THE LOCOMOTION OF DAIRY COWS IN PASSAGEWAYS WITH DIFFERENT LIGHT INTENSITIES

C J C Phillips[1,2†], I D Morris[2], C A Lomas[2] and S J Lockwood[2]

[1] Department of Clinical Veterinary Medicine, University of Cambridge, Cambridge CB3 0ES, UK

[2] School of Agricultural and Forest Sciences, University of Wales, Bangor LL57 2UW, UK

[†] Contact for correspondence and requests for reprints.

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Abstract *Animal Welfare 2000, 9:* 421-431

Guidelines for the housing of dairy cows do not address the provision of supplementary lighting in passageways, other than for inspection of the animals. Two experiments were conducted to investigate whether lighting passageways to various intensities influenced the locomotion of dairy cows. The first experiment compared the locomotion of dairy cows in a dark or lighted passageway as they walked back to their accommodation from milking. When the passageway was dark, the cows took shorter but more rapid steps – which probably increased their stability. In the second experiment, cows walked down a cubicle passageway to receive a food reward, with the light intensity in the building varying from 0–250 lux. Step length and stepping rate were recorded, as well as the angles of the cows' leg joints (which were measured from video recordings). Once again, the cows increased their stepping rate in the dark, and this resulted in an increased walking rate, perhaps because they wished to return more rapidly to other members of their group and found the darkness aversive. In addition, the arcs of travel of the metacarpophalangeal joint and of the fore- and hindfeet angles to the floor were reduced in the dark, probably increasing the cows' stability, and were greatest at 119 lux. The slowest walking rate was observed at 39 lux. Hence, the optimum illumination for dairy cow locomotion may lie approximately between 39 and 119 lux, as measured by our technique.

We conclude that during locomotion in dark passageways cows have to modify their walking behaviour significantly, so that the provision of at least a low level of lighting is desirable at night.

Keywords: *animal welfare, dairy cow, light intensity, locomotion*

Introduction

Most recommendations for the welfare of dairy cows do not include advice on the provision of supplementary light for housed cows, although the *UK Codes of Recommendation for the Welfare of Cattle* suggests that consideration should be given to providing 'light during the hours of daylight, and lighting readily available to enable the animals to be inspected at any time' (Ministry of Agriculture, Fisheries and Food *et al* 1983). In extreme latitudes, dairy cows may be kept inside in the dark for two-thirds of the day during winter, and their welfare may suffer if a combination of high stocking densities and the absence of light impedes normal behaviour. Grazing dairy cows are reluctant to feed at night, only doing so if they are unable to obtain sufficient food during daylight hours (Phillips & Denne 1988). The conserved food offered to housed dairy cows is consumed much faster than fresh grass can be grazed by outdoor cows (Phillips & Leaver 1986), but aggression at the feeding trough during the day forces some subordinate cows to feed at night. Providing supplementary light at night encourages more cows to feed at this time (Phillips & Schofield 1989) and may increase the confidence that the cows have in moving around a crowded building. Hence, although individually tethered or stalled cattle show only a slight preference for performing certain behaviours in the light, principally feeding (Phillips & Arab 1998), loose-housed cattle are more affected by supplementary light, and alter their behaviour patterns to take account of the extended day (Phillips & Schofield 1989; Weiguo & Phillips 1991). Movement around the building is likely to be affected, especially to and from feed supplies, with dairy cows strongly avoiding dark passageways (Morris 1994).

Dairy cows have large eyes with a high concentration of rods (approximately five or six rods to one cone at the periphery [Rochon-Duvigneaud 1943]), and a tapetum (light reflecting layer), and are, therefore, well adapted to low light levels. They do not have a fovea for object discrimination at a point, as humans do, but possess a broad band of high retinal cell density that we assume gives them good vision on the horizon (Heffner & Heffner 1992). The response of dairy cows to different light intensities in passageways has not been studied before. The visual acuity of calves is reduced at light intensities of less than 2 lux (Eiermann 1978). There is also behavioural evidence of greater object recognition at 100–130 lux than at 2–20 lux, since Dannenmann *et al* (1985) found that penned calves were more socially active at high light intensities (100–130 lux), although one cannot eliminate photostimulation as an explanation for their observation. Brightness discrimination in calves is not as good as in humans (Phillips & Weiguo 1991).

