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Haptic Stiffness Identification by Veterinarians and Novices: A Comparison

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Abstract

Palpation is important in both veterinary and medical health professions. It is however difficult to learn, teach and assess. More must be understood about the skills involved in palpation. The present study compares the ability of practicing veterinarians and veterinary students to identify stiffness values. An absolute identification paradigm was used where a force-feedback device rendered virtual surfaces with 5 levels of stiffness within a "clinically relevant" range of 0.2 – 0.5 N/mm. The results from 12 veterinarians and 14 veterinary students show that the veterinarians performed significantly better than the students ($p < 0.001$). The mean information transfer was 0.97 bits (almost 2 perfectly-identifiable stiffness levels) for the veterinarians and 0.58 bits (1 correctly-identified stiffness level) for the students. However, neither group was able to reliably identify more than 2 levels of stiffness, indicating that the success of veterinarians in clinical practice probably relies on additional properties such as size, shape and texture. Our findings suggest that stiffness perception in the context of veterinary medicine is a learned clinical skill. Quantifying expert ability will help inform teaching methods and set targets for students. Similar psychophysical methods can also be used to monitor student performance throughout the learning process. Future work will examine the contributions of other object properties as well as motor strategies to palpation performance.

Keywords: palpation, stiffness identification, comparison of experts and novices, veterinary medical education, haptics.

Index Terms: C.0 [Computer Systems Organization]: General - Hardware/software interfaces; J.4 [Computer Applications]: Social and Behavioral Sciences – Psychology

1 Introduction

In both human and veterinary medicine, health professionals use palpation as part of many clinical examinations. When palpating a structure, the clinician uses the sense of touch to assess properties such as size, shape, texture and stiffness. The information gathered helps in the diagnostic process. Examples of palpation based examinations in human medicine include the detection of prostate and breast cancer and in veterinary medicine the diagnosis of pregnancy in several species.

Learning and teaching palpation is difficult, especially when the examination is internal and unsighted. Opportunities for trainees to practice on real patients are limited by ethical considerations and have been further reduced by rising student numbers. Additionally, the level of skill required is hard to quantify which makes setting targets for students and assessing competence difficult. Simulators provide a potential solution to some of these issues and a number of medical and veterinary palpation simulators have been developed. Most are mannequins or part-task trainers (for example, the E-Pelvis for teaching pelvic examinations [1]). But there are also a few virtual reality (VR) simulators that use haptic technology, which is particularly important for techniques that rely on palpation. For example, in human medicine, VR haptic simulations have been developed to teach palpation in the context of diagnosing prostate cancer [2] [3] and breast cancer [4], and learning osteopathic techniques [5]. In the veterinary domain, The Haptic Cow [6] has been developed to teach palpation of the bovine reproductive tract. The increasing number of techniques being simulated is indicative of the potential of haptics in this area, but training benefits need to be demonstrated before such simulators will be widely adopted. To this end, The Haptic Cow system has been proven to be effective at training veterinary students to locate the uterus in cows. It has been integrated into the undergraduate curriculum at the Faculty of Veterinary Medicine, University of Glasgow [7] and more recently at other veterinary schools in the UK.

In the present study we focus on the skills involved in palpation. When diagnosing the particular state of pregnancy in the cow, veterinarians feel for a reduction in the stiffness of the uterus associated with the presence of fetal fluid. Experienced veterinarians can estimate the gestation stage of a pregnant cow to within a few weeks or even days, an ability that untrained veterinary students do not possess until they have examined many cows. Palpation is an important skill in medical diagnosis in general when, for example, the clinician is identifying types of a lump, e.g., abscess, cyst or tumor. More needs to be understood about the skills involved in palpation in order to maximize the training benefits that simulators offer. We are particularly interested in revealing the aspects of palpation that separate practicing veterinarians from veterinary students so that proper training modules can be developed to train more students in less time. To begin with, we examined a single element of palpation: judging stiffness. We sought to answer the following research question: *Is there a perceptual difference between experts and novices in terms of stiffness judgments*? By comparing the abilities of veterinarians with those of students, we investigated if stiffness perception is affected by clinical practice. The results will be used to inform the design of future simulators. Also, by quantifying expert ability we can identify the level of skill that a student might need to achieve in order to be competent.

