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A study using a canine hydrotherapy treadmill at five different conditions to kinematically assess range of motion of the thoracolumbar spine in dogs

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Effects of inclined underwater treadmill exercise on range of motion of the canine thoracolumbar spine

Abstract

Background: Incline treadmill and underwater treadmill (UWTM) exercises are common canine rehabilitation modalities , which are often used in isolation in dogs recovering from spinal surgery. Early use of an incline during UWTM exercise may have the potential to improve rehabilitation outcomes in dogs, but, it is hypothesised that dorsoventral movement of the spine may be excessive meaning it is unsuitable in some circumstances.

Objectives: The purpose of this study was to identify changes in canine spinal kinematics in dogs when using a dry treadmill at different angles of incline compared to an underwater treadmill using the same inclines.

Methods: Eight dogs were encouraged to walk on a dry, horizontal, underwater treadmill as well as under the same conditions with both a 10% and 20% incline. This was then repeated at a 10% and 20% incline with the addition of water to hock level. Data were collected using reflective anatomical markers placed at the occipital protuberance, T1, T13, L3, L7 and sacral apex, captured by a high-speed camera facing the lateral aspect of the treadmill. Dorsoventral motion of the spine as well as flexion, extension and range of motion (ROM) of T1, T13, L3 and L7 were recorded.

Results: We found significant differences in dorsoventral spinal ROM at T1, L3 and L7, but no significant differences in T13 ROM. No significant differences were found in flexion and extension of any of the joints assessed when comparing dry conditions to the use of water ($P>0.05$).

Conclusions: The lack of significant differences in joint flexion and extension at T1, T13, L3 and L7 indicates the potential safe use of combining underwater treadmill and incline exercise in canine rehabilitation. However, a lack of uniformity in results makes distinguishing any patterns of significance difficult. More research is needed to establish the effects of these exercises in additional planes of motion before a treatment protocol can be established.

KEYWORDS
canine, hydrotherapy, kinematics, rehabilitation, spine, treadmill

1 | INTRODUCTION

Incline treadmill and underwater treadmill (UWTM) exercises are commonly used in canine fitness and rehabilitation programmes (Bertocci et al., 2018), but are often used in isolation from each other for the rehabilitation of dogs with spinal pathologies or following spinal surgeries (Hamilton et al., 2004; Carr et al., 2013). A number of aquatic treadmill systems enable the combination of aquatic exercise and incline exercise, however, there is currently no published research on the effects of combining these exercises in dogs, which may enable earlier loading and strengthening of the pelvic limb musculature (Carr et al., 2013). Preventing excessive atrophy of pelvic limb musculature where a spinal pathology is present is a significant challenge to therapists but incline exercises are generally only introduced once the patient is able to bear increased weight on the pelvic limbs (Hamilton et al., 2004; Carr et al., 2013). Conversely, some equine studies have shown that higher water depths may not be suitable for horses with existing back pathologies due to increased thoracolumbar movement (Nankervis et al., 2014; Nankervis et al., 2016; Tranquille et al., 2017). We speculated that the combination of incline and UWTM exercises may encourage pelvic limb engagement earlier in the rehabilitation process (Dycus et al., 2017), by decreasing the total weight supported by the patient (Levine et al., 2010); however, we also wanted to understand if excessive movement would be created which may make the combination unsuitable for some canine patients with back pathologies. Using an UWTM with an incline may assist in reducing the extent of muscular atrophy, encourage recovery of neuromotor control mechanisms, and reduce recovery time (Olby et al., 2005). However, we hypothesised that an inclined under water treadmill would create excessive dorsoventral movement of the spine, making it unsuitable for some rehabilitation programmes.

2 | MATERIALS AND METHODS

2.1 | Animals

Four female and four male dogs were used for the trial. Breeds were three Terriers, two cross breeds, one Pug, one Bodeguero and one Cocker Spaniel. Age varied (4.38 years ± 2.89; range 1 to 10 years), as did body mass (11.69 kg ± 6.52; range 6.05 to 22.05 kg), and height (40.63 cm ± 11.59; range 28 to 59 cm). Inclusion within the study was dependant on a gait assessment carried out by a veterinarian prior to data collection to confirm each dog was fit and well, having no existing orthopaedic conditions. Because all dogs met these criteria, none were excluded.

