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Sheep welfare in the virtual fencing system NoFence
- Trials 2012

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Sammendrag:

NoFence er et usynlig gjerdesystem og har en målsetting om å holde dyr innenfor en definert grense hvor tradisjonelle fysiske gjerder ikke er et alternativ. Systemet består av en klave med innebygd GPS-teknologi. Når et dyr med en aktivert klave passerer en, på forhånd programmert, grense vil klaven gi et lydsignal. Dersom dyret snur og går tilbake til beiteområdet stopper lydsignalet. Dersom dyret fortsetter å gå rett fram ut av beiteområdet vil klaven gi dyret et strømstøt gjennom to elektroder plassert på dyrets nakke. Bioforsk Økologisk har vært innleid til å gjennomføre en uavhengig evaluering av dyrevelferden ved bruk av dette systemet. Målet med forsøkene i 2012 har vært å evaluere om og hvordan NoFence påvirker dyrevelferden hos sau, og hvor raskt dyrene kan lære seg systemet.

Vi inkluderte 27 sau i et forsøk som ble trinnvis gjennomført. Ingen sau fikk fortsatte videre til neste trinn dersom de ikke besto innlæringskriteriet som var bestemt på forhånd. I første trinn skulle 27 sauer lokkes over en NoFence-grense maksimalt tre ganger. Innlæringskriteriet var at sauen maksimalt fikk to strømstøt, og dermed valgte å snu på lydsignalet den tredje gangen de ble forsøkt lokket over grensen. På grunn av tekniske problemer og stress blant dyrene var det kun 16 sauer som gjennomgikk denne testen. Av de 16 dyrene var det ni (56%) som klarte innlæringskriteriet (maksimalt to strømstøt). Disse ni dyrene ble delt inn i tre grupper med tre dyr i hver gruppe. Hver gruppe ble plassert på et beite i fem dager. I løpet av disse dagene ble den ene siden av gjerdet byttet ut med en NoFence-grense. Først med et fysisk gjerde utenfor NoFence-grensen, og deretter uten. På dag fem ble NoFence-grensen flyttet til den andre siden av beitet. Ale dyrene holdt seg innenfor NoFence-grensen de fire første dagene, og fikk i gjennomsnitt 1,9 strømkorrigeringer i løpet av fire dager. Da NoFence-grensen ble flyttet var det bare to av de tre gruppene som holdt seg innenfor beiteområdet. Den gruppen som krysset grensen hadde ikke et fysisk gjerde utenfor NoFence-grensen. For de to resterende gruppene ble det satt opp et fysisk gjerde utenfor NoFence-grensen. Første dagen dyrene gikk med NoFence-klave på seg spiste de mer og hvilte mindre enn da de gikk uten klave. Bortsett fra det ble det ikke funnet forskjell i dyrenes adferd med eller uten klave.

Konklusjon: Det virker som om dyrene har vanskelig med å forbinde lyd, strømstøt og ny grense dersom det ikke er satt opp et fysisk gjerde i tillegg til NoFence-grensen. I tillegg var det det kun 56 % av dyrene som gikk videre til trinn to i forsøket. I neste forsøk vil det være nødvendig å fokusere på innlæringsprosedyrer for systemet. I løpet av årets kontrollerte forsøk kunne vi ikke se at bruk av NoFence-systemet medførte redusert dyrevelferd.

Summary:

NoFence is a virtual fencing system with the aim of finding a solution to the problems with keeping animals within a predefined when physical fences not are an option. The system consists of a collar based on GPS technology. When an animal wearing an activated collar crosses a predefined border, a sound signal will be given. If the animals then turns and walks back into the grazing area, the sound signal will stop. If the animal instead continue to walk over the border, the collar will give the animals an electric correction through two electrodes placed on the neck of the animal. Bioforsk Økologisk was hired to perform an independent evaluation about the welfare situation among animals on NoFence pastures. The aim with the trials 2012 was hence to do a first evaluation if/how NoFence affects sheep welfare and how quick the animals can learn the system.

Twenty-seven female sheep were included in the experiment that was performed stepwise and no sheep continued to the next step without reaching the predefined learning criteria. In level 1, all 27 sheep were lured over a NoFence border maximum three times. The criteria for learning was that the sheep received a maximum of two electric corrections, and hence instead turned on the sound cue the third time. Due to technical problems and stress among some of the animals, only 16 sheep went through this step and of those 9 (56%) reached the learning criterion. The nine animals were divided into groups of three and each group were placed on a pasture for five days. During these days, one of the sides of the physical fence were exchanged to a NoFence border, first with a physical fence present outside and later without a physical fence outside. On day 5, the NoFence border was moved to the other side of the pasture. All animals stayed within the NoFence border during day 1-4 and received on average in total 1.9 corrections over the four days. However, when the NoFence border was moved, only two of the three groups stayed within the grazing area. The group that crossed the new border did not have any physical fence outside, which was then added for the two last groups. The sheep were feeding more and resting less during the first day wearing NoFence collars compared to when not wearing the collars, otherwise no differences in behaviour were found.

