Electromyographic Analysis of Muscle Activation Patterns During Bovine Transrectal Palpation and the Development of the Bovine Pregnancy Diagnosis Improvement Exercise Program

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ABSTRACT

The unusual and tiring physical activity of bovine transrectal palpation (TRP) requires a novel approach to improve students' TRP and pregnancy diagnosis (PD) skills. It has been shown that students who participated in an exercise program and students who had a grip strength (GS) of more than 30 kilograms performed better in bovine PDs. Participation in the exercise program increased students' sensitivity (ability to identify pregnant cows) but did not increase total arm muscle strength. To identify which muscles are used during TRPs and to improve the exercise program, an electromyographic (EMG) analysis was used to identify muscle activation patterns and muscle activity levels during bovine TRPs. Eight subject matter experts (SMEs) each palpated two live cows and one Breed'n Betsy® rectal examination simulator while an EMG Triggered Stimulator recorded muscle activity. Muscle activation was higher for forearm muscles compared with all other examined muscle groups ($p < .001$); was higher during retraction of the uterus and palpation of left and right uterine horn, compared with palpation of cervix, uterine body, left ovary, and right ovary ($p < .001$); and showed an endurance pattern. Findings have been used to modify the previously developed exercise program in effort to improve students' TRP and PD skills. The Bovine PD Improvement Exercise Program is available to students through an online application (http://icarus.up.ac.za/vetmlp/) and aims to not only improve GS and TRP accuracy but also stamina and well-being while adding fun to busy study schedules.

Key words: veterinary education, bovine pregnancy diagnosis, transrectal palpation training, veterinary students, EMG, exercise program, student well-being

INTRODUCTION

Training methods, rectal examination simulator use, and factors influencing students' transrectal palpation (TRP) and pregnancy diagnosis (PD) performance have been previously studied in efforts to improve bovine TRP student training.[1–10] A recent study evaluated whether arm strength has an effect on PD accuracy and if a 6-week exercise program aimed at improving arm muscle strength could improve PD accuracy among students.[11] This investigation was based on the assumption that the bovine TRP procedure[12] requires an unusual physical effort that can cause fatigue, especially in examiners not used to TRPs, which might be a factor influencing PD accuracy. Participation in the exercise program and a grip strength (GS) of more than 30 kilograms were shown to be significant predictors of veterinary students' PD accuracy.[11] However, total arm strength did not correlate with students' overall palpation accuracy, sensitivity, or specificity.[11] Participation in the 6-week exercise program also did not increase total arm strength. A possible explanation for this could be that the exercise program increased arm muscle endurance rather than total muscle strength.[11] Since isokinetic strength measurements were done using the Humac®/Norm™ Testing System that measures total muscle strength in torque (newton-meters) and not endurance, an increase in endurance among the participants might not have been detected.[11] This would also explain why none of the whole arm strength measurements were correlated to PD accuracy. These findings warrant further investigation into which muscle groups are used during bovine TRPs and a description of muscle activation patterns during TRPs. Electromyographic (EMG) analysis has been used to describe other movements, including pedaling.[13] Muscle activation patterns and muscle activity levels provide information on a specific movement technique.[13] Because no EMG information is available on bovine TRP, an investigation using this technique is warranted to follow-up on the recent GS and exercise program data related to students' PD accuracy.[11]

Student PD sensitivity for early pregnancy stages is lower for students trained on Breed'n Betsy® (BB) rectal examination simulators compared with students trained on live cows even though the live cow training did not include early pregnancy stages.[3] This is counterintuitive since the BB simulators are specifically designed to improve early PD. A possible explanation for this apparent contradiction might be that overcoming the unusual experience of TRP may be more difficult than the actual ability to palpate.[3] Another possible explanation could be that rectal examination simulators do not imitate the same movements and muscle activations during TRPs as the same procedure on live animals. This could be due to the absence of rectal peristalsis, anal sphincter tone, and other internal organs such as a bladder and rumen, as well as the absence of the cow's body movement responses during TRP. A difference in muscle activation could be a potential reason for the variation in training outcomes for BB- and live cow–trained students. An investigation into this phenomenon could give insights into why simulator training does not have the same outcome as live cow training.

Muscle endurance is described as "the specific form of strength displayed in activities that require a relatively long duration of muscle tension with minimal decrease in efficiency."[14] Performing TRPs might require more muscle endurance than strength due to the demand for repetitive motions during the procedure. Differentiation of total muscle strength (defined as the ability of specific muscle groups producing maximum force to overcome a resistance within a single exertion) and muscle endurance (defined as muscle activity that can generate submaximal force over a sustained period of time or through repeated movements)[15] during TRPs could be useful information to modify the previously described exercise program to optimize the positive benefits on TRP performance.[11]

This study aimed to use EMG analysis to determine which muscle groups are activated during TRPs on live cows and BBs, and to identify muscle group contraction patterns during the same movement (TRP). The second objective was to use the EMG data to develop an exercise program aimed at training and strengthening muscles used during TRPs (the Bovine PD Improvement Exercise Program).

Based on the previously reported positive predictive value of GS for PD accuracy,[11] and the fact that GS is a measure of hand and forearm strength, it was hypothesized that forearm muscles (extensors and flexors) would be the most and strongest activated muscle groups during TRPs. It was also hypothesized that muscle activation for BB palpations would be less compared with those for live cow palpations and that the EMG patterns would show that muscle endurance rather than total strength was more important during TRPs. It was further hypothesized that muscle activation is highest for uterus retraction and uterine horn palpations.

MATERIALS AND METHODS

EMG Study

Participants in the EMG Data Collection

Study participants were veterinarians experienced in bovine TRP and PD (subject matter experts: SMEs).