All dogs were provided by the research institution staff members, and as such were routinely used for hydrotherapy practical demonstrations for students. A period of additional habituation to the UWTM in both wet and dry conditions was therefore not deemed necessary.

2.2 | Experimental design

Dogs were randomly allocated into two groups of four animals; group one was exposed to each incline without water, followed by exposure to each incline grade with the addition of water; group two were exposed to each incline with water, followed by exposure to the same incline without water. Subsequent randomisations occurred within these two groups to establish the order of incline gradient exposure, with two animals from each group being exposed to both conditions at the 10% grade incline followed by the 20% grade incline, and the remaining animals being exposed to conditions at the 20% grade incline followed by the 10% grade incline. A final randomisation occurred to establish treatment order. All animals were first exposed to the flat condition without water to establish the baseline spinal kinematics which acted as each participant's control. Water level was in line with the hock of each participant, with water level adjusted as necessary when incline was applied to ensure the water level remained at hock height. A Canine Hydro-Physio Aqua Treadmill (Tudor treadmills, Sheffield, UK) was used for the treadmill exercise.

2.3 | Data collection

Reflective spinal markers were attached to the dog's fur using a commercially available double-sided tape at the occipital protuberance, the dorsal spinous process of T1, the dorsal spinous process of T13, the dorsal spinous process of L3, the dorsal spinous process of L7, and the sacral apex, which were located by palpation by the researcher. The same researcher applied the markers and lead the dog into the treadmill, which remained consistent across participants to control variation. A handler treadmill, in front of each animal to ensure dogs continued to move with the belt, however, interference by the handler was kept to a minimum with any strides captured at points of interference removed for data analysis purposes. The treadmill itself was operated by a qualified hydrotherapist.

Each dog was allowed to walk at a pace deemed appropriate for the animal as it could not be standardised across participants due to breed variances in height and stride length. Once pace was established horizontally on the dry treadmill, it was recorded and maintained throughout the subsequent data collections. Dogs were exposed to each condition for a minimum of 2 min, prior to data capture recording lasting 20 s, or until three consecutive walking strides without lateral head movement were captured. A 2-min rest period then occurred whilst conditions were changed to reduce the effects of fatigue.

A single high-speed camera (Quintic USB3 1.3 MPixel, Quintic Consultants, Birmingham, UK) was positioned 1 m away from the treadmill, capturing the left side of the dog at 300 Hz and 1280×500 pixels, with a field of view capturing the full area of the treadmill window (approximately 2 m). A halogen light was used to illuminate the markers. High-speed video data were recorded and downloaded to a laptop and processed using two-dimensional motion capture (Quintic Biomechanics v31, Quintic Consultants, Birmingham, UK). Automatic marker

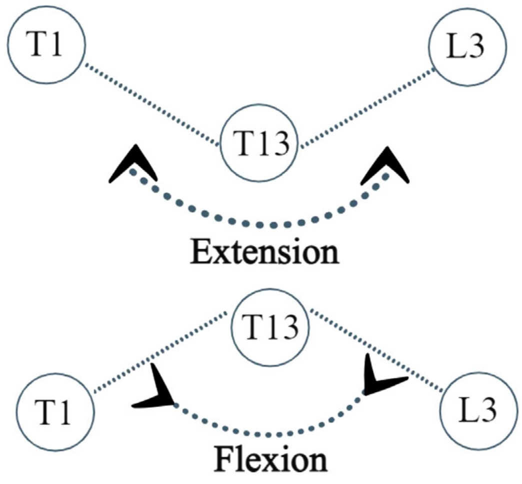

FIGURE 1 Illustration of how flexion and extension of the lumbar and thoracic vertebrae are measured in dogs by using reflective markers at T1, T13 and L3

tracking was used to investigate T1, T13, L3 and L7 angular displacement, including maximum flexion, maximum extension and range of motion (ROM). This was calculated by measuring the angular displacement data for each marker versus the markers cranial and caudal to it – for example, T13 angular displacement was calculated using T1, T13 and L3 data, as can be seen in Figure 1.

2.4 | Statistical analysis

Statistical analysis was performed in SPSS [v25, IBM Corporation, Armonk, NY, USA)]. Kinematics outcome parameters were assessed for normality using Shapiro–Wilk test of normality. The conditions flat, 10% incline dry, 20% incline dry, 10% incline with water and 20% incline with water were compared using either repeated measures ANOVA (for parametric data) or Friedman's test (for non-parametric data). Post-hoc tests applying Bonferroni correction followed when a significance was encountered. Significance value of $p<0.05$ was set.

