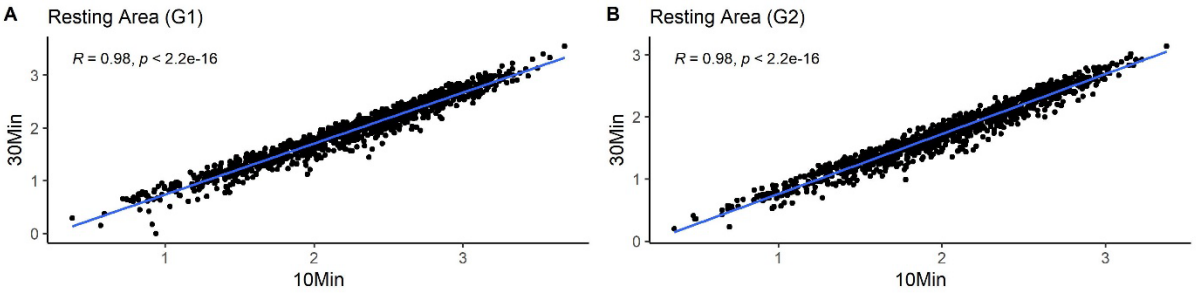

Figure S16. Correlation plot of the contact rate using either an accumulated duration of contacts threshold of 10 Min or 30 Min, in the resting area: A) for G1, B) for G2.