Two experiments were conducted to examine the effects of lighting passageways to various intensities on the locomotion of dairy cows. Experiment 1 took place on return from milking, down a passageway which the dairy cows normally traversed rapidly to return to their accommodation for food; Experiment 2 took place in a cubicle building, with dairy cows walking down a passageway to obtain a small food reward.

Materials and methods

Experiment 1: Locomotion of cows down a brightly lit or unlit passageway on return from milking

Sixteen, early lactation, British Friesian dairy cows of even gait were selected for an investigation of the effect of lighting a passageway on their locomotion. The 3m-wide passageway chosen for the study was that used by the cows to return to their accommodation after milking. While the cows were out of the building, a complete diet was made available at the feeding barrier in their accommodation, so that they normally proceeded down this passageway quickly in order to reach the food. The experimental passageway was bounded by solid walls and a roof without skylights and had a smooth concrete floor, which had a light covering of slurry during the tests. Measurements were conducted after the afternoon milking between 16 November and 14 December, when there was no natural or artificial light in the passageway other than that used in the lighted treatment.

On alternate days, the cows were recorded after the afternoon milking as they walked individually down the passageway either with, or without, supplementary light. Six replications of each treatment were conducted on 12 days. The light was provided by a single 500W halogen lamp in the centre of the passageway. The mean light intensity was 259 lux. This was recorded with a spectroradiometer (Macam Digital Spectroradiometer SR 3000, fitted with a cosine corrected Photometric Adaptor; Macam Photometrics, Livingston, Scotland) in the six directions of the faces of a cube at cow eye-level. Cows were held in a race at the beginning of the passageway for approximately 20min, during which time they accustomed themselves to the light in the passageway, before being released individually from a crush at the end of the race to the passageway. The number of steps and the time taken for the hindlimb of each cow to traverse a marked 14m length of the passageway, starting 3m after the crush, were recorded by observers who were obscured from the cows' view. (A step was defined as the sequence of movements between one lift phase of one of the hindlimbs and the next.) From these measurements, the cows' stepping rate, step length (the distance covered between two consecutive lift phases of the same limb) and speed were calculated.

Statistical analysis

After ensuring normality of the data (Ryan *et al* 1985), the significance of light treatment was examined by a two-way analysis of variance (ANOVA) with treatment and cow number as factors in the model (Ryan *et al* 1985). Pearson product-moment correlation coefficients were calculated between the locomotion variables.

Experiment 2: Effect of light intensity on cow locomotion in a cubicle passageway

Five, mid-lactation, British Friesian cows in their third to fifth lactation and with an even gait were selected for this study of their locomotion in a passageway under different levels of supplementary lighting up to 250 lux. An experimental cubicle building with two, 20x2.5 m concrete aisles and two rows of 12 cubicles was used for this experiment (Figure 1). One aisle ran between the two rows of cubicles, the other between a cubicle row and a row of feeding troughs. The cubicles adjacent to aisle 1 were blocked off to prevent entry by the cows and only the cubicles between gates 1 and 2 could be accessed by them. The two aisles were connected at each end of the building by a short passageway so that the cows could complete a circuit around one of the cubicle rows. All passageways in the building were of recently laid tamped concrete, with no surface contamination with slurry or urine. The coefficient of static friction of this floor was 0.55 (Phillips & Morris in press), considerably above the value (0.4) at which cattle become more likely to slip (Irps 1981).

A gate was placed to restrain each cow before she started walking down the first aisle. The cow was released down the aisle, in the second half of which her locomotive behaviour was recorded, and then she progressed along the passageway connecting the two aisles and returned by the second aisle. At the end of this passageway and the start of the second aisle a feed reward of approximately 50g of concentrate was placed in a trough. The positioning of the reward ensured that her walking movements in the first aisle were not influenced by her proximity to the reward. After receiving her reward, the test cow was allowed to join the other cows in an area with cubicles and food provided in individual troughs. The cows were trained daily for 2 weeks to complete the circuit and collect the reward.