Study Design and EMG Recordings

For purposes of this observational study, SMEs (n = 8) were asked to volunteer for TRP of two nonpregnant live cows and one BB rectal examination simulator (BB set up as a non-pregnant cow with ovaries) for EMG recording purposes. A NeuroTrac®MyoPlus 2 (MYO220A) dual channel EMG ETS (EMG Triggered Stimulator) was used to record muscle activity (Verity Medical Ltd., Romsey, Hampshire, UK) (Figure 1A). Each dual conductor lead wire (one per channel) ends in a negative black pin and positive red pin that are connected to the electrodes. SMEs were prepared for the TRP EMG recording by placing self-adhesive round (32mm Ø) electrodes onto the skin over the major parts of the muscles to be recorded. Skin areas were wiped using Neosafe alcohol swabs (Neomedic Limited, Hertfordshire, UK) prior to each application of electrodes to ensure optimal adherence. Two electrodes were placed on the skin over each muscle body in line with the muscle fiber about 1 to 2 centimeters apart as per the NeuroTrac® Electrode Placement Manual.[16] Electrode placement was done by a physiotherapist (CAE) (Figure 1C). The electrode connected to the negative pole (black pin) was placed near the proximal insertion of the muscle. The electrode connected to the positive pole (red pin) was placed closest to the center of the muscle body.

Electrodes were placed on four antagonistic muscle groups: (a) forearm muscles (forearm extensors and flexors), (b) upper arm muscles (biceps and triceps), (c) shoulder muscles (anterior and posterior deltoid muscle), and (d) shoulder girdle supportive muscles (pectoralis and rhomboid muscle) (Figures 1D, 1F, 1H). The pins of the lead wire from the EMG device were then inserted into the electrode wire connectors (Figure 1D). The NeuroTrac® MyoPlus 2 was placed in a moon bag secured around the waist of the SME. The EMG data were transferred instantly via Bluetooth to a laptop computer using NeuroTrac® software (Verity Medical Ltd., Romsey, Hampshire, UK) to create the database (Figures 1E–H). Muscle activation was set at a minimum of 25 microvolts (μV).

Because a dual channel EMG machine was used, each muscle group had to be recorded individually. Therefore, each SME had to repeat the TRP four times per cow or BB, one palpation per one of the four muscle groups. After recording for one muscle group, lead wires were disconnected from the electrodes and reconnected to the electrodes for the next muscle group. The TRP was subdivided into seven steps: (a) palpation of the cervix, (b) palpation of the uterine body, (c) retraction of the uterus, (d) palpation of the left uterine horn, (e) palpation of the left ovary, (f) palpation of the right uterine horn, and (g) palpation of the right ovary. SMEs were asked to relax the arm for 2 to 3 seconds between each step to enable visualization of individual steps on the recorded EMG. The SMEs could use their preferred arm for the palpations. During the palpations, one assistant operated the laptop to ensure correct data recording and saving. A second assistant ensured that the SMEs followed the palpation steps in the correct order and that SMEs relaxed arm muscles between steps. Each SME first palpated two live cows and then one BB. For each SME, 12 data sheets were recorded: (a–b) LC forearm flexors and extensors (cows 1 and 2); (c–d) LC biceps and triceps (cows 1 and 2); (e–f) LC anterior and posterior deltoid (cows 1 and 2); (g–h) LC pectoralis and rhomboid (cows 1 and 2); (i) BB forearm flexors and extensors; (j) BB biceps and triceps; (k) BB anterior and posterior deltoid; and (l) BB pectoralis and rhomboid. EMG data were initially saved as graphic displays (Figures 2–4) and later exported as Microsoft Excel files for data analysis using a conversion function within the NeuroTrac® software.

Statistical Analysis of EMG Data

Continuous EMG recordings were manually categorized into the seven steps of the bovine rectal palpation examination. The area under each EMG recording was estimated using an approximate integration method as the average of adjacent EMG values multiplied by the time interval between successive recording points (trapezoid method). Total area was calculated as the sum of individual areas and categorized by step, operator, cow, and BB simulator. The time necessary to complete each step was manually determined from EMG recordings, and a total muscle activation rate was calculated as the total area under the EMG curve divided by the time required to complete each examination step. Quantitative data were assessed for normality using commercial software (MINITAB Statistical Software, Release 13.32, Minitab Inc., State College, PA, USA) by calculating descriptive statistics, plotting histograms, and performing the Anderson–Darling test. Data were descriptively presented as the median and interquartile

Figure 1: EMG recording set up and data collection

A NeuroTrac®Myo Plus 2 (MYO220A) dual channel EMG ETS (EMG Triggered Stimulator, Verity Medical LTD Romsey, Hampshire, UK)
B NeuroTrac®Myo Plus 2 (MYO220A) dual channel EMG ETS: technical information and channel 1 (red) and 2 (green) EMG electrode wire plug ins.
C SME preparation for the TRP EMG recording. Placement of self-adhesive round (32mm Ø) electrodes onto the skin over the major parts of the muscles to be recorded. Two electrodes were placed on the skin over each muscle body in line with the muscle fibre about 1-2 cm apart as per Neurotrac® Electrode Placement Manual. Electrode placement was done by a physiotherapist (CAE).
D Connection of the dual conductor lead wire (one per channel) to the electrodes.
E EMG data collection for a BB palpation: SME is palpating while EMG data is transferred instantly via Bluetooth to a laptop using NeuroTrac Software (Verity Medical LTD Romsey, Hampshire, UK) to create the database. The assistant operates the laptop to ensure correct data capture.
F EMG data collection for a live cow palpation.
G EMG data collection for a BB palpation.
H View of the electrode placement for triceps, posterior deltoid and rhomboid muscle.