3 | RESULTS

The mean joint angles and ROM (± standard deviation) can be seen in Table 1. Mean joint angles were established by measuring movement of each marker relative to the markers cranial and caudal to it. For example, T1 used the angular differences between the occipital protuberance and T13 as shown in Figure 1. We found significant differences in dorsoventral spinal ROM at T1, L3 and L7, but no significant differences in T13 ROM or flexion and extension of any of the joints assessed when comparing dry conditions to the use of water ($P>0.05$).

3.1 | T1

T1 ROM was analysed by repeated measures ANOVA and showed statistically significant differences between the different conditions, $F(4, 24) = 2.913$, $p = 0.043$. Post-hoc analysis revealed that ROM was statistically significantly decreased with 20% grade incline when compared to flat (−6.629 (95% CI, −12.774 to −0.483)°, $p = 0.039$), and statistically significantly decreased with 10% grade incline when compared to 20% grade incline with water (−6.431 (95% CI, −12.173 to −0.690) °, $p = 0.034$) (Figure 2).

3.2 | L3

L3 ROM was analysed using Friedman's test and decreased from (data are median) 5.21° at a 10% grade incline with water to 5.01° at a 20% grade incline with water. It then decreased to 4.20° at flat to 4.10° at a 20% grade incline, and finally to 3.54° at a 10% grade incline. ROM was statistically significantly different with the different conditions,

TABLE 1 Mean joint angles ± standard deviation for each condition at the four levels measured (T1, T13, L3, L7) of dogs at walk on treadmill n =8

Joint	Condition	Flat	10%	20%	10% WW	20% WW
T1	**Mean flexion (°)**	185.2 ± 8.5[a]	193.2 ± 9.8[a]	187.5 ± 10.8[a]	188.6 ± 11.4[a]	187.6 ± 9.6[a]
	Mean extension (°)	204.7 ± 10.8[a]	204.0 ± 12.7[a]	200.3 ± 13.8[a]	205.5 ± 16.5[a]	204.8 ± 13.7[a]
	Mean ROM	19.5 ± 7.0[a,b]	10.8 ± 5.1[b,d]	12.8 ± 5.9[c,d]	16.8 ± 6.4[a,b,c,d]	17.2 ± 7.8[a,c]
T13	**Mean flexion (°)**	175.5 ± 7.9[a]	177.1 ± 8.1[a]	174.2 ± 6.8[a]	171.6 ± 10.7[a]	174.2 ± 10.9[a]
	Mean extension (°)	182.1 ± 6.8[a]	183.5 ± 8.3[a]	180.6 ± 8.2[a]	182.7 ± 12.2[a]	182.8 ± 11.6[a]
	Mean ROM	7.8 ± 4.7[a]	6.4 ± 1.6[a]	7.0 ± 2.4[a]	11.0 ± 8.5[a]	8.6 ± 2.3[a]
L3	**Mean flexion (°)**	166.0 ± 6.2[a]	167.0 ± 7.5[a]	165.9 ± 9.4[a]	164.9 ± 8.3[a]	165.2 ± 7[a]
	Mean extension (°)	171.3 ± 4.8[a]	171.2 ± 6.2[a]	171.3 ± 5.8[a]	172.5 ± 6.5[a]	171.6 ± 5.6[a]
	Mean ROM	5.2 ± 2.5[a,b]	4.2 ± 2.3[b]	5.4 ± 4.9[a,b]	7.2 ± 6.2[a]	6.3 ± 3.6[a]
L7	**Mean flexion (°)**	163.0 ± 3[a]	165.6 ± 5.0[a]	166.1 ± 5.6[a]	165.2 ± 7.0[a]	167.2 ± 7.1[a]
	Mean extension (°)	171.5 ± 5.3[a]	171.4 ± 6.1[a]	172.9 ± 4.6[a]	176.7 ± 5.1[a]	175.6 ± 6.5[a]
	Mean ROM	8.4 ± 3.3[a]	5.8 ± 1.9[b]	6.8 ± 3.4[a,b]	11.5 ± 5.1[c]	8.4 ± 3.0[a,c]

[a,b,c,d] Different letters within each row denote significant differences ($p<0.05$)