During the experiment, six light levels (0, 0.7, 4.3, 31.8, 118.8 and 250.5 lux) were created in the building by the following, respective, luminaires placed to produce the most

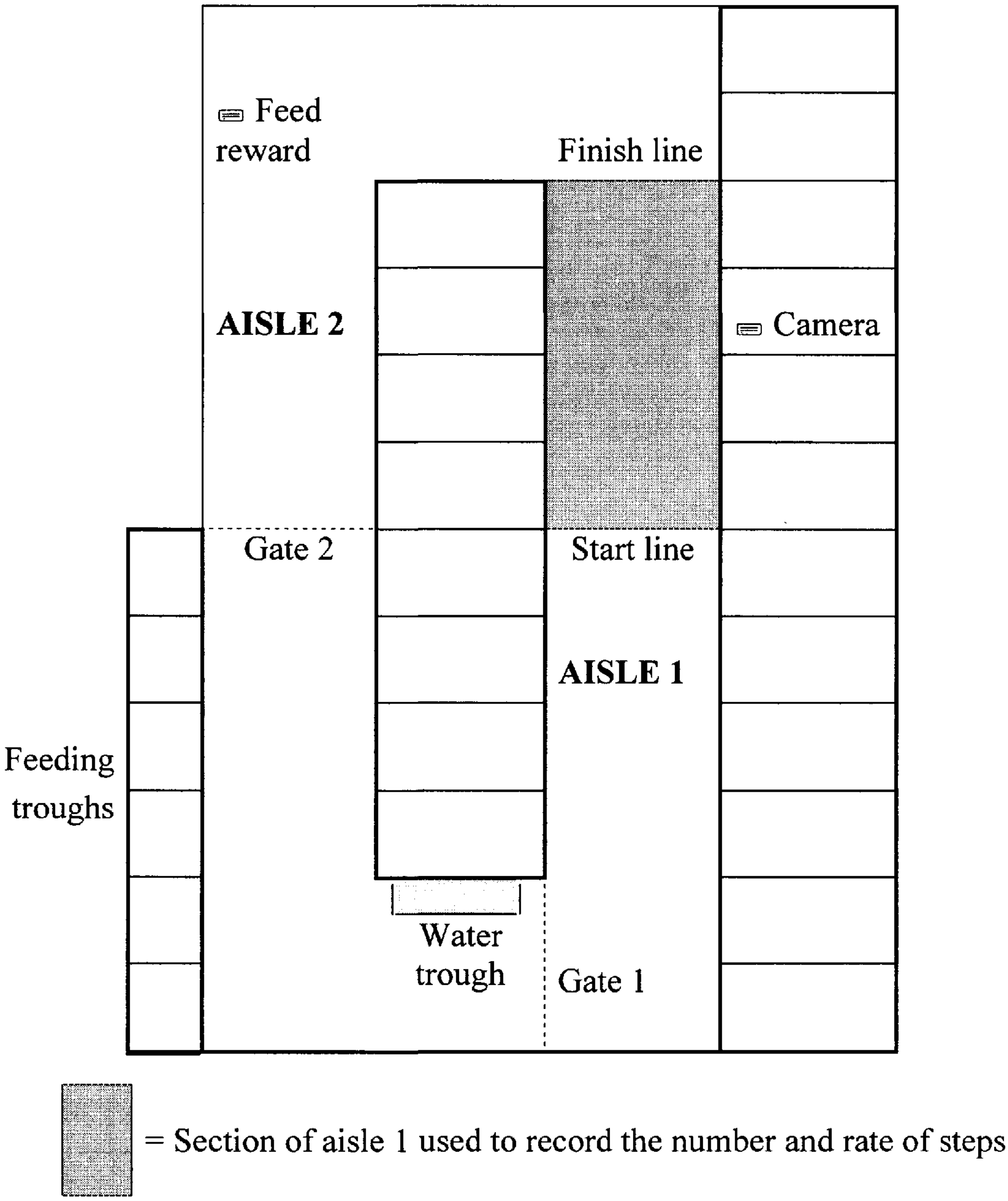

Figure 1 **Overhead elevation of the building used for Experiment 1.**

even light distribution over the building: none, two 25W tungsten filament bulbs, two 100W tungsten filament bulbs, four 80W fluorescent tubes, sixteen 80W fluorescent tubes and thirty-two 80W fluorescent tubes. (Tungsten filament light sources were used for low light intensities because of the difficulty of producing low light intensities with fluorescent sources.) Light intensity was measured on two occasions by the method described in Experiment 1. These lighting levels were chosen as they were approximately on a log linear scale, providing more treatment comparisons at lower lighting levels, and also because they were relevant to possible levels that could be provided in dairy cow sheds. The mean ratio of light intensities recorded using the 'box' technique (Smith 1988), was 28:10:1 for measurements in the upwards, sideways and downwards directions.

The zero light intensity treatment reflected conditions in an unlit building. The next two lowest light intensities were close to that reported by Eiermann (1978) to be the minimum intensity (2 lux) at which dairy cows can distinguish objects. The next highest intensity (32 lux) was close to the mean level recommended in European countries (Table 1), with the next highest level (119 lux) being approximately the highest level recommended in Europe and also the level at which acuity appears to be improved, compared with 2–20 lux (Dannenman *et al* 1985). The highest level (250 lux) was chosen to represent a level at which object discrimination would probably be further improved but was still within the boundaries of the amount of light that could realistically be provided in dairy cow buildings.