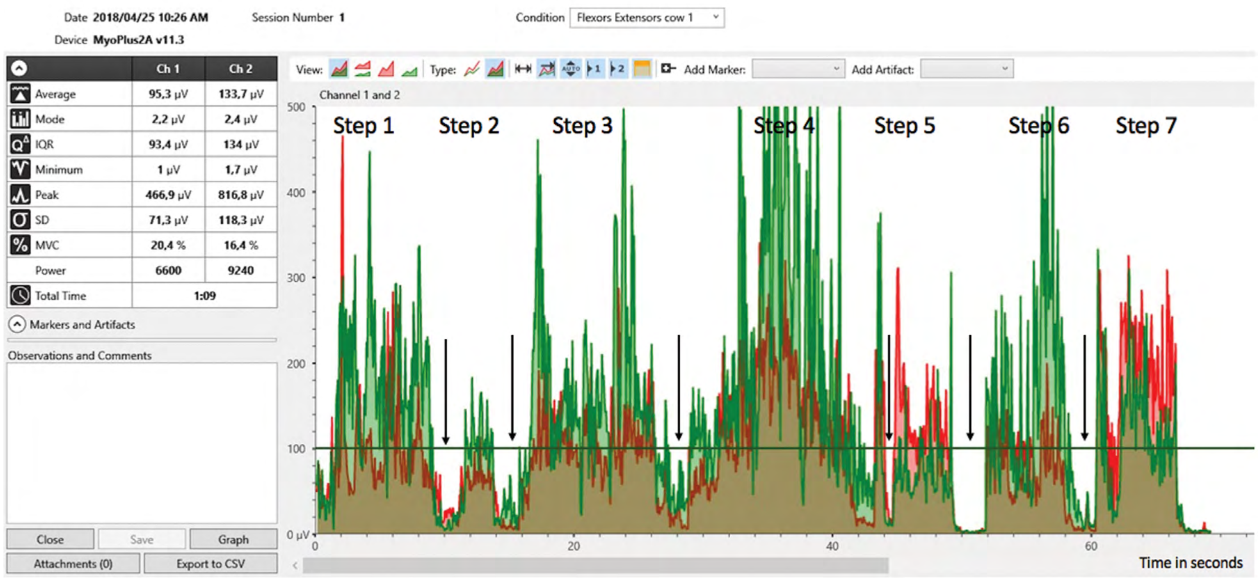

Figure 2: Example of a graphic EMG data capture file for forearm muscles (extensors and flexors) for a live cow palpation. Ch1: Channel one (red) EMG recordings for forearm extensors during a live cow palpation. Ch2: Channel two (green) EMG recordings for forearm flexors during a live cow palpation

Step 1: palpation of the cervix
Step 2: palpation of the uterine body
Step 3: retraction of the uterus
Step 4: palpation of the left uterine horn
Step 5: palpation of the left ovary
Step 6: palpation of the right uterine horn
Step 7: palpation of the right ovary
↓ black arrows indicate areas of muscle relaxation between TRP steps

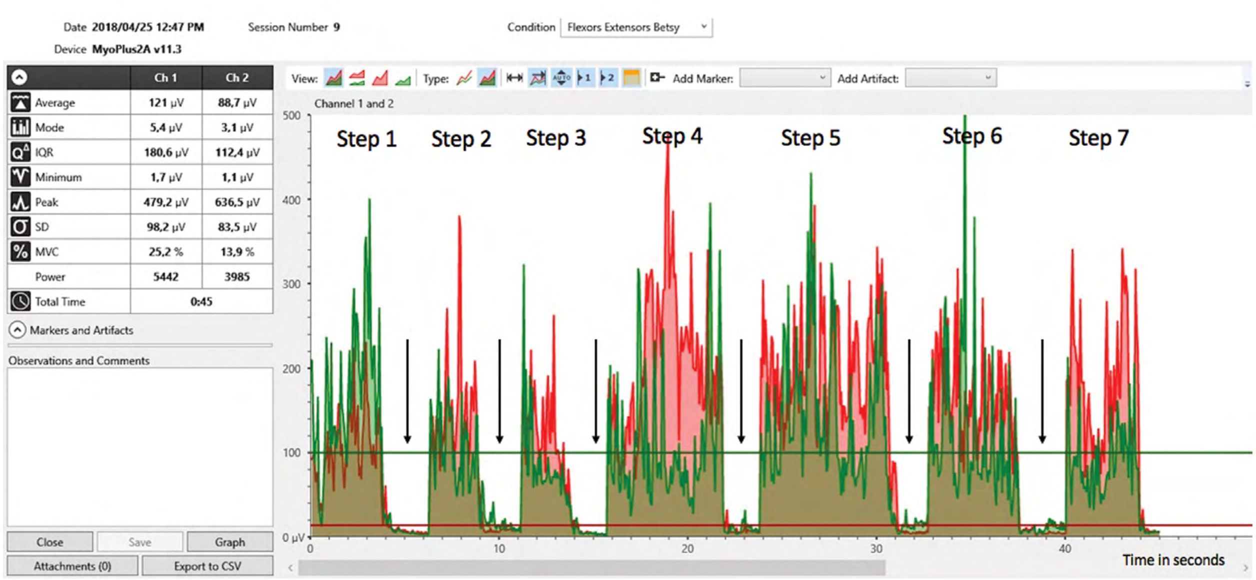

Figure 3: Example of a graphic EMG data capture file for forearm muscles (extensors and flexors) for a Breed'nBetsy® palpation. Ch1: Channel one (red) EMG recordings for forearm extensors during a live cow palpation. Ch2: Channel two (green) EMG recordings for forearm flexors during a live cow palpation

Step 1: palpation of the cervix
Step 2: palpation of the uterine body
Step 3: retraction of the uterus
Step 4: palpation of the left uterine horn
Step 5: palpation of the left ovary
Step 6: palpation of the right uterine horn
Step 7: palpation of the right ovary
↓ black arrows indicate areas of muscle relaxation between TRP steps