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Psychophysical studies can quantify stiffness perception in terms of detection, discrimination or identification [8]. In the case of detection, the ability to recognize the presence of a stimulus is measured as the Absolute Threshold, or the smallest detectable stimulus intensity. In the case of discrimination, the ability to discriminate between two stimuli is measured as the Difference Threshold, the just noticeable difference (JND), or the smallest change in the intensity of a stimulus that is noticeable. A third paradigm, absolute identification, estimates the participants' ability to recognize stimulus values in isolation; i.e., without a reference or comparison value. In this case, given a particular type of stimulus, the maximum amount of information that the human sensory system can transmit, the information transfer (IT) or channel capacity, is determined experimentally (see [9]; and [10] for a practical overview of conducting absolute identification experiments). The clinical task faced by practicing veterinarians, namely the assessment of the gestation stage of a pregnant cow, is closest in concept to the absolute identification paradigm.

Most existing studies of stiffness perception have used a discrimination paradigm. The results are often reported as the Weber fraction, i.e., the JND divided by the reference stiffness. Weber's law states that this ratio is a constant indicating that JND is proportional to the reference stiffness. The Weber fraction is reported to be 23% for the elbow joint [11], 22% for a pinch grip between the thumb and forefinger [12], and 10% for unrestricted active probing using a PHANToM stylus [13]. One previous study of stiffness perception used an absolute identification paradigm [14]. It reports an information transfer of 1.46 bits over a stiffness range 0.2–3.0 N/mm for a group of college students and researchers with no clinical experience. This translates to the reliable identification of only 2–3 stiffness levels when stiffness is judged in isolation.

The present study follows the protocol of [14] with two important differences. Two groups of participants, experienced veterinarians and inexperienced veterinary students, were tested and their performance compared. In addition, the stiffness range was chosen to be "clinically relevant" to allow the practicing veterinarians to take advantage of their domain-specific knowledge and skills. Therefore, the present study was designed to assess the perceptual differences, if any, between experts and novices in a controlled yet clinically relevant experimental setting.

2 METHODS

2.1 Participants

Fourteen veterinary students (9F, 5M) and 12 practicing veterinarians (7F, 5M) participated in the experiment. The students (the "novices" in the present study) were in the 3rd year of the 5 year veterinary course at The Royal Veterinary College, University of London. They were at a stage in their course just prior to beginning clinical practical experience. The veterinarians (the "experts") had been working in veterinary practice for between 4 and 24 years.

2.2 Apparatus

A force-feedback haptic device (PHANToM Premium 1.5, SensAble Technologies, Woburn, MA, USA) was used in the experiment to render a virtual surface to which a variety of stiffness values were assigned. The participant interacted with the virtual surface using the middle finger inserted in the PHANToM thimble (Figure 1). In the context of The Haptic Cow, veterinarians favoured the use of the middle finger, as they judged it to provide a more realistic experience than using the index finger [7]. The haptic device was placed inside a box and concealed from view by a curtain. The participant was seated with

Figure 1. The PHANToM Premium 1.5 and other apparatus as configured for the experiment. Shown on the computer screen are the instructions and a simple visualization of the virtual surface and haptic interaction point presented during the pre-experiment tutorial. No graphical information was shown during the experiment.

the arm supported by a cushioned arm rest. The PHANToM rendered a stiff constraint (see 2.3 Stimuli) that restricted movement of the fingertip to the up-down dimension (y-axis). Beyond this no restrictions were imposed on the range of vertical movements the participant could make. The participant wore headphones to eliminate possible audible cues and distractions.

2.3 Stimuli

A horizontal virtual surface (in the x-z plane of the PHANToM workspace) was simulated with the haptic device. The elastic stiffness values of the virtual surface varied from 0.2 to 0.5 N/mm. This range was representative of stiffness values that would be commonly encountered by a veterinarian during palpation. This clinically relevant range was based on values previously selected by veterinarians to represent a range of tissue types (during the development of The Haptic Cow, a validated veterinary haptic palpation simulator) [15].