In conclusion, the animals do not seem to be able to generalize the association between sound and correction to a new border if a physical fence is not present outside. Moreover, only 56% did pass the first step of the experiment. Hence, further experiments need to be focussed on evaluating a learning procedure. During this year's very controlled experiments, we could not see any signs of decreased welfare for the animals.

Land/Country:	Norway
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Innhold

1. Introduction
During summertime, Norwegian sheep production is still mainly based on grazing on extensive pastures, which is considered an animal welfare friendly way of producing meat. It is also an important way to keep the culture landscape open. Although, with a large sheep population of which most are let loose on rangeland pastures during the summer months, there are bound to be some conflicts. The use of physical fences to keep the animals within a defined area is not possible on all rangelands and hence, sheep may be present in areas not suited for them, such as cottage fields and roads. This leads to conflicts between land and animal owners as well to an animal welfare problem when the animals are killed in the traffic or on railways. Also, as today, the law states that the animals on a rangeland pasture must be supervised at least once a week, which logically may lead to that sick animals may not be detected in time. A system that keeps the animals within a predefined area can facilitate a more frequent supervision. The company "NoFence" aims at finding a solution to the problems with keeping animals within a predefined area by developing a device for a fenceless system. The technical system consists of a collar based on GPS technology. When an animal wearing an activated collar crosses a predefined border, a sound signal will be given. If the animals then turns and walks back into the grazing area, the sound signal will stop. If the animal instead continue to walk over the border, the collar will give the animals an electric correction through two electrodes placed on the neck of the animal. The thought with NoFence is that it should function just like a physical fence, but that the visual signal of the fence is exchanged to an auditory cue. Safety measures are built into the product, for example will the system be deactivated if the GPS signal is bad to prevent the animals to receive a faulty sound signal while still in the grazing area. The system is also deactivated if the animal runs quickly over the border, so that they should be able to escape from for example predators. This would mean that animals wearing NoFence collars would have a greater possibility to escape from fearful stimuli (such as predators) compared to animals that are fenced with the help of a physical fence.

Figure 1. The NoFence collar. Photo: Oscar Hovde Berntsen

With proper learning and usage, the aim with NoFence is that the sheep should get no more electric corrections with the NoFence system compared to a physical fence and that the animal welfare in the system should be at least as good as with a physical fence. One of the goals with NoFence is hence to increase animal welfare through a more controlled grazing where the animals can be supervised more often and be excluded from unsuitable areas. At the same time they (as well as wild animals) do not risk to get stuck in physical fences. Although, as with all new technique, the system needs to be tested to ensure that animal welfare is maintained and that the animals are able to learn the system without stress. NoFence is not the first company trying to develop a so called virtual fence. According to Umstatter (2011), the first patent regarding a simple virtual fence for domestic animals was filed 1971, this is still available and is mainly targeting dogs. After this, a few other systems have been reported and some of them are GPS based (see Umstatter 2011 for a review). Recent years, quite a few studies reporting results from different kinds of virtual fences for farm animals have been reported, some more successful than others (e.g. Bishop-Hurley et al., 2007; Jouven et al., 2012; Tiedemann et al., 1999). Since none of these systems are used on a commercial basis for farm animals in practice, not many studies regarding how such systems affects stress and welfare exist. It is known that electric stimuli may cause both stress and severe harm in different species in both short and long term (see for example Lee et al., 2008; Schilder & van der Borg, 2004 and Weiss et al., 1981) therefore the welfare of such a system must be evaluated before used.

Due to the aversive effects when using electric shocks on animals, the laws and regulations in Norway are rather strict. Trainers with a special license are allowed to use electric shock collars on dogs when training hunting dogs to avoid hunting grazing farm animals. It is also allowed to use "cow trainers" to avoid that the cows are defecating in the cubicles. This is hence allowed despite its known partly negative implications on dogs (e.g. Schilder & van der Borg, 2004) and cows (Oltenacu et al., 1998). In the Norwegian animal welfare law §8 it is stated that "The one who is marketing and selling new operating methods, equipment and technical solutions for use in animals or livestock, must ensure that they are tested and found to be suitable for animal welfare" (translated from Norwegian). For this reason, Bioforsk Økologisk was hired to perform an independent evaluation about the welfare situation among animals on NoFence pastures. The first pilot trials started in 2010 and the results were reported in Henriksen & Berntsen (2011). Since so few animals participated (9 sheep and seven goats) and were performed during a very short time period (2 days with NoFence), no certain conclusions could be drawn. Although, it seemed to be large differences in how the animals experienced the electric correction and it also took too many corrections before the animals actually may have learned the system. The aim with the trials 2012 was hence to do a first evaluation if/how NoFence affects sheep welfare and how quick the animals can learn the system. A quick and safe learning is necessary to be able to ensure the animals wellbeing. During the trials, all measures were taken to reduce stress and negative effects on the individual animals' welfare.