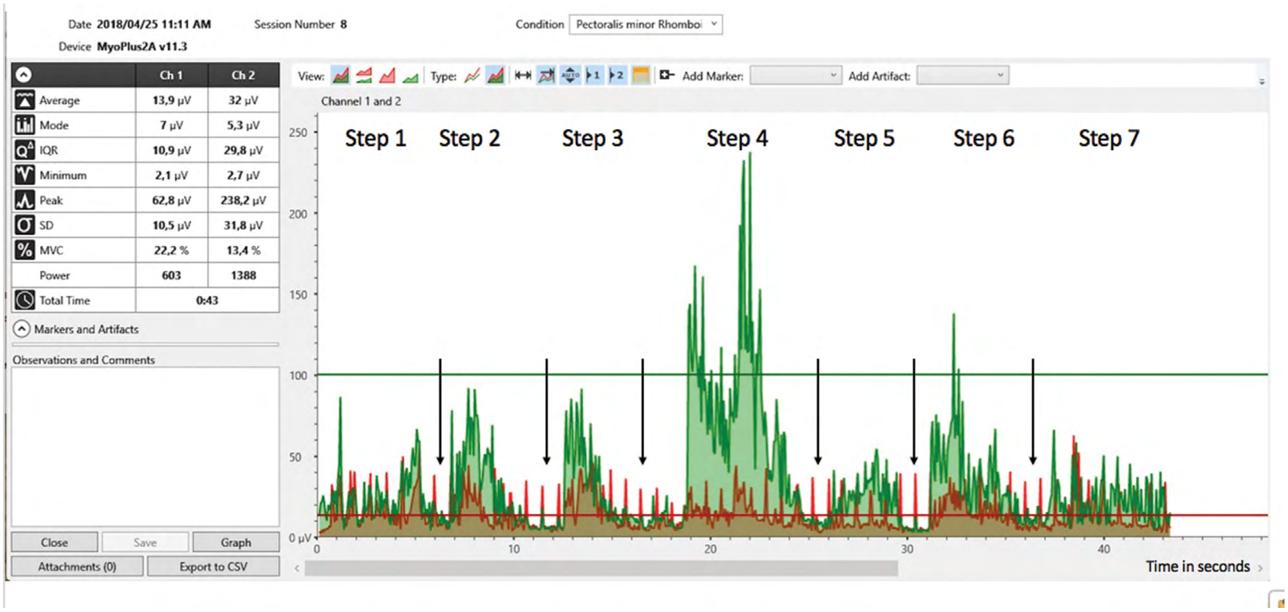

Figure 4: Example of a graphic EMG data capture file for shoulder girdle supportive muscles (pectoralis and rhomboid muscle) for a live cow palpation Ch1: Channel one (red) EMG recordings for the pectoralis minor muscle during a live cow palpation. Ch2: Channel two (green) EMG recordings for the rhomboid muscle during a live cow palpation

Step 1: palpation of the cervix
Step 2: palpation of the uterine body
Step 3: retraction of the uterus
Step 4: palpation of the left uterine horn
Step 5: palpation of the left ovary
Step 6: palpation of the right uterine horn
Step 7: palpation of the right ovary
↓ black arrows indicate areas of muscle relaxation between TRP steps

range and transformed using the natural logarithm prior to statistical analysis. Total muscle activation rate was compared among examination steps, muscle groups, antagonistic muscle groups (grouping for muscle group 1 [forearm extensors, biceps, anterior deltoid, and pectoralis muscles] was based on muscle activation at a 90-degree shoulder flexion position, which is similar to the arm position at the beginning of a TRP while entering the rectum. Grouping for muscle group 2 [forearm flexors, triceps, posterior deltoid, and rhomboid muscles] was based on expected muscle activation during the actual TRP procedure with downward movements of the arm and use of the hand), and cow/palpation simulator using linear mixed models. Linear mixed models included a random-effect term for SME and fixed-effect terms for cow versus palpation simulator, examination step, muscle group, and flexor/extensor. Post hoc comparisons were adjusted using the Bonferroni correction. Similar mixed models were fit independently for each step of the examination. Commercial software (IBM SPSS Statistics v. 25, International Business Machines Corp., Armonk, NY, USA) was used to fit statistical models and significance was set as $\alpha = .05$.

Subjective Evaluation of EMG Data Graphic Displays

An experienced physiotherapist (CAE) subjectively evaluated the EMG data graphic display files to determine whether each muscle activation pattern indicated use of total muscle strength or endurance. Muscle activation was evaluated for each TRP step based on duration (longer/sustained activation periods indicated endurance compared to short activation periods for total muscle strength) and force of muscle activation (submaximal force over a sustained time period/TRP step indicates muscle endurance and maximum force within a single exertion indicates total muscle strength).

Design of the Bovine PD Improvement Exercise Program

The analyzed and interpreted EMG data in combination with previous GS data[11] were used to design a 3-month exercise program with the help of an experienced biokineticist. All exercises were then demonstrated by a former female gymnast and video-recorded by a University of Pretoria–employed video producer during the program's development phase. The narrated videos explain how the exercises should be executed. All video clips were edited and uploaded with all the necessary information on the University of Pretoria's mobile online learning platform.

Ethical Considerations

This study was approved by the Animal Ethics and Research Committee of the University of Pretoria (Protocol V122–15).

RESULTS

Study Participants

The study population consisted of eight SMEs, of which three were female and five were male. Five of the SMEs (three males and two females) used their left arm for palpations while three (two males and one female) used their right arm.

Examples of the graphic EMG data sheets are shown in Figures 2–4.

Table 1: Median and interquartile range in microvolts (μV) for area under the electromyographic (EMG) curve for individual live cow and Breed'n Betsy® transrectal palpation (TRP) steps for antagonistic muscle groups listed as muscle group 1 and muscle group 2