Table 1 Recommended minimum lighting levels in dairy cow buildings in various European countries.

Country	Minimum recommended intensity (lux)	Reference
France	30	Blommaert and Van de Velde (1984)
Germany	20	Dannenmann *et al* (1985)
Switzerland	60–120	Rist *et al* (1974)
United Kingdom	20[1]	Electricity Council (1977)

[1] Providing adequate daylight enters the building, otherwise 50 lux is recommended.

Tests were conducted on 6 days, beginning at 1800h, with three light levels tested on each evening in a changeover design which provided three replicates of the measurements at each intensity. The cows were allowed a period of 30min to adjust to the light level before each test. At other times, the test cows remained with the rest of the herd in another cubicle building where they were fed a complete diet (68% silage, 22% wheat distillers' grains, 7% molasses, 2% barley and 0.3% mineral and vitamin supplement) available *ad libitum*; and with fresh food being offered daily.

Measurements

During the passage of each cow down the first aisle, the number of steps and time taken to complete the last 7m of the aisle were recorded with a stopwatch. A video camera (Panasonic WV-1450/B; Mitsushita, Uxbridge, Middlesex) was positioned three-quarters of the way down the aisle. With the aid of a video recorder (Hitachi VT-L30ED-UK; Hitachi, Hayes, Middlesex), this recorded one support phase[1] of the left fore- and hindlimbs as the cow passed. Infrared light was provided in all treatments to aid identification of limb action when the light intensity was low. The elbow, carpal and metacarpophalangeal joints of the forelimb and the stifle, tarsal and metatarsophalangeal joints of the hindlimb (Figure 2) were marked with a spot of blue paint at the fulcrum to aid identification of the centre point of the joint during angle measurements. The video recordings were replayed on a flat television screen

[1] Lasting from placement of the hoof on the floor until lifting of the hoof at the end of the stride.