2. Methods

2.1 Animals and management

Twenty-seven female sheep were included in the trials. The sheep were between 15 and 39 months old and were of different breeds. Before the trials, all sheep were shaved around their necks to assure that the collar had contact with the skin.

2.2 Functions of the NoFence collars

As described in the introduction, the NoFence collar (see Figure 1) is a GPS based virtual fence system and in this year's trials the second prototype of the collar was used. Based on the results from last year's trials, as well as a small pilot study earlier this year, a few changes of the functions of the collars were made. If the animal crossed the NoFence border, the sound cue continued either until the animal turned away and moved back towards the grazing zone or for a maximum of five seconds, after which the correction was given. Another change from last year's trials was that the collars could give a maximum of four corrections during one day. After this the collar was deactivated (but still gave a sound signal if the animal crossed the border).

2.3 Treatments

The trials were performed on a commercial sheep farm in western Norway in August-September 2012. The different NoFence treatments were tested stepwise and no sheep went from one level to another without having passed the learning criteria that was decided beforehand.

2.3.1 Level 1 - learning NoFence

In level 1, all 27 sheep were lured over a NoFence border maximum three times. This was done by a caretaker (well known to the animals) walking with a bucket filled with feed over the border. The sheep were tested individually in a fenced arena measuring approximately 10 x 30 meters with the NoFence border 10 meters from the physical fence. The already tested sheep were visible outside the fenced arena. The reactions of the sheep on the sound cue and electric correction was noted and if the animal turned in the opposite direction when receiving sound or correction, it was defined as a correct reaction. The criteria for learning was that the sheep received a maximum of two electric corrections, and hence instead turned on the sound cue the third time. Unfortunately, there were technical problems with the first collars, meaning that the electricity in the correction was so low that the first four sheep did not feel it at all, leaving 24 sheep that was tested with collars that worked in a correct way. Sheep that were too stressed (mainly because of being separated from the other animals) or that did not show any reaction on the electrical correction were taken out from the trials. In the end, 16 animals performed the trials as intended.

2.3.2 Level 2 – Habituation (Day 1) and learning NoFence with a physical fence (Day 2-3)

The sheep that met the learning criterion in level 1 (N=9) were randomly allocated into three groups (three per group). They were marked individually with spray colour on their back. The sheep were held in groups of three on a pasture that measured 20 x 30 meters. Except for the possibility for grazing, they were fed with silage ad lib and with small amounts of concentrate before and after the observations. In the middle of the pasture, there was a small shelter with roof for protection from sun and rain. The sheep were left undisturbed on the pasture for habituation for two days. On day one of the trial, the behaviour of each sheep as well as its' location on the pasture were recorded for two hours in the morning (between 9 and 11). Instantaneous scan sampling was used, and the position (stand, laying down with head up, laying down with head down, walk or run), behaviour (eat, drink, ruminate, nothing or other) and location (zone A, B, C, Shelter or Exclusion zone 1) was noted every fifth minute resulting in 25 observations of each sheep per day.

Figure 2. The pasture. Black solid lines represent physical fences, black dotted lines are borders between the zones within the grazing zone. The shelter is situated in zone B. Red lines represent the two NoFence borders, the red line to the right were used for level 2-3 and the one to the left were used for level 4. The vertical physical fence to the right was removed during level 3 and the physical fence to the right were removed during level 4.

On the morning of day two and three, one of the physical fences was exchanged by a NoFence border with a physical fence five meters outside the NoFence border (See figure 3). The sheep were gathered in the shelter and NoFence collars were put on and they were released on the pasture again. Observations were performed in the same way as the day before, but the animals were also video recorded if crossing the NoFence border. After the observations, the NoFence collars were taken off and the inner physical fence were put back. The criterion for the animals to continue to the next level was that they could get maximum one correction on day three. Unfortunately, one of the collars did not work properly (did not give sound cue or correction) on day two for the first group of sheep, meaning that the data from day two are based on the registrations from in total eight sheep.

2.3.1 Level 3 – NoFence without a physical fence (Day 4)

Level three was performed in the same way as day two and three in Level 2, with the difference that there were no physical fence outside the NoFence border. For being able to continue to level 4, the animals could not receive more than one correction. If the animals went out from the pasture and stayed there for five minutes, the trial was ended.

2.3.2 Level 4 – Moving the NoFence border (day 5)

On the morning of day 5, the NoFence border was moved to the opposite side of the pasture and the physical fence on that side was removed (see Figure 3). The same criterion for learning as earlier was used and if the animals went out from the pasture, the trial was ended.

2.4 Cortisol

Fecal samples were taken each morning on day 1-5 at 9AM. The samples were then kept in -20°C until they were analysed using DetectX® Cortisol Immunoassay kit (Arbora Assays LLC, Ann Arbor, Michigan, USA) and the instructions were followed.