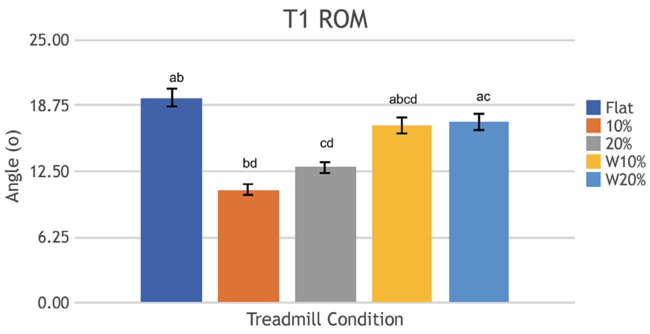

FIGURE 2 Range of motion of the vertebrae at T1 (°) in dogs (n = 8) walking during each of the following treadmill conditions: Flat (control), 10% dry incline, 20% dry incline, 10% wet incline and 20% wet incline. Standard error is shown. Different letters above each bar denote significant differences by repeated measures ANOVA (p<0.05)

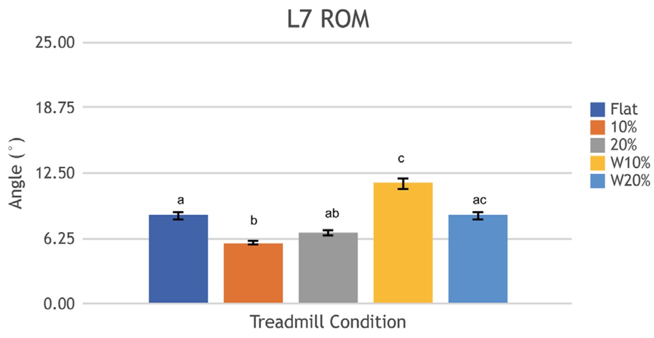

FIGURE 4 Range of motion of the vertebra at L7 (°) in dogs (n = 8) using a treadmill under each of the following conditions: Flat (control), 10% dry incline, 20% dry incline, 10% wet incline and 20% wet incline. Standard error is shown. Different letters above each bar denote significant differences by repeated measures ANOVA (p<0.05)

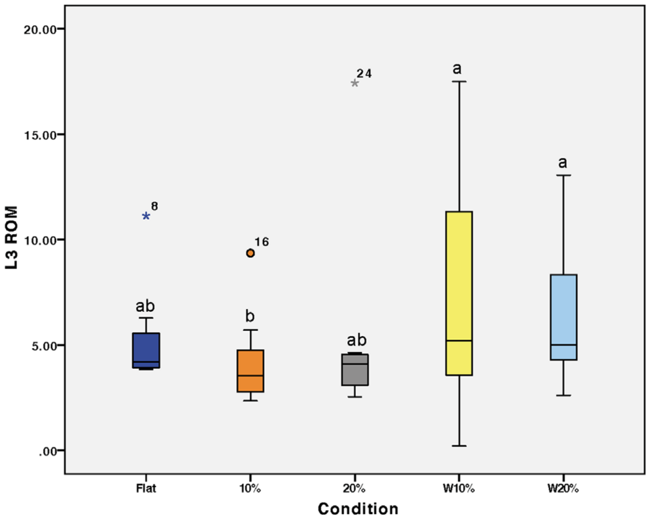

FIGURE 3 Range of motion at the L3 vertebrae in dogs (n = 8) walking on a treadmill in different conditions: Flat (control), 10% dry incline, 20% dry incline, 10% wet incline and 20% wet incline. The bottom and top of the box are the first and third quartiles, and the band inside the box is the second quartile (the median). The lines extending vertically from the boxes (whiskers) indicate the minimum and maximum of all of the data. Different letters above each box denote significant differences by Friedmans test (p<0.05)

X^2 (9) = 14.311, p = 0.006. Post-hoc analysis revealed statistically significant differences in L3 ROM between 10% grade incline without water (Mdn = 3.53°) and 10% grade incline with water (Mdn = 5.21°) (p = 0.01), and 10% grade incline without water (Mdn = 3.54°) and 20% grade incline with water (Mdn = 5.01°) (p = 0.017) (Figure 3).