	Live cows		Breed'n Betsy®	
	Muscle group 1*	Muscle group 2†	Muscle group 1*	Muscle group 2†
Step/muscle group	μV	μV	μV	μV
Cervix palpation (1)				
Forearm	421 (266, 1,087)	605 (355, 1,485)	364 (208, 524)	413 (257, 673)
Arm	108 (70, 166)	235 (178, 379)	69 (45, 102)	85 (69, 240)
Shoulder	91 (39, 144)	158 (97, 253)	85 (43, 331)	115 (65, 155)
SGSM	63 (24, 103)	115 (71, 144)	76 (53, 127)	84 (63, 145)
Uterine body palpation (2)				
Forearm	441 (162, 637)	314 (271, 810)	381 (143, 465)	319 (235, 449)
Arm	116 (58, 164)	240 (162, 386)	103 (78, 137)	142 (87, 317)
Shoulder	197 (102, 297)	218 (185, 346)	184 (141, 272)	131 (75, 269)
SGSM	63 (28, 87)	123 (90, 148)	48 (35, 135)	50 (42, 101)
Uterus retraction (3)				
Forearm	657 (434, 1,283)	941 (662, 1,408)	650 (367, 1,148)	496 (337, 1,171)
Arm	257 (147, 415)	306 (231, 541)	259 (76, 424)	183 (145, 505)
Shoulder	234 (127, 314)	289 (247, 509)	243 (117, 405)	213 (57, 504)
SGSM	82 (49, 135)	163 (109, 295)	157 (95, 211)	163 (68, 331)
Left horn palpation (4)				
Forearm	942 (615, 1,441)	1364 (734, 2,520)	760 (366, 1,200)	647 (497, 777)
Arm	346 (186, 436)	415 (360, 639)	322 (127, 417)	281 (196, 454)
Shoulder	267 (143, 480)	453 (164, 994)	526 (221, 640)	507 (143, 627)
SGSM	105 (68, 141)	298 (197, 479)	158 (93, 207)	201 (173, 272)
Left ovary palpation (5)				
Forearm	784 (315, 1,178)	758 (537, 1,094)	332 (313, 1,215)	581 (494, 742)
Arm	171 (108, 222)	170 (135, 293)	112 (64, 169)	140 (78, 192)
Shoulder	196 (118, 349)	255 (131, 528)	171 (99, 312)	111 (74, 222)
SGSM	76 (39, 111)	230 (125, 276)	125 (53, 281)	91 (79, 142)
Right horn palpation (6)				
Forearm	824 (485, 1,246)	999 (806, 1,369)	964 (515, 1,593)	665 (584, 773)
Arm	197 (114, 283)	267 (152, 372)	624 (188, 729)	298 (108, 374)
Shoulder	196 (123, 271)	285 (199, 442)	401 (323, 707)	238 (120, 494)
SGSM	55 (45, 78)	134 (91, 235)	161 (66, 196)	181 (118, 277)
Right ovary palpation (7)				
Forearm	520 (288, 720)	679 (515, 744)	387 (207, 531)	277 (126, 637)
Arm	99 (69, 394)	232 (122, 372)	142 (115, 166)	91 (54, 120)
Shoulder	133 (78, 195)	157 (82, 300)	223 (101, 321)	102 (41, 157)
SGSM	69 (55, 94)	159 (88, 260)	38 (31, 84)	82 (41, 110)

SGSM = shoulder girdle supportive muscles (pectoralis and rhomboid muscles)
*Muscle group 1: forearm extensors, biceps, anterior deltoid, and pectoralis muscles
†Muscle group 2: Forearm flexors, triceps, posterior deltoid, and rhomboid muscle

Pairwise Comparisons of Total Muscle Activation Rate for Individual Muscle Groups

Overall total muscle activation rate (microvolts per seconds, μV/s) for all steps of the TRP was significantly higher for forearm muscles (forearm extensors and flexors) compared with upper arm muscles (biceps and triceps), shoulder muscles (anterior and posterior deltoid muscle), and shoulder girdle supportive muscles (pectoralis and rhomboid muscle) ($p < .001$, Tables 1 and 2).

Overall total muscle activation rate for upper arm muscles (biceps and triceps) was not different than shoulder muscles

Table 2: Median and interquartile range in microvolts per seconds (μV/s) for rate of muscle activation for individual live cow and Breed'n Betsy® transrectal palpation (TRP) steps for antagonistic muscle groups listed as muscle group 1 and muscle group 2

	Live cows		Breed'n Betsy®	
	Muscle group 1*	Muscle group 2†	Muscle group 1*	Muscle group 2†
Step/muscle group	μV/s	μV/s	μV/s	μV/s
Cervix palpation (1)				
Forearm	84 (60, 112)	119 (87, 173)	78 (68, 86)	97 (76, 129)
Arm	26 (14, 36)	50 (36, 62)	14 (11, 20)	30 (21, 36)
Shoulder	15 (11, 30)	37 (28, 59)	26 (15, 51)	28 (14, 39)
SGSM	14 (10, 19)	23 (17, 31)	17 (12, 19)	17 (14, 29)
Uterine body palpation (2)				
Forearm	56 (46, 76)	80 (57, 133)	63 (55, 92)	76 (45, 123)
Arm	21 (16, 27)	46 (34, 64)	22 (15, 25)	33 (19, 55)
Shoulder	44 (22, 54)	50 (30, 64)	30 (25, 36)	33 (14, 63)
SGSM	16 (9, 21)	29 (21, 40)	17 (9, 21)	17 (14, 30)
Uterus retraction (3)				
Forearm	93 (72, 101)	132 (90, 153)	83 (62, 152)	96 (47, 184)
Arm	34 (25, 58)	54 (41, 82)	40 (26, 51)	44 (31, 59)
Shoulder	34 (22, 45)	44 (34, 89)	33 (23, 61)	43 (16, 93)
SGSM	16 (10, 18)	37 (24, 51)	24 (20, 38)	24 (16, 54)
Left horn palpation (4)				
Forearm	104 (74, 134)	183 (92, 209)	117 (89, 165)	81 (68, 124)
Arm	35 (27, 55)	64 (46, 73)	38 (27, 54)	42 (38, 49)
Shoulder	49 (30, 62)	97 (25, 142)	69 (41, 93)	52 (22, 109)
SGSM	14 (12, 21)	48 (38, 73)	20 (15, 23)	40 (19, 57)
Left ovary palpation (5)				
Forearm	95 (77, 129)	109 (69, 134)	93 (54, 117)	104 (70, 152)
Arm	30 (24, 45)	44 (26, 61)	26 (12, 32)	26 (18, 31)
Shoulder	38 (25, 69)	45 (27, 99)	35 (24, 59)	30 (13, 39)
SGSM	11 (8, 20)	43 (26, 51)	17 (10, 29)	18 (14, 27)
Right horn palpation (6)				
Forearm	85 (70, 127)	130 (94, 185)	152 (103, 178)	94 (80, 118)
Arm	30 (26, 59)	49 (40, 59)	74 (32, 174)	43 (35, 52)
Shoulder	41 (24, 62)	46 (28, 85)	63 (40, 92)	37 (25, 64)
SGSM	14 (8, 19)	34 (23, 45)	17 (11, 25)	26 (22, 34)
Right ovary palpation (7)				
Forearm	68 (53, 96)	81 (54, 129)	68 (57, 91)	69 (49, 85)
Arm	21 (17, 47)	40 (28, 51)	33 (12, 52)	20 (16, 24)
Shoulder	28 (22, 36)	31 (16, 79)	32 (32, 41)	15 (11, 17)
SGSM	12 (8, 16)	21 (16, 54)	10 (8, 19)	17 (13, 22)