2.5 Data analysis

The behaviour (position and behaviour) on each observation was transformed into one of four behavioural categories (see Table 1 for details on this transformation). The proportion of time spent on each behaviour on day 2, 3, 4 and 5 (wearing NoFence) was then compared with day 1 (control). To search for differences, the Wilcoxon 1-sample test in Minitab was used to test if the difference in proportions between two days was significantly different from zero. Since day 1 was regarded as a control day, day 2, 3, 4 and 5 was compared pairwise with day 1.

Table 1. Behaviours recorded and behavioural categories used in the data analysis.

Behavioural categories	Definition
Feed	Feeding, drinking or ruminating while standing/lying with head up/walking
Rest	Lying down with head up or down without performing any other behaviour
Stand	Standing up without performing any other behaviour
Walk	Walking without performing any other behaviour
Body	Body care

3. Results

3.1 Level 1 - Learning NoFence

In the beginning of this experiment there were technical problems with the collars, resulting in that only 24 sheep wore functioning collars and hence were included in the trial. Of the 24 sheep that participated, eight were taken out from the trial either due to stress (N=5) or since they did not show any reaction to neither the sound warning nor the correction (N=3). Out of the 16 animals that were left, nine (56%) reached the learning criterion. Seven animals out of nine met the criteria in the third trial, one reached it in the second and one in the first trial. The sheep that reached it in the first one had been in a NoFence pilot study approximately two months earlier. The results for each animal are shown in table 2.

Table 2. The reactions to sound cue (sound) and correction (corr) for all animals included in the trial. A correct reaction on the sound warning is defined as that the animal turns to avoid the correction. A correct reaction in response to the correction is defined as that the sheep independently turns and go back over the border.

	Trial 1		Trial 2		Trial 3		
Animal	**Sound**	**Corr**	**Sound**	**Corr**	**Sound**	**Corr**	**Learn?**
1	Not correct	Correct	Not correct	Correct	Correct	-	Yes
2	Not correct	Not correct	Not correct	Correct	Correct	-	Yes
3	Correct	-	-	-	-	-	Yes
4	Not correct	Correct	Not correct	Correct	Correct	-	Yes
5	Not correct	Not correct	Not correct	Correct	Correct	-	Yes
6	Not correct	Correct	Not correct	Correct	Correct	-	Yes
7	Not correct	Not correct	Not correct	Correct	Correct	-	Yes
8	Not correct	Correct	Not correct	Correct	Correct	-	Yes
9	Not correct	Correct	Correct	-	-	-	Yes
10	Not correct	Not correct	Not correct	Not correct	Not correct	Not correct	No.
11	Not correct	Not correct	Not correct	Not correct	Not correct	Correct	No.
12	Not correct	Correct	Not correct	Correct	Not correct	Not correct	No.
13	Not correct	Correct	Not correct	Correct	Not correct	Correct	No.
14	Not correct	Correct	Not correct	Correct	Not correct	Not correct	No.
15	Not correct	Not correct	Not correct	Correct	Not correct	Correct	No.
16	Not correct	Correct	Not correct	Not correct	Not correct	Correct	No.

3.2 Level 2-4

3.2.1 Sound warnings and corrections

In the four days during which the animals wore NoFence collars, they received between 2 and 10 sound warnings (mean±S.E. 4.9±0.8) and between 0 and 3 corrections (1.9±0.4). The mean number of sound cues on day 2-5 varied from between 3.3±0.5 on day 2 to 0.3±0.2 on day 4. The mean number of corrections was highest on day 2 (1.9±0.4) and lowest on day 4 and 5 (0.0±0.0). The number of sound warnings and correction for each animal and day are shown in table 3.

Table 3. The number of sound cues and corrections received by all participating animals during day 1 (only physical fence), day 2-3 (NoFence with a physical fence), day 4 (NoFence without physical fence) and day 5 (NoFence border moved). A * indicates missing value.

	Day 1		Day 2		Day 3		Day 4		Day 5	
Animal	**Sound**	**Corr.**	**Sound**	**Corr.**	**Sound**	**Corr.**	**Sound**	**Corr.**	**Sound**	**Corr.**
1	0	0	5	0	0	0	0	0	*	*
2	0	0	4	3	1	0	0	0	*	*
3	0	0	*	*	1	1	1	0	*	*
4	0	0	4	2	0	0	0	0	3	0
5	0	0	2	2	1	0	0	0	0	0
6	0	0	1	1	1	0	0	0	1	0
7	0	0	3	2	1	0	0	0	1	0
8	0	0	4	3	1	0	2	0	3	0
9	0	0	3	2	1	1	0	0	0	0
Mean±S.E.	0.0±0.0	0.0±0.0	3.3±0.5	1.9±0.4	0.8±0.1	0.2±0.1	0.3±0.2	0.0±0.0	1.3±0.6	0.0±0.0

Unfortunately, one of the collars did not work properly day 2 (it did not give any sound signal or correction), so the data from this animal were excluded from day 2. With the first group of three animals, the last step of the trial (day 5, moving the border) was performed without a physical fence outside the new border. This resulted in that the animals escaped from the pasture within one minute (despite wearing functioning collars) and no data are therefore available from this group.