3.3 | L7

ROM at L7 was analysed by repeated measures ANOVA and statistically significantly different between the different conditions, $F(4, 28)$ = 7.174, p = 0.000415. Post-hoc analysis revealed that ROM was statistically significantly decreased with flat condition when compared to both 10% grade incline with water (−3.072 (95% CI, −6.085 to −0.060)°, p = 0.047) as well as 10% grade incline without water (−2.648 (95% CI, −4.326 to −0.969)°, p = 0.007). Similarly, ROM decreased at 10% grade incline when compared to 10% grade incline with water (−5.720 (95% CI, −9.406 to −2.034)°, p = 0.008), 10% grade incline when compared to 20% grade incline with water (−2.628 (95% CI, −4.302 to −0.953)°, p = 0.008), and 20% grade incline when compared to 10% grade incline with water (−4.680 (95% CI, −8.375 to −0.985)°, p = 0.020) (Figure 4).

4 | DISCUSSION

This study found significant differences in the full ROM of the vertebra at T1, L3 and L7, when comparing canine gait on a dry versus a wet treadmill, however, no significant differences were found in the degree of flexion and extension of any joints using the same comparison.

Upon analysis of data across all joints, it became apparent that the greatest degree of joint extension was never observed during flat motion. The greatest ROM of three out of four joints was seen at a 10% grade incline with water, with the exception of T1. The least amount of joint flexion (greatest joint angles) of three out of four joints occurred at a 10% grade incline, with L7 being the exception. Furthermore, a 10% grade incline also resulted in the lowest ROM of three out of four joints, with T13 being the exception. Nevertheless, the lack of consistency of results is apparent, and comparability difficult. Clear and consistent patterns in data, that could distinguish differences in motion of the joints between treadmill conditions, were therefore not evident in the results from this trial but would warrant further study using a larger or more homogenous sample.

A lack of research on canine spinal motion during incline walking or on an UWTM presents a challenge in comparing the results of this study to existing literature. Gradner et al. (2007) looked at vertical and transverse spinal ROM in canines walking on an on-land treadmill with no inclinations and highlighted that the thoracolumbar spine had minimal vertical ROM when compared to the S3 marker, but had greater transverse ROM. The authors stipulated that the greater vertical ROM at the lumbar and sacral spine may be due to a change in articular facet position from horizontal to sagittal. However, the findings of this study do not correlate with the current study, whereby no single joint had clear increases in ROM compared to another. These differences may be due to our sample containing dogs of varied breed and size, which cause variances in motion (Benninger et al., 2006), whereas the study by Gradner et al. (2007) contained participants of a single breed.

It has been shown that limb motion has a direct influence on the motion of the spine in horses (Faber et al., 2001; Greve and Dyson, 2014); however, only one study has shown similar results in canine research that combines limb and spinal kinematic data (Aleotti et al., 2008). Both incline exercise and UWTM exercises have been shown to alter limb joint ROM in horses and dogs (Holler et al., 2010; Mendez-Angulo et al., 2013; Mooij et al., 2013), with ramp ascents of 11% grade inclination significantly increasing flexion of the elbow, carpal, hip and tarsal joints, as well as increasing extension of the carpal and stifle joints in dogs (Holler et al., 2010). In horses, the addition of water during UWTM exercise has been shown to increase distal limb joint ROM (Mendez-Angulo et al., 2013; Nankervis et al., 2016). Limb kinematics were not assessed during the current study, but it could be expected that the effects of incline and UWTM exercise on increasing limb joint ROM would influence spinal kinematics. Although ROM of T1, L3 and L7 were significantly different, these changes were somewhat random between conditions. The flat condition occasionally resulted in greater ROM than the incline and aquatic conditions, despite the changes in limb joint ROM indicated in research.

It is possible that the small changes in spinal flexion and extension seen in this study are due to increased activation of spinal stabilisation muscles, which occur as exercise dynamics intensify in order to prevent excessive motion (Peham et al., 2001). Further research expanding on the current study may therefore need to include assessment of the same muscle activation in canines. This may be of clinical importance as dogs with spinal pathologies may experience atrophy of spinal stabilisers, increasing the chance of fatigue and destabilising the spinal column if not monitored (Kim et al., 2006). Additionally, limb motion in walk produces a snaking-like motion in the vertebra due to tension cycles within the spinal column (Aleotti et al., 2008). This motion may mean that greater changes in spinal kinematics are occurring in the transverse plane, similar to those observed in horses at different gaits (Faber et al., 2001; Zaneb et al., 2013). Further research is therefore also required to investigate the effects of the exercises used in this study on lateral bending of the spine.