Five different stiffness values were used in the present study. According to [10], the number of stimulus levels in an absolute identification experiment should be (1) higher than the expected best performance so that channel capacity can be estimated, and (2) as low as possible in order to minimize the number of trials required. In our earlier study on stiffness identification [14] where a wider range of stiffness values (0.2 – 3N/mm) was used, the best individual performance was an information transfer of 2.06 bits, or the correct identification of 4 stiffness levels. Since a smaller stiffness range (0.2 – 0.5 N/mm) was used in the present study, we expected the best performance to be less than 4 stiffness categories (see [16] for discussion on why information transfer increases with stimulus range for auditory intensity identification). Therefore, 5 stiffness levels were considered sufficient in the present study. With regard to the second consideration, it has been shown that a minimum of $5k^2$ trials are needed in order to obtain an unbiased estimate of information transfer (where k is the number of stimulus alternatives) [17]. With $k = 5$ in the present study, $5k^2 = 125$ trials, which was manageable. We chose to collect twice the minimum required number of trials per participant ($10k^2 = 250$) in keeping with our previous study on stiffness identification [14]. Finally, the 5 stiffness values were equally spaced on a logarithmic scale between 0.2 and 0.5 N/mm. Earlier studies showed that Weber's Law holds for stiffness discrimination (e.g., [11]). Therefore, placing stiffness values equally on a logarithmic scale ensured that adjacent stiffness values were equally discriminable, or equivalently, that perceived stiffness increased linearly for the 5 stiffness values in the stimulus set.

The movement of the thimble was constrained to the up and down (y-axis) direction to make it easier for the participants to interact with the virtual surface. It also served to standardize the location within the haptic device's workspace at which each participant could make contact with the virtual surface. The latter was important because the characteristics of the haptic device are not uniform across the whole workspace. Preliminary testing revealed that the perceived stiffness of the virtual constraint needed to be larger than the highest stiffness level of the virtual surface. Otherwise the haptic interaction point would slip across the horizontal virtual surface while the participant tried to move it in the up-down direction. Such transverse movements would lead the participant to confuse the perceived stiffness of the constraint with the stiffness of the virtual plane. A PD controller was implemented to achieve a sufficiently hard constraint without destabilizing the haptic device.

The actual force levels the participants experienced depended on the penetration depth into the virtual plane and the constraint. The maximum force output of the haptic device was set at 5N to prevent the motors from overheating. Whenever the 5N output force was reached, a warning message was displayed to the participants instructing them to press more lightly on the virtual surface. This however was not treated as an error trial; the trial continued and the participant responded to the stiffness presented.

2.4 Procedures

The experiment used a one-interval five-alternative forced-choice absolute identification procedure. Prior to the experiment, the participants followed an automated tutorial on the computer. Computerized instructions described the correct operation of the haptic device and participants were able to feel an example virtual surface. A simple graphic visualization of the surface, haptic interaction point and virtual constraint were provided. The experiment itself consisted of a training session followed by a testing session. No graphical representation of the surface was provided during the training and testing sessions. In the training session participants learned to associate the five different stiffness levels of the virtual surface with the numbers 1 to 5. The softest surface was associated with the number 1 and the hardest with the number 5. The training program allowed the participant to press any number between 1 and 5 on the keyboard and then feel the corresponding stiffness via the haptic device (see Figure 1). The participant was free to choose the order in which s/he experienced the stiffness levels and could revisit the same stiffness multiple times. The participant was limited to changing the stiffness level 20 times after which the testing session began.

During the testing session, on each trial, the participant was presented with a surface of a stiffness value randomly selected from the same five values experienced in the training session. The participant's task was to identify the stiffness of the surface and press the corresponding number key. No visual information was shown on the computer screen during palpation of the virtual surface. After a response was entered, the correct answer was shown on the screen. A total of 250 trials were collected per participant. A 5-minute break was enforced after the initial 125 trials to prevent fatigue from affecting the participant's performance.