According to the criteria for learning, all nine animals reached the learning criterion in step one and two, but only the two last groups reached the criterion on day 5.

3.2.2 Behaviour

Over the five days, the animals spent on average 65% of their time feeding (including grazing, feeding silage, drinking and ruminating), 20% of their time resting (lying down with head up or down, without ruminating), 13% standing up (without performing any other behaviour such as feeding or ruminating) and 2% of the time walking.
Mean values and standard errors for the proportion of time spent on each behaviour on each separate day are shown in table 4.

Table 4. The proportion of time (mean±S.E.) that the sheep spent performing each behaviour during day 1 (only physical fence), day 2-3 (NoFence with a physical fence), day 4 (NoFence without physical fence) and day 5 (NoFence border moved). A * indicates missing value.

	Feed	**Rest**	**Stand**	**Walk**	**Body**
Day 1	0.53±0.04	0.26±0.05	0.17±0.03	0.03±0.01	0.01±0.01
Day 2	0.77±0.06	0.04±0.03	0.16±0.06	0.03±0.01	0.00±0.00
Day 3	0.55±0.07	0.33±0.05	0.12±0.02	0.00±0.00	0.00±0.00
Day 4	0.67±0.08	0.21±0.06	0.09±0.03	0.02±0.01	0.00±0.00
Day 5	0.75±0.06	0.11±0.05	0.11±0.05	0.03±0.01	0.00±0.00

When comparing the proportions of time spent on each behaviour on day 2, 3, 4 and 5 with day 1, there was a difference on the first day with NoFence with a physical fence(day 2 versus day 1) on which the animals spent more time feeding (P=0.02) and less time resting (P=0.03) with NoFence. No other pairwise differences in proportions spent performing each behaviour were significantly different from zero.

3.2.3 Position on the pasture

On average over all five days, the sheep spent most time in zone A and B (38 and 37% respectively) while they spent 10% of their time both in zone C and Exclusion zone 1. Only 5% of the time was spent in or within one meter from the shelter. No observations of the animals were made in Exclusion zone 2.

Mean values and standard errors for the proportion of time spent on each behaviour on each separate day are shown in table 5.

Table 5. Proportion of time the sheep spent in each zone during day 1 (only physical fence), day 2-3 (NoFence with a physical fence), day 4 (NoFence without physical fence) and day 5 (NoFence border moved).

	A	B	C	Exclusion 1	Shelter
Day 1	0.49±0.11	0.27±0.08	0.21±0.07	0.00±0.00	0.03±0.02
Day 2	0.27±0.04	0.53±0.06	0.11±0.03	0.00±0.00	0.09±0.06
Day 3	0.53±0.08	0.30±0.06	0.05±0.02	0.00±0.00	0.12±0.06
Day 4	0.36±0.09	0.58±0.09	0.05±0.03	0.00±0.00	0.01±0.01
Day 5	0.17±0.09	0.13±0.06	0.08±0.03	0.63±0.15	0.00±0.00

When comparing the proportion of time spent in zone A and C on day 2, 3, 4 and 5 with day 1, the animals spent less time in zone C on day 5 (P=0.04). When comparing the amount of time spent in exclusion zone on day 4 with day 5, the sheep spent more time outside the first NoFence border on day 5 (P=0.04).

3.2.4 Cortisol

Due to problems with getting enough sample material, it was only possible to get 24 fecal samples and it was only for one of the sheep that it was possible to obtain samples every day. The animals in group 2 were very stressed when collecting them for the sampling procedure so it was only possible to get one sample from one of the animals. Hence, this group is excluded from the cortisol results. The cortisol values for all six animals are presented in figure 3 and mean values for each day in figure 4.