A two-dimensional system was used to capture data for this study due to cost and availability, and, as such, assessment of movement across some planes was limited. Back kinematics in two dimensions have previously been validated by Feeney et al. (2007), with sagittal joint kinematics provided under the hypothesis that the dogs sagittal plane coincides with the plane identified by the vertical axis of the global frame and the direction of progression of the dog.

Repeating the study using a three-dimensional kinematic capture system would provide a greater understanding of the changes that we observed but would have to be carried out in a more specialist environment.

A limitation of this work was that it became apparent during the trial that ROM at T1 was greatly influenced by head and neck position, which varied considerably between strides. This is similar to existing equine studies, which found that head and neck position significantly alters the kinematics of lumbar vertebra (Rhodin et al., 2005; Gómez Alvarez et al., 2006). Attempts were made to control head and neck position during data collection, allowing for three continuous strides to be analysed, but it was noted that even a small amount of lateral head movement would influence the marker position at T1.

This study only assessed the effects of the exercises with water at hock height which has been shown to provide therapeutic benefit in existing studies (Levine et al., 2014; Tomlinson, 2012). Similar beneficial effects have been found at coxofemoral height (Levine et al., 2014; Bertocci et al., 2018), which would suggest that studies of a similar nature to ours, but using different water heights, may aid in establishing treatment protocols in future. Furthermore, this study only contained clinically sounds participants with no diagnosed orthopaedic conditions. For the combination of inclines and UWTM therapy to be deemed suitable for the rehabilitation of spinal patients, it may be necessary to complete a study assessing any potential variances in motion between the different conditions in dogs with spinal abnormalities.

Our sample size of $n = 8$ was determined using the resource equation approach (Arifin and Zahiruddin, 2017) as it was not possible to assume the standard deviation or effect size of our study. In addition, our sample was based on convenience, which resulted in substantial variances of breed, height, age and weight across participants. Although this provided a more accurate representation of the heterogenous nature of the general population, it may have influenced the reliability of data due to the anatomical differences in facet joints between breeds can contribute to variances in motion (Smolders et al., 2013). It is also noted that a greater sample size may have reduced the influence of outliers. Variances in marker placement were minimised during this trial by having a single individual complete all marker placements throughout the trial. Nevertheless, cutaneous and subcutaneous tissue can move relative to the underlying bone (Benninger et al., 2006) which reduces the reliability of kinematic data from these types of studies.

5 | CONCLUSION

The results from this study provide a positive basis of support for the combining of UWTM and incline exercises in canine rehabilitation. The lack of significant differences in dorsoventral spinal flexion and extension between conditions may indicate that incline underwater treadmill exercise is suitable for spinal patients, due to the lack of excessive spinal motion in this anatomical plane. However, a number of other factors, not assessed in this study, may indicate the combination of these exercises to be contraindicative in canine rehabilitation. This study only assessed the dorsoventral motion of the spine in healthy canines, with water limited to hock height. Prior to the combination of these exercises being deemed safe to spinal patients, further research is needed. The lateral flexion and extension of the vertebrae may pose a significant risk to spinal patients if excessive, and therefore need to be fully investigated. Nevertheless, the results from this study provide a basis for the potential of combining UWTM and incline exercises, which poses a particular benefit to the rehabilitation of canines with spinal pathologies and following spinal surgery.

AUTHOR CONTRIBUTIONS

Scott Blake: Review and editing (lead). Heidi Hodgson: Conceptualisation (lead); writing – original draft (lead); formal analysis (lead); writing – review and editing (equal); software (equal); methodology (lead); writing – review and editing (equal). Roberta Godoy: Conceptualisation (supporting); writing – original draft (supporting); writing – review and editing (supporting); software (equal).

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CONFLICT OF INTEREST

No conflicts of interest are present with this submission.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICAL ANIMAL RESEARCH

The authors confirm that the ethical policies of the journal, as noted on the journal's author guidelines page, have been adhered to and approved by the Animal Welfare Ethics Committee of Writtle University College (protocol 98354317/2018). Although the procedures performed were non-regulated, the guidelines on The Animal (Scientific Procedures) Act 1986 were followed.

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PEER REVIEW

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