In both the training and testing sessions the participant was required to lift the thimble up from the virtual surface before the stiffness of the surface was changed. This prevented any sudden change in the force output of the haptic device. It also prevented the participants from using the sudden increase or decrease in force as a cue for identifying stiffness. The participants were aware that their finger movements were constrained to the up-down direction, but no specific instructions were given regarding the palpation technique to be used for stiffness identification.

2.5 Data Analysis

For each participant, the recorded stimulus-response pairs were used as indices into a confusion matrix (5 rows representing the 5 stiffness levels, 5 columns representing the responses). Each cell in the confusion matrix accumulated the number of times that a specific stimulus-response pair occurred. The entries along the main diagonal correspond to the trials where the participant correctly identified the stimuli. For each participant, data from the first and second sets of 125 trials were combined to form one confusion matrix.

Equation (1) shows the formula for calculating information transfer. By applying this equation to the confusion matrix, the amount of information communicated via the sensory system can be calculated [10]. In Eqn. (1), k is the number of stimulus alternatives, n is the total number of trials, n_{ij} is the cell entry in the i-th row and j-th column of the confusion matrix, n_i is the sum of the entries in the i-th row, n_j is the sum of the entries in the j-th column, and IT denotes information transfer. The number of stiffness levels that the participants can identify without error can then be calculated as 2^{IT}.

$$IT = \sum_{j=1}^{k} \sum_{i=1}^{k} \frac{n_{ij}}{n} \log_2 \frac{(n_{ij} \cdot n)}{(n_i \cdot n_j)} \qquad (1)$$

3 Results

Table 1 shows the information transfers estimated from the 250 trials per participant. The results for the 12 experienced veterinarians varied from 0.72 bits to 1.15 bits, with an average of 0.97 bits and a standard deviation of 0.14 bits. This corresponds to the identification of 2.0 levels of stiffness. The results for the 14 veterinary students varied from 0.05 bits to 0.78 bits, with an average of 0.58 bits and a standard deviation of 0.23 bits. This corresponds to the identification of 1.5 levels of stiffness. The best veterinarian could correctly identify 2.2 stiffness levels, but the best student could only identify 1.7 stiffness levels without error. The differences between the student and veterinarian groups can be clearly seen in Figure 2 that compares the spread of information transfers calculated from the 12 veterinarians and 14 students. Shown in each boxplot are the smallest and largest values (the whiskers), the lower and upper quartiles (the bottom and top of the box, respectively) and the median (the line inside the box). Essentially, the veterinarians could correctly identify (almost) 2 stiffness levels without errors, and the students could only identify 1 level. A one sample Kolmogorov-Smirnov (KS) test showed that IT for both the veterinarian and student groups was normally distributed. An independent samples t-test showed that the difference in IT between the veterinarians and students was highly significant ($p < 0.001$).

For both the veterinarian and student groups, a paired samples t-test showed no significant difference between the IT measured for a participant during the first set of 125 trials and the second. This lack of significant training effect indicated that the task itself was easy to learn, and that the participants' ability to identify stiffness levels was stable throughout the 250 trials.

The stimulus-response confusion matrices are shown in Table 2a for the students and Table 2b for the veterinarians. The entries along the main diagonals are the correct responses whereas all other entries are errors. A visual inspection indicates that there are a lot more errors for the students that are further away from the main diagonal line than the veterinarians. This means that the

Table 1. Information transfers (IT) for stiffness identification

Students	IT (bits)	Veterinarians	IT (bits)
S1	0.26	V1	1.15
S2	0.70	V2	1.13
S3	0.46	V3	0.76
S4	0.44	V4	0.72
S5	0.05	V5	1.01
S6	0.77	V6	1.04
S7	0.49	V7	0.99
S8	0.76	V8	0.92
S9	0.78	V9	0.99
S10	0.78	V10	0.83
S11	0.77	V11	1.14
S12	0.73	V12	0.99
S13	0.69		
S14	0.46		
Average	**0.58**	**Average**	**0.97**
Std. Dev.	**0.23**	**Std. Dev.**	**0.14**