SGSM = shoulder girdle supportive muscles (pectoralis and rhomboid muscles)
* Muscle group 1: forearm extensors, biceps, anterior deltoid, and pectoralis muscles
† Muscle group 2: Forearm flexors, triceps, posterior deltoid, and rhomboid muscle

(anterior and posterior deltoid muscle, $p = 1.000$) but higher than the muscle activation rate for shoulder girdle supportive muscles (pectoralis and rhomboid muscle, $p < .001$). Overall total muscle activation rate for shoulder muscles (anterior and posterior deltoid muscle) was higher than for shoulder girdle supportive muscles (pectoralis and rhomboid muscle, $p < .001$). Overall total muscle activation rate for shoulder girdle supportive muscles (pectoralis and rhomboid muscle) was significantly less than for all other muscle groups ($p < .001$, Tables 1 and 2).

Pairwise Comparisons of Total Muscle Activation Rate for Individual TRP Steps

Compared to cervix palpation (step 1), total muscle activation rate was higher for steps 3, 4, and 6 (retraction of the uterus, palpation of left and right uterine horn, $p < .001$), but not different for steps 2 (palpation of uterine body, $p = 1.000$), 5 (palpation of left ovary, $p = .171$), and 7 (palpation of right ovary, $p = 1.000$). Muscle activation rates in µV and µV/s for all muscle groups and individual steps are listed in Tables 1 and 2, respectively.

Comparison of Muscle Activation Rate for Live Cow and BB Palpations

Total muscle activation rate (all TRP steps combined) was not different for cow 1 palpations or cow 2 palpations ($p = .294$).

Total muscle activation rate for BB palpations overall for all steps was not different than cow 1 palpations ($p = .053$) but was lower than cow 2 palpations ($p < .001$). Within individual steps, palpations performed on cow 2 resulted in a higher muscle activation rate for steps 1 ($p = .028$), 2 ($p = .030$), 5 ($p = .002$), and 7 ($p = .030$) compared with BB palpations. There was no difference in muscle activation between cow 2 and BB palpations for steps 3 ($p = .518$), 4 ($p = .152$), and 6 ($p = .358$). Muscle activation rates in µV and µV/s for live cow and BB palpations and individual steps are listed in Tables 1 and 2, respectively.

Comparison of Muscle Activation Rate for Antagonistic Muscle Groups

Overall muscle activation rate was higher for group-2 muscles (forearm flexors, triceps, posterior deltoid, and rhomboid muscle) compared with group-1 muscles (forearm extensors, biceps, anterior deltoid, and pectoralis muscle) for all steps ($p < .001$). Within individual steps, group-2 muscle activation was higher for TRP steps 1–6 ($p < .001$ for steps 1–4, $p = .005$ for step 5, and $p = .008$ for step 6) compared to group-1 muscle activation, but activation was not different for step 7 ($p = 1.000$).

Subjective Evaluation of EMG Data Graphic Displays

Subjective evaluation of the EMG data graphic display files suggests a muscle endurance activation pattern with submaximal muscle force activation over a sustained time period rather than single exertion of maximum muscle force that would be associated with total muscle strength.

Design of the Bovine PD Improvement Exercise Program

The exercise program was developed to specifically target GS (forearm extensors and flexors and hand muscles) and upper arm and shoulder as well as core muscle strength and endurance. It is divided into three levels, starting with easier entry-level exercises and building up to more advanced exercises. Participation in the program takes 30 minutes, three times a week. The program was designed in a way that allows students to exercise in a relatively short time period with any comfortable clothes (no changing of clothes required) and readily available exercise equipment. The exercise equipment used is GS-specific equipment—Powerballs (Mantality, Canero Business Park, Johannesburg, South Africa), egg exercisers, hand exercise webs (both from the Physio and Wellness Warehouse, Willow Park Manor, Pretoria, South Africa), and dumbbells—as well as general exercise equipment—yoga mats, Powercore exercise balls (65 cm, 150 kg carrying capacity), and different strengths of TheraBand® latex exercise bands (Hitech Therapy CC, Bryanston, South Africa) (Figure 5). Each day of the exercise program starts with a warm-up and is followed by one powerball, two egg exerciser, and two hand exercise web exercises. These exercises are then followed by an additional two exercises per day that vary from day 1 to day 3 of the program and concentrate on whole arm, shoulder, back, core or abdominal, and leg muscle strength. The combination of exercises ensures a variety of training routines and a balanced workout that concentrates on the muscle groups listed above. All edited and narrated video clips were uploaded with all the necessary information on the University of Pretoria's mobile online learning platform. The exercise program is called the Bovine PD Improvement Exercise Program and can be accessed online (http://icarus.up.ac.za/vetmlp/) on smartphones, tablets, desktop computers, and laptop computers. A 2-minute welcome video message gives students information on the background of the exercise program, information on targeted muscle groups, the time commitment required, and the expected outcome. Links to download the program, to a short introduction video on the exercise equipment, to levels 1–3 of the program, and to acknowledgments are provided (Figure 5). The exercise program videos per individual day can be accessed through links to levels 1, 2, and 3 of the exercise program.

All necessary exercise equipment as well as a handheld digital GS dynamometer, CAMRY Model EH 101 (Camry Scale, South El Monte, CA, USA) were purchased by the teaching institution and made available to students within the veterinary skills laboratory. The skills laboratory has tablets available for students to use who do not have a smartphone or tablet.

DISCUSSION

The EMG analysis of muscle activation patterns and muscle activity levels during bovine TRP improved understanding of the TRP movement technique.