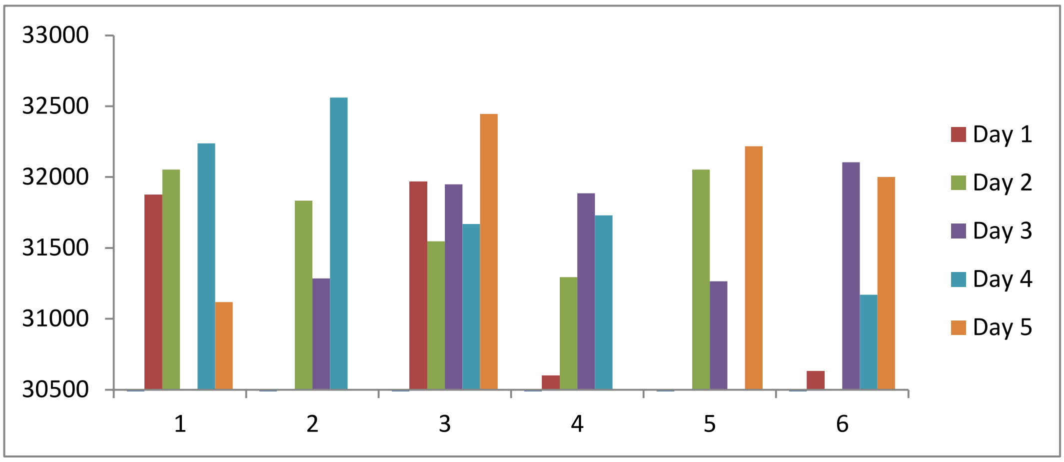

Figure 3. Fecal cortisol levels (ng/ml) measured for six sheep on five days. Day 1 and 2 represent two control days while day 3-5 represent days when the sheep wore NoFence collars.

When interpreting the results it is important to remember that cortisol measured in fecal samples represent the cortisol secretion approximately 12 hours earlier. Hence, the samples taken on day 1 represent the secretion on the evening on day 0 and so on.

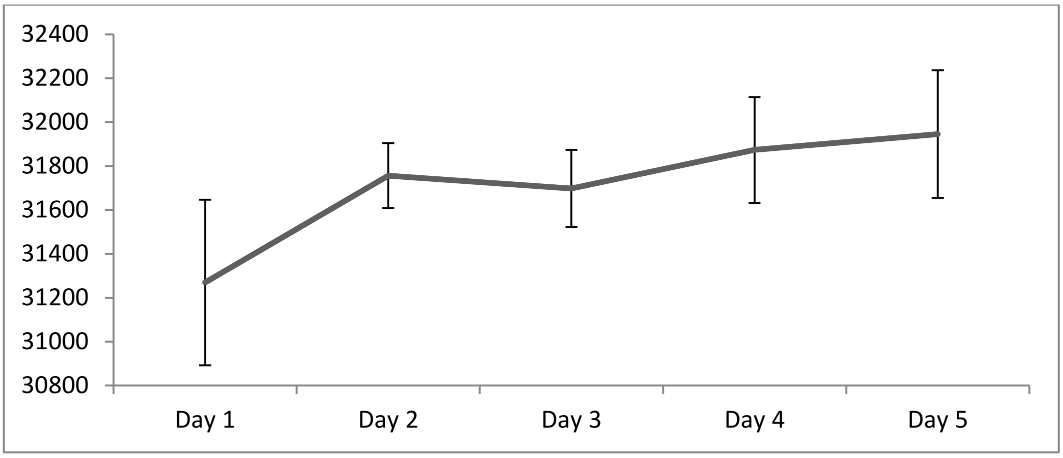

Figure 4. Fecal cortisol levels (mean±S.E., ng/ml) measured in six sheep on five days. Day 1 and 2 represent two control days while day 3-5 represent days when the sheep wore NoFence collars.

4. Discussion

The aim with the evaluation of NoFence 2012 was to further develop the trials from last summer and letting more animals participate in the project to evaluate how the system affects animal welfare. Unfortunately, the pilot trials in the beginning of the summer revealed technical problems with the collars, as well as difficulties for the animals to quickly learn the system. Except for solving the purely technical problems, a few changes in the programming of the collars were performed to enable an efficient learning and ensure animal welfare. In prototype 1 of the NoFence collar, the timing of the electric correction was based on how many meters the animals moved outside the border when the sound cue was given (the correction was given three meters outside the border). This resulted in that if the animals crossed the border and then stopped or walked slowly parallel with the border, the sound signal continued but no correction was given. During the pilot project, it was noticed that some animals spent a large amount of time grazing in the exclusion zone with a constant sound signal, but without receiving any correction. According to the report by Henriksen & Berntsen (2011), this was seen also in the trials 2010-2011. Of course, this inconsequence between the sound signal and the correction made it very difficult for the animals to associate the sound cue to the correction. Failing to learn the system properly will mean that the animals will not stay within the NoFence borders (grazing zone). It will also affect the welfare of the animals since it is a risk of not being able to control how to avoid the corrections, something that is known to be very stressful in other species (e.g. Feldmann & Brown, 1976; Weiss, 1981). The association between sound cue and electrical correction was therefore changed so that the sound cue was given for a maximum of five seconds. If the animal turned in the direction towards the grazing zone, the sound signal stopped and no correction was given. If the animals instead continued to move out of the NoFence border (in the exclusion zone) or stopped, an electric correction was given after five seconds. After this change, the sound signal was always associated with a correction (if the animal did not react in the proper way) and enabled learning in a much better way. It could although be discussed if five seconds is the optimal time between sound cue and correction. The timing was chosen since we wanted as short time as possible between the cue and the correction to facilitate learning. However, it is also important that the animals have enough time to be able to leave the exclusion zone. Five seconds between sound cue and correction was also used in a virtual fencing system reported by Tiedemann et al. (1999).