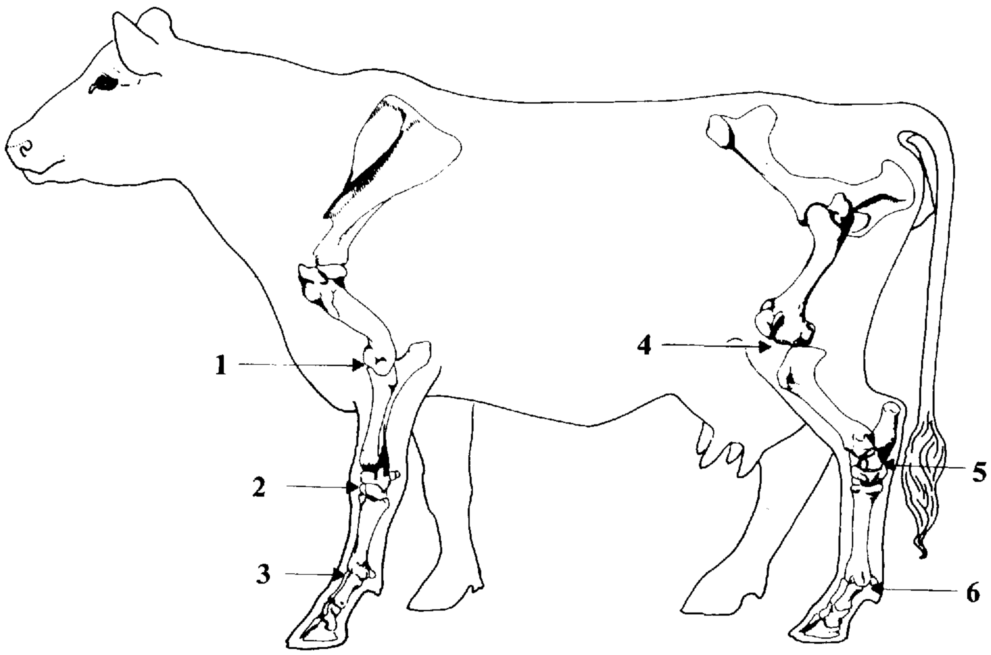

Figure 2 **Location of the limb joints for which movement was recorded in Experiment 2. 1 – elbow; 2 – carpal; 3 – metacarpophalangeal; 4 – stifle; 5 – tarsal; 6 – metatarsophalangeal. (Modified from Figure 9.1 in Blowey R W, *A Veterinary Book for Dairy Farmers*, and reproduced with the permission of Farming Press, Ipswich, UK.)**

and the angle of each joint to the horizontal at the start and end of the supporting phase of a step were recorded, as well as the angle between the heel of the fore- and hindfeet and the floor ('foot angle'), which is a reflection of the combined angles of the proximal and distal inter-phalangeal joints. This technique has been used successfully to identify changes in the leg action of dairy cows on different floors (Phillips & Morris in press).

Statistical analysis

The data on cow movement and leg angles were subjected to the Anderson-Darling test (Ryan *et al* 1985) and found to be normally distributed. They were then subjected to an ANOVA, with treatment (nested within replicate and circuit), replicate, cow and circuit (nested within replicate) as factors in a generalized linear model, constructed within the Minitab® statistical package (Ryan *et al* 1985).

Results

Experiment 1

Cows took significantly longer strides at a lower stepping rate when light was provided, with their walking rate being unaffected (Table 2). There was a high Pearson product-moment correlation coefficient ($r = 0.94$, $P < 0.01$) between stepping rate and walking rate.

Table 2 **Comparison of the locomotory behaviour of dairy cows walking down a lighted or unlighted passageway in Experiment 1. (ns – not significant.)**

	Lighted	Unlighted	SED[1]	*P* value
Walking rate (m s^{-1})	0.90	0.90	2.57	ns
Step length (m)	68.3	64.8	0.73	< 0.001
Stepping rate (step s^{-1})	1.31	1.39	0.038	0.01

[1] Standard error of the difference between any two means.

Experiment 2

There was no significant ($P < 0.05$) effect of circuit number on the measured parameters, suggesting that the cows did not change their behaviour systematically over time. The walking rate was fastest when no supplementary light was provided (Table 3). As light intensity increased, the walking rate declined to a minimum at 32 lux and then increased at higher intensities. These differences were due to changes in the stepping rate, with step length remaining unchanged.

The movements of the upper forelimb joints were not affected by light intensity. However, the arcs of travel of the metacarpophalangeal joint and of the forefoot:floor angle were greatest under 119 lux conditions and considerably reduced in the dark, compared with the treatments where some light was provided. In the metacarpophalangeal joint this was principally due to changes in the joint angle at the end of the stride (E), with the lower limb being held more vertically at this point in the dark than in the other treatments. However, for the arc of travel of the forefoot:floor angle, this was due to changes at the start of the stride, with the angle being less vertical in bright light conditions.