The finding that muscle activation of the forearm (flexors and extensors) during TRPs were higher than muscle activation of any other muscle group is consistent with the previously described predictive value of GS (= combined hand and forearm muscle strength) for students' PD accuracy.[11] The method of bovine TRP and PD,[12-17] where palpation of the female reproductive tract is done through the rectal wall to feel for positive signs of pregnancy, as well as gestational age or nonpregnancy, suggests that the muscles of the whole arm are used in the procedure. However, the results of this study confirm that locating and thoroughly palpating the reproductive structures, moving from the cervix to uterine horns, palpating uterine horns up to the ovary, and fixing the ovaries to enable palpation of ovarian structures mostly uses finger movements facilitated by forearm muscles, in combination with forearm pronation and supination movements (which allow hand and forearm rotation).

Total muscle activation within individual steps was consistent with the hypothesis that retraction of the uterus and palpation of left and right uterine horn require higher muscle activation compared with all other TRP steps. These results and the finding that group-2 muscles (forearm flexor, triceps, posterior deltoid, and rhomboid muscle) are more strongly activated compared with group-1 muscles (forearm extensor, biceps, anterior deltoid, and pectoralis muscle) could be explained by the technique used to perform these steps of the TRP procedure. To retract the uterus, using the intercornual ligament technique, the middle finger is hooked under the ventral intercornual ligament before a simultaneous dorsal and caudal movement of the hand and forearm draws the uterus into the pelvic cavity. This movement often reflects the uterus back on itself and allows for complete

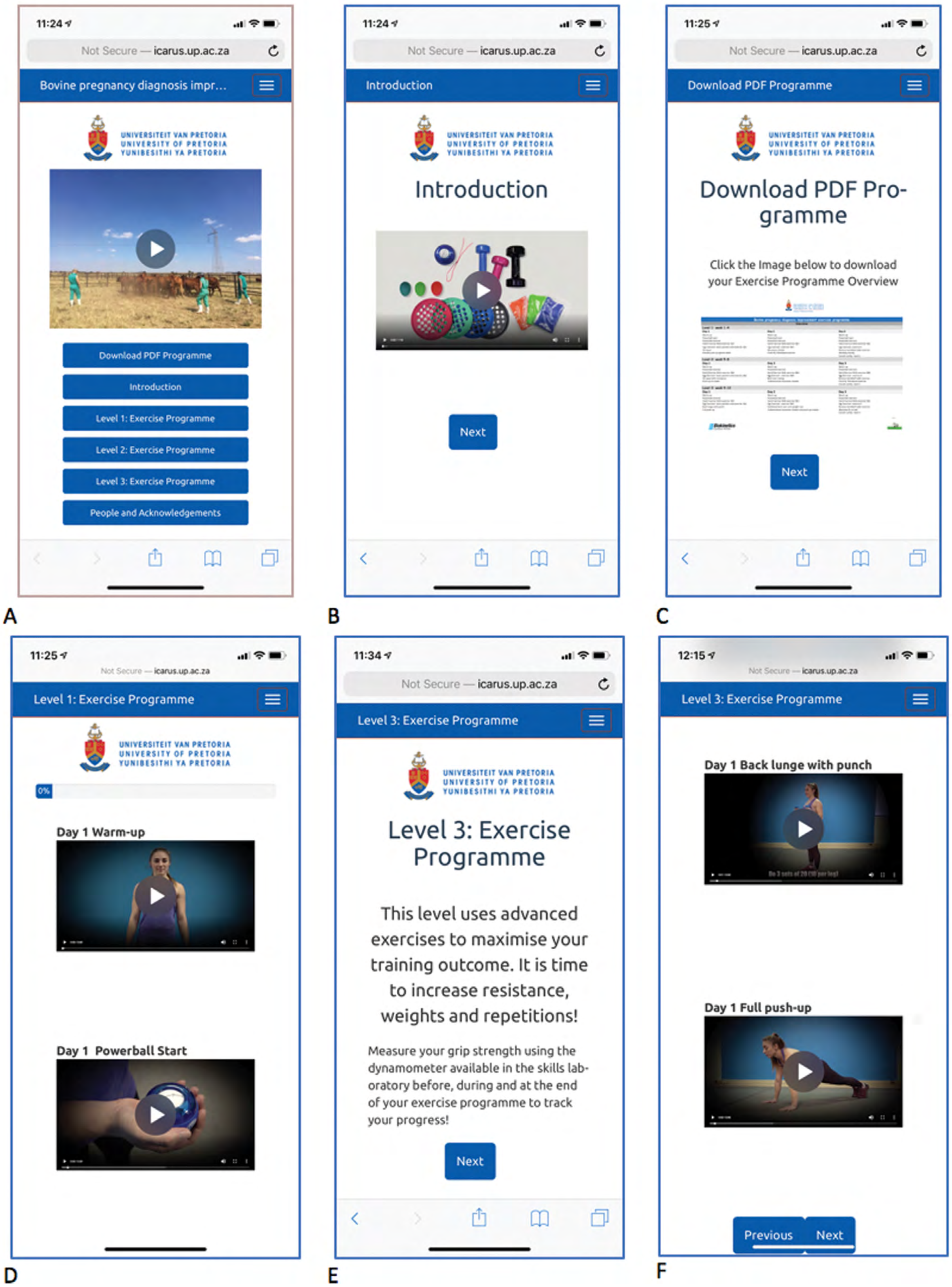

Figure 5: Screenshots of the "Bovine pregnancy diagnosis improvement exercise program App" as seen on smartphone accessed through: http://icarus.up.ac.za/vetmlp/

A Homepage with the welcome video and all links of the exercise program. B Link with the introduction video to the exercise equipment. C Link to download the exercise program overview. D Link to exercise Level 1: videos demonstrating the exercises. E Links to the different exercise levels give additional information and remind users to track their progress via grip strength measurements. F Examples of two Level 3 exercises.

and thorough examination of both horns. Palpation of uterine horns starts at the base of the uterine horn at the bifurcation with the index, middle, and ring fingers on the ventral side of the horn and the thumb on the dorsal side. Keeping the fingers in that same position, the hand now moves up from the base of the horn toward the tip while uterine horn size, tone, contents, and consistency are examined. This movement pattern would explain why these TRP steps require more muscle activation than, for example, the downward and lateral movements required to locate cervix and uterine body. The same can be expected for ovarian palpation compared with uterine body retraction or horn palpation. Once the ovary is fixed in the hand by placing the mesovarium between middle and ring finger with the ventral "free" ovarian border dorsally, only the thumb is used to examine ovarian size and structures, while no further arm movement is involved in this step.