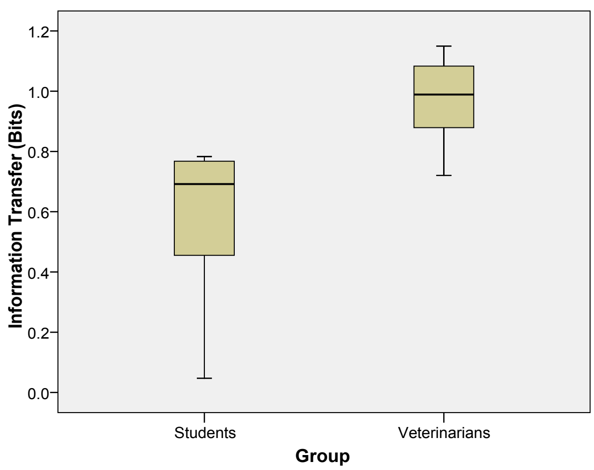

Figure 2. Comparison of the range of information transfer for the student and veterinarian groups

Table 2. Confusion matrices for (a) student and (b) veterinarian groups. S1-S5 denote the five stimulus levels, and R1-R5 the five response labels. The n_j rows show the number of times each response label was used.

(a) Students

	R1	*R2*	*R3*	*R4*	*R5*
S1	375	194	80	29	15
S2	155	267	213	77	21
S3	34	137	223	181	67
S4	21	46	178	270	216
S5	13	26	84	218	360
n_j	*598*	*670*	*778*	*775*	*679*

(b) Veterinarians

	R1	*R2*	*R3*	*R4*	*R5*
S1	461	137	14	4	0
S2	142	285	153	16	0
S3	14	108	338	131	10
S4	2	11	167	313	124
S5	0	3	36	150	381
n_j	*619*	*544*	*708*	*614*	*515*

veterinarians made “smaller” errors (i.e., identifying a level 1 stiffness as 2, but not 5) than the students, which is consistent with the difference in IT for the two groups. Note also that there is no systematic response bias for either group as indicated by the consistent number of times each response label was used (see the rows labeled n_j).

4 Discussions

The present study measured the haptic perceptual abilities of veterinarians and veterinary students when identifying the stiffness of a virtual surface. The veterinarians were significantly better at the task, being able to identify more values within a set range. These findings indicate that stiffness perception in the context of veterinary medicine is a learned clinical skill i.e., with clinical experience the skill of assessing stiffness improves.

Our results can be compared to those from our previous stiffness identification experiment where a larger stiffness range was used (0.2 – 3.0 N/mm as opposed to 0.2 – 0.5 N/mm used in the present study) [14]. As expected our information transfer estimates for both groups (0.97 and 0.58 bits for veterinarians and students, respectively) were lower than the information transfer obtained with what can be considered non-experts in [14] (1.46 bits). The difference is most likely due to the differences in the stiffness range used in the two studies. There were also two additional differences in the methodologies of the two experiments that preclude a direct comparison of results. Firstly, the haptic devices were different in the two studies, and the previous study used a stylus interface whereas the present study used a thimble interface. Secondly, the previous study prescribed the use of a tapping technique, while the present study allowed participants to use any method they desired. The possible influence of motor strategy on stiffness perception is an interesting and important issue that warrants further investigation in our future studies.

One might argue that the (almost) 2 levels of perfectly-identifiable stiffness levels achieved by the experienced veterinarians in the present study is not very impressive. Indeed, within a clinically-defined stiffness range, a practicing veterinarian would be expected to identify a number of different states of bovine pregnancy from not pregnant to several stages of early pregnancy. However, in the experiment the veterinarians barely identified two levels of stiffness across a slightly wider range. The ability of veterinarians to perform better when assessing pregnancy in a cow as compared to identifying stiffness values in the current study is probably related to the diagnosis depending on changes in other properties, such as size and shape, in conjunction with stiffness. Additionally, the veterinarian used one finger with the haptic device whereas during the real task s/he can use multiple digits. The ability to combine component skills and make diagnostic judgments is also important in the development of expertise. Therefore, as well as considering skills in isolation, the other factors that create the clinician should also be considered in our future work.