In the hindlimb, significant effects of light intensity on movement were only observed at the hindfoot:floor junction, with the arc of travel of the foot increasing with light intensity up to 119 lux. This was due to an increase in the angle at which the hindfoot was placed on the floor as light intensity increased.

Discussion

Both experiments demonstrated that cows adopt a faster stepping rate when walking in the dark. However, it was only in Experiment 2 that this resulted in a faster walking rate. This may have been because the cows could safely increase speed on the better surface that was provided in this experiment. The increase in stepping rate and reduction of step length in Experiment 1 probably represented the safest strategy for maintaining speed in dark conditions, when the motivation of the cows to traverse the passageway was high but the risk of encountering obstacles or slipping was increased. The strong correlation between stepping rate and walking rate supports the contention that stepping rate was increased to maintain speed – which would normally be reduced with declining step length.

Experiment 2 demonstrated that cows place their fore- and hindfeet more vertically in the dark, presumably to avoid slipping. The cows in Experiment 1 probably walked faster than those in Experiment 2 because of their eagerness to return to their accommodation after milking, when they would normally feed for an extended period. They may have been conscious of the fact that any delay in the return to their accommodation and feed, caused by the test, could have disadvantaged them in competition with other cows for food.

Table 3 Comparison of mean walking behaviour, angles of forelimb and hindlimb joints[1] to the horizontal and the arcs travelled by these joints during the support phase of a stride in Experiment 2. (S – start of stride; E – end of stride; arc – arc of travel; ns – not significant.)

Parameter	Light intensity						SED[2]	*P* value
	0	0.7	4	32	119	250		
Walking rate (m s⁻¹)	0.70	0.655	0.64	0.62	0.65	0.64	0.009	0.001
Step length (m)	1.2	1.2	1.2	1.2	1.2	1.2	0.04	ns
Stepping rate (step s⁻¹)	0.56	0.52	0.51	0.50	0.53	0.52	0.004	< 0.01
Forelimb								
Elbow joint S, °	74	73	73	73	72	72	0.39	ns
Elbow joint E, °	117	116	117	116	115	114	0.58	ns
Elbow joint arc, °	43	43	44	44	43	43	0.57	ns
Carpal joint S, °	106	107	107	107	107	108	0.38	ns
Carpal joint E, °	63	63	63	63	65	66	0.56	ns
Carpal joint arc, °	43	44	44	44	43	43	0.57	ns
Metacarpophalangeal joint S, °	106	105	106	105	107	106	0.42	0.06
Metacarpophalangeal joint E, °	60	55	56	55	53	54	0.73	< 0.01
Metacarpophalangeal joint arc, °	46	50	50	51	55	52	0.81	< 0.01
Forefoot:floor S, °	127	128	128	128	134	134	0.89	0.001
Forefoot:floor E, °	90	85	85	86	86	90	1.4	ns
Forefoot:floor arc, °	38	42	43	42	49	44	1.2	0.02
Hindlimb								
Stifle joint S, °	86	87	87	87	87	88	0.42	ns
Stifle joint E, °	132	132	132	131	134	133	0.42	0.08
Stifle joint arc, °	45	45	45	45	48	45	0.53	ns
Tarsal joint S, °	94	93	93	93	93	92	0.43	ns
Tarsal joint E, °	48	48	48	48	46	47	0.43	ns
Tarsal joint arc, °	45	45	45	45	48	45	0.54	ns
Metatarsophalangeal joint S, °	119	120	119	119	121	120	0.66	ns
Metatarsophalangeal joint E, °	70	72	72	70	72	72	1.26	ns
Metatarsophalangeal joint arc, °	49	48	48	48	49	48	0.57	ns
Hindfoot:floor S, °	133	133	135	136	140	140	0.62	< 0.001
Hindfoot:floor E, °	90	87	87	87	82	83	1.19	0.08
Hindfoot:floor arc, °	43	47	48	49	58	57	1.32	< 0.001

[1] Forefoot:floor and hindfoot:floor denote the 'foot angle' – the angle between the heel of the fore- or hindfoot and the floor and reflect the movement of the combined proximal and distal inter-phalangeal joints.