The fact that there was only a difference in muscle activation between cow 2 and BB palpations but not between cow 1 and BB palpations, while the muscle activation for cow 1 and cow 2 palpations was similar, is interesting. While the latter finding was expected, we hypothesized that muscle activation for TRPs in live cows would be higher than for TRPs in BBs. This hypothesis could be used to explain the difference in training outcomes for BB-trained and live cow–trained students.[3] It was based on the reasoning that rectal examination simulators might not require the same movements and muscle activations during TRPs as what is required for live animals.[3] However, the absence of rectal peristalsis, anal sphincter tone, and other internal organs such as a bladder and rumen did not cause a significant difference in muscle activation between BB and cow 1 palpations. The fact that cow 2 palpations required higher overall muscle activation for all steps combined compared with BB palpations might be due to more intense rectal straining during cow 2 palpations. It is interesting that within individual steps, the steps requiring the most muscle activation (retraction of the uterus and palpation of uterine horns) were similar for cow 2 and BB palpations. Based on these findings, a difference in muscle activation for BB and live cow palpations as a potential reason for the difference in training outcome for BB- and live cow–trained students, as hypothesized previously,[3] is less likely to be true.

However, it seems easier to relax between individual TRP steps for BB palpations than for live cow palpations, as seen in Figures 2 and 3. Figures 2 and 3 show forearm muscle activation for a live cow and a BB palpation, respectively. The areas of muscle relaxation between TRP steps, as indicated by arrows in these figures, are more distinct for BB palpations. This finding was consistently seen for all muscle groups during BB palpations.

The fact that evaluation of the graphic EMG recordings suggests an endurance pattern of muscle activation supports a previous hypothesis that endurance is more important during TRPs rather than total muscle strength.[11] Students who participated in a previously described exercise program were better at identifying pregnant cows, while an increase in total muscle strength was not measurable on completion of the exercise program.[11] The proposed explanation for this finding is that the exercise program increased muscle endurance rather than total muscle strength.[11] The increased endurance as a hypothesized reason for better PD performance was supported by the results of the current study. This finding was subsequently used to modify the previously described exercise program[11] and to design a 3-month exercise program aimed at GS and improving arm muscle strength and endurance. The finding that group-2 muscles (forearm flexor, triceps, posterior deltoid, and rhomboid muscle) were more strongly activated than group-1 muscles (forearm extensor, biceps, anterior deltoid, and pectoralis muscle) was also considered to compile the revised exercise program outline.

Making the Bovine PD Improvement Exercise Program available through a user-friendly online application considers previous students' improvement suggestions to make such a program widely available to more students with added time and location flexibility.[11] Feedback on the previously described exercise program showed that students not only experienced physical benefits but also had fun and felt relaxed while exercising, socializing, taking part in comradery, and releasing stress. Exercise has been described to be one of the most important pursuits to improve physiological as well as psychological health.[18,19] Reduced risk for depression and anxiety, improved mood, better sleep quality, and better cognitive functioning are known psychological benefits of exercising.[18–20] Since stress-related disorders are common among veterinary students worldwide,[20–28] implementation of an exercise program not only benefitting arm strength and indirectly TRP accuracy but also improving general student well-being could be a positive addition to veterinary curricula. However, physical activity can become less of a priority among veterinary students because of heavy workload within the veterinary program combined with stress of academic performance.[20] It has also been shown that students require motivators to exercise.[20,29] Increased GS and arm muscle endurance through participation in this program will have positive effects not only on veterinary hands-on skills (bovine TRP and PD) but potentially also on other aspects of student activities. Therefore, if participation in an exercise program not only increases arm strength and indirectly palpation accuracy but also general student well-being, these additional physiological and psychological benefits are hoped to motivate students to exercise and use the Bovine PD Improvement Exercise Program.

A study limitation was the technical restriction due to limited EMG ETS availability and logistics around using EMG ETS technology (portable vs. fixed machines) in a bovine examination crush setup. Because the only portable EMG ETS machines available for use in the experiment were two-channel machines, the number of muscle groups that could be examined simultaneously was restricted. If, for example, an eight-channel EMG machine had been available, inclusion of further muscle groups, such as back and core muscles, would have been possible. Including these muscle groups would have been advantageous since musculoskeletal disorders related to the veterinary profession, and large animal procedures and rectal examination in particular, have been widely described.[30–34] Future EMG studies should investigate additional muscle activation patterns with a view of musculoskeletal disorder prevention through posture improvement, for example.

Another limitation is that the results for cow 1 and cow 2 had to be reported separately. This was because the study design required modeling the cow as a fixed effect in the linear mixed model for the statistical analysis. Modeling the cow as a random effect would have been preferable, but this was not possible because the BB measurements were not repeated. Therefore, joining the formal statistical data for cow 1 and cow 2 and a pooled comparison between cow and BB was not possible. Furthermore, substantial variation existed between cows in ease of palpation, and including more live cow palpations in the study design would have been advantageous.

CONCLUSIONS

The EMG analysis of muscle activation pattern and activity during bovine TRP adds novel information to the existing literature concerning bovine TRP and PD. In conclusion, muscle activation was highest for forearm muscles; was higher during retraction of the uterus and palpation of left and right uterine horn, compared with palpation of cervix, uterine body, left ovary, and right ovary ($p < .001$); was higher for group-2 muscles (forearm flexors, triceps, posterior deltoid, and rhomboid muscles) than group-1 muscles (forearm extensors, biceps, anterior deltoid, and pectoralis muscles) ($p < .001$); and showed an endurance pattern. These results have been used to modify a previously developed exercise program to improve students' TRP and PD skills. The Bovine PD Improvement Exercise Program is available to students through an online application (http://icarus.up.ac.za/vetmlp/) and aims to improve not only GS and TRP accuracy but also stamina and well-being while adding fun to busy study schedules. This use of technology can complement traditional TRP training in effort to maximize training outcomes for programs with limited live animal exposure.

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