Another change that was made was that no sheep could receive more than four corrections during 24 hours. However, the collars still gave sound cues if the animal crossed the border also after the four corrections were received. For the animals that actually did pass the first learning trial, no collars were deactivated due to too many corrections, indicating that four corrections were more than enough. This criterion was a significant change from the trials 2010 and 2011, in which the animals received many more corrections the first days. The two changes in the function of the collars are therefore considered successful.

4.1 Ability to learn NoFence

The learning criterion during the first learning trial was rather strict and was meant to reflect how quickly an animal learns to avoid a physical fence, with the view that the welfare in a NoFence system should be at least as good as with a physical electric fence and the animals should learn both systems quickly. As stated by Lee et al. (2007), the electric fence is a good example of associative learning where the animal quickly learns to avoid the fence. Although, we were not successful in finding any studies on how long time it takes for an animal to learn to avoid an electric fence and therefore the criterion set in level 1 was based on own experience. Tiedemann et al. (1999) did however report that cattle grazing with a similar virtual fencing system seldom required more than two electric corrections to achieve the right response. Of the 16 animals that went through the learning experiment in level 1, only nine learned to associate the sound cue with the correction in only three trials and hence reached the learning criterion. The reason for this can only be speculated in, but the situation in which the animals were tested was rather unnatural. Even if the animals could see other sheep, they were separated from their herd mates. This was clearly stressful for some of the animals and probably affected the ability to learn. Although, the low number of animals that learned the system could also reflect individual variation in learning ability among the animals, something that the results from the trials in 2010 and 2011 also indicate. Our experience is also that it is important to have a physical fence near the NoFence border to help the animals understand that they can avoid the aversive stimuli by turning back to the grazing area. There were also a few animals that did not show any reaction to the electric correction at all and also these were excluded from the trials. This difference in sensitivity to the correction was also seen in the trials 2010-2011. This could be a problem both for the function of NoFence and for animal welfare. If some animals in a group are not at all sensitive for the electric correction, these will most probably walk over the border and there is then a risk that the others are tempted to follow, even though they have learned the association. Henriksen & Berntsen (2011) suggested that one solution to this could be to increase the strength of the electricity; I do not agree with this and do not see this as an option since a majority of the animals reacted very intensively (mainly by running or jumping) when receiving the correction. The strength of the electricity in the system must be adjusted to the most sensitive animals to secure their welfare. The large behavioural differences between individuals in trials regarding virtual fences have also been reported by for example Bishop-Hurley et al. (2007) and Jouven et al. (2012).

All nine animals went through day 2-4 and were hence successful in reaching the learning criteria using the first NoFence border. This is a positive indication. It is a clear improvement since last years' trials, in which the animals received many more corrections before learning to associate the sound cue with the correction. This is probably due to the functional change leading to that the animals could not get a constant sound signal without getting a correction. Hence, this change is regarded successful and is probably necessary for the system to work. The fact that the sheep on average got only two corrections in total, support our hypothesis that it is possible to have the same demand (a low number of corrections when learning NoFence) as it is when learning a physical electric fence.

That not only the number of corrections, but also the number of sound cues decreased by each day, indicates that the animals did not only learn to associate the sound cue with the correction, but also learned the physical position of the NoFence border. This association has been reported also in cattle on a virtual fence pasture (Tiedmann et al., 1999). This was also clear when the border was moved since the number of attempts to cross the border increased again. For the first group of sheep, there was no physical fence outside the new NoFence border on day 5, resulting that all three sheep escaped from the pasture within a few minutes. The first sheep to cross the border did not show any reaction to the sound cue, but simply kept running out of the pasture. The two following sheep stopped on the sound cue, but then followed the first sheep. From this, it can be concluded that learning NoFence with only one border is not enough to generalize the association to another border without a physical fence outside. The animals do not seem to know at all how they are supposed to react to the sound stimuli without the physical fence outside. Similar reactions to the sound and electric stimuli were reported in cattle in the report by Tiedemann et al. (1999). An effective learning procedure is not only important for the function of NoFence, but also for the welfare of the animals and developing a protocol for the learning procedure should therefore be prioritized in the further testing of NoFence. Also, it clearly shows that the motivation to reach an area with a better pasture as well as following the other animals can be higher than the motivation to avoid the aversive stimuli, which was even clearer in the results reported by Henriksen & Berntsen (2011) and has also been reported in other studies (e.g Bishop-Hurley, 2007 and Tiedemann et al., 1999). Although, it should be noted that the animals in group two and three clearly had learned to turn on the sound cue also when the border was moved, indicating that the association between sound cue and correction was clear, but that a physical fence was necessary with the new border.