[2] Standard error of the difference between any two means.

The cows' stepping rate was lower in Experiment 2 than in Experiment 1. This was probably also due to a reduced motivation to traverse the passageway. Their step length in Experiment 2 was much greater, nearly twice that in Experiment 1, reflecting the better floor conditions, with nearly new concrete and an absence of excreta on the floor. The cows in darkness walked faster by increasing their stepping rate without altering step length, which would probably maintain the same risk of slippage or encountering obstacles. They demonstrated an increased motivation to complete the test sooner by their faster walking rate, probably due to the increased stress of traversing the passageway in the dark. The minimum speed and stepping rate occurred at 32 lux, which may represent an optimum in terms of the animals' comfort in locomotion. The arcs of travel of both the fore- and hindlimbs (ie of the metacarpophalangeal joint and of the fore- and hindfeet angles to the floor) were maximum at 119 lux. There was a decline in the arcs of travel of both the metacarpophalangeal joint and the forefoot:floor angle at 250 lux, so 119 lux may represent an optimum for object discrimination. The efficiency of limb movement is likely to be increased with greater arcs of travel of the joints, but the risk of slippage is increased. At greater arcs horizontal movement is maximized relative to the vertical movement, which represents wasted energy for forward propulsion.

Only the movements of the lower limb joints were affected by light conditions, as might be expected if the angle to the floor is the principal concern. On slippery floors dairy cows change the angle of their lower limb joints to become more vertical, thereby reducing the horizontal force which will initiate slipping (Morris 1994). For the reasons described in the *Introduction*, visual object discrimination may be limited at close range. This accords with observations of the cows' behaviour. The improvement in discrimination ability at high luminance levels may be a critical factor in determining the speed at which dairy cows walk.

The highest light intensity (250 lux), may have caused glare that prevented optimum object discrimination. In humans, glare impairs many visual functions – principally visual acuity (Dorley 1948), object contrast (Dorley 1948), accommodation (Peterson & Simonson 1952), brightness discrimination (Fry & Alpern 1955) and motion perception (Anderson & Holliday 1996). It is not known which of these effects occur in dairy cows, since some effects rely on stray light obscuring the fovea (Fry & Alpern 1955) which cattle do not possess. However, the eyes of cattle are located prominently in the head, with less protection from the overhead glare produced by low level luminaires than is normally afforded by the forehead in humans. The advantages of good peripheral vision in locating predators may predispose dairy cows to suffer from glare from bright luminaires at a low height.

Conclusions

Our study has demonstrated:

i) When dairy cows were walking quickly on a slippery floor, they reduced their length of step if the passageway was dark, to reduce their risk of slipping, and increased their stepping rate.

ii) When dairy cows were walking slowly on floors providing high levels of friction, they increased their rate of walking if the passageway was dark, by increasing their stepping rate. By this means they completed Experiment 2 faster and could return to the relative safety of their accommodation. At the same time, they tended to hold their lower limbs more vertically during the support phase of the stride, which probably increased the cows' stability and motion confidence.

iii) Confidence in locomotion may have increased with light intensity up to 32–119 lux, and then declined at 250 lux.

Animal welfare implications

When housed dairy cows walk in dark, their normal locomotory behaviour is disrupted. The research presented here, together with other published evidence (Phillips & Schofield 1989), suggests that they try to avoid being in dark passageways for longer than necessary. At the high stocking densities which prevail in modern dairy buildings, it may improve the welfare of these cows if farmers provide a low level of lighting in passageways at all times. The optimum intensity of this light may be between 32 and 119 lux, although the changes we observed in locomotory behaviour at intensities between 0.7 and 250 lux were small relative to the differences we observed in dairy cows' locomotion between unlit and lit conditions. Some preliminary evidence that the highest light intensity (250 lux) may have induced glare is presented.

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