Several questions should be asked when deciding how a learning procedure should be developed. The first question to be answered is if a larger proportion of the animals are able to learn NoFence if using the strategy of level 2 (with a physical fence outside) instead of luring the animals over the border. Another thing to be tested is how many different NoFence borders with a physical fence outside that have to be used before the animals are able to generalize the NoFence system to any new border.
With the results from this year's trials, it could of course be questioned if it may be necessary to learn every new border with a physical fence outside. Or, even more important, if it at all is possible to use NoFence without any visual border (i.e. at least a simple physical fence). This is of high importance to determine the actual use of NoFence as well as for animal welfare. If the trials next year indicate that it is necessary to have a visual cue for NoFence to work, it may be possible to use a very simple physical fence that is easy to put up and move and that prevent the animals to get stuck in it. It is possible that the purpose of such a fence is not necessarily to keep the animals within the grazing area, but instead only to give them a visual cue to help them turn in the right direction when given a sound signal. Such an easy fence is much more manageable compared with using ordinary sheep fences.

Regarding how long time it takes for the animals to learn a border with a physical fence outside, it seems like a few hours are enough. An important thing to specify in a protocol for learning NoFence is how many animals that can learn the system at the same time at the same pasture. The risk of letting too many animals on a NoFence pasture before they have learned it properly is that if one or two animals run over the border the others will follow. There is also a risk that some of the animals only mimic the other animals' reaction to the sound cue, without ever getting any correction, which would mean that they fail to make the association between sound cue and correction. It has also been questioned if it is possible to use virtual fencing systems on only some of the animals in a flock. It is also important to know if the learning procedure must be performed every year or if the sheep once they have learned the system will remember it also the next pasture season. Another important question to be answered is how the learning, functioning and welfare in the NoFence system is affected if the sheep have got young lambs and how the mother react if the lambs go outside the border.

4.2 Behaviour

No large changes in behaviour were noted. The animals rested less on the first day with NoFence. This could be a sign that they were more stressed on this day, but it could also be that they were more active and motivated to eat and to go to the exclusion zone where the pasture was better than in the grazing zone. Since this difference in behaviour was absent the rest of the days, we could not see any signs of stress or reduced welfare on basis of the behaviour of the sheep. The lack of differences between the location on the pasture indicates that the animals used the whole pasture in a similar way with NoFence.

That they spent less time in zone C on the last day is probably a result of that they spent much time in the first exclusion zone, were there was a much better pasture.

4.3 Cortisol

Unfortunately, it was a challenge to get the fecal samples for the analysis of cortisol. We aimed to get one sample each day, which would be five samples per animal and in total 45 samples, but only managed to get in total 24 samples. It was only from one animal that we managed to collect fecal samples each day and for group two we only managed to collect one sample. Since the cortisol levels are highly affected by the individual, the results from the cortisol measurement should be very cautiously interpreted and hence no statistical analysis was performed. However, the mean values do not indicate differences between days, i.e. when wearing NoFence collars or not. The largest increase in mean cortisol was found in when comparing the samples taken day 1 with the samples on day 2. These days would represent the cortisol secretion day 0 and 1 respectively, which both were the control days without NoFence. The difference between these days is that the animals were handled day 1, something that may have led to the increase in cortisol levels. In a study by Lee et al. (2008), it was reported that plasma cortisol levels were equally increased when exposing the animals to ordinary handling procedures, as when they mild electric shocks.

It should be discussed if cortisol levels in faecal samples taken once a day is the best way of indicating stress among the animals. The samples were taken around 9 AM each day, meaning that this mainly would represent the cortisol values 12 hours earlier. Since the animals wore NoFence for only a few hours each morning during a very short period, any differences in cortisol may not be shown in the evening. Although, no indications of prolonged stress reactions are seen. It should be evaluated if a stress test commonly used in sheep, including plasma cortisol measurements before and after the test, is a better way of catch any differences between animals wearing NoFence collars compared to control sheep.

4.4 Conclusion and future studies

In conclusion, the results from this year's trial gave us several indications about which aspects of NoFence that need to be further developed and tested during 2013. It is absolutely crucial that all technical problems with NoFence are solved for each individual collar until next year so that we are using a technically stable system. Technical problems were reported also by Henriksen & Berntsen (2011). Unfortunately, the technical problems with NoFence delayed the testing this year. Regarding the welfare of the animals, we could not see any indications that the animals experienced a higher stress or reduced welfare with NoFence compared to with a physical fence. Although, it should be mentioned that the trials were very controlled and performed in a small scale, so more information on this is needed in future trials. The main question from the trials is to determine if it is possible to develop a learning protocol so that each individual sheep learn to associate the sound cue with the correction in an efficient and, most importantly, animal welfare friendly way. It must also be investigated if animal welfare can be secured if NoFence is used on sheep with young lambs. If it can be ensured that the NoFence works properly regarding learning, animal welfare and technical issues, NoFence will also have to be tested in larger groups for a longer period and on a larger mountain pastures. Although this cannot be performed until more tests have been performed strictly controlled trials as well as including more animals. Although, if NoFence works in a proper way with regard to both function and animal welfare, there may be that the system even has possibilities to increase animal welfare in sheep compared with letting to non-fenced rangeland pastures or smaller pastures with physical fences.

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