The nature of the simulated stimuli probably also contributed to the measured IT being lower than expected. It has been suggested that the kinesthetic channel contributes just one quarter of the information used to assess stiffness, with cutaneous cues providing the rest [18]. Unlike the palpation of organic tissue, our simulated stimuli lacked the cutaneous cues generated by surface deformation. Therefore we would expect our measured IT to be an underestimate compared to performance in real clinical scenarios. However, since the performance of both groups was affected, this does not alter our finding that veterinarians performed better than students.

What might explain the difference in performance between the veterinarian and student groups who participated in the present study? One might also ask whether the difference is due to a peripheral mechanism (that the veterinarians have more sensitive fingers) or a central mechanism (that the veterinarians have developed better sensory-motor strategies and can use the sensory information from their fingers more effectively). As far as we are aware, humans do not possess “stiffness sensors” in the skin of the fingers. Instead, stiffness judgment comes from an appreciation of changes in force in relation to changes in displacements. Both tactile and kinesthetic information play a part in the perception of stiffness. It has been shown that stiffness perception is affected by whether the compliant surface is deformable or rigid, with performance being better on deformable surfaces. Furthermore, in the case of a deformable surface, tactile information alone is sufficient for discrimination, while for rigid surfaces, both tactile and kinesthetic information is required [19]. A subsequent study using similar deformable surfaces found no difference between the stiffness discrimination abilities of participants whether they touched the surfaces directly with the middle finger or via a rigid stylus tool [20]. Interestingly, the same study found that softness discrimination was significantly better when tapping as opposed to pressing the objects with the stylus, presumably due to the presence of higher-frequency tactile cues available when the stylus struck and deformed the object during tapping. Recall that the Exploratory Procedure for hardness judgment is pressure, not necessarily tapping, when participants with no particularly discernable manual skills were tested [21]. This again brings up the need to investigate the motor behavior of the experts to better understand why experts demonstrate better stiffness judgments.

There are many groups of people, other than clinicians, who might be considered likely to have haptic expertise. One example is visually impaired people. The ability to discriminate the relative orientations of haptic lines was measured for groups of sighted and visually impaired participants [22]. The visually impaired group might be considered the “expert” group in this context. The study showed no difference in the abilities between the groups. However, other studies have shown that visually impaired people can outperform sighted participants in haptic perception tasks with which the former group are very familiar. For example, it has been shown that blind Braille readers exhibit better tactile spatial resolution than sighted participants [23]. It has also been shown that reading speeds with the Optacon device [24] can be greatly improved with training [25]. This suggests that experience and practice can improve performance in a task that depends on haptic perception. The present study also found that clinical practice affects performance for a skill dependent on the sense of touch. These results are encouraging for veterinary and medical education, suggesting that skills involving touch, such as palpation, can be improved by practice.

The findings from the present study have important implications for veterinary education in the sense that students clearly need to improve their skills in stiffness perception above the level that is innate or has been acquired during other manual tasks. The progress of the novice along the path to clinical competence will involve repeated deliberate practice. The boxplots in Figure 2 show a much wider spread of information transfer values observed in the student group than that in the veterinarian group. The plots could suggest that with training the poorest performing students can reach an “expert” level and that it would be interesting to follow these students, re-testing them at intervals throughout their education, to look for trends in their information-transfer scores over time. It is also possible that those who find such manual skills difficult to master never reach the practicing veterinarian population, perhaps choosing to pursue other career options. Also, testing final year veterinary students would reveal what level of expertise in stiffness perception is developed during their student education compared with the ongoing development of expertise acquired during professional practice.

As an option to supplement current “hands-on” experience in veterinary education, training in a virtual environment could be provided. The advantages of such an environment would be that skill levels could be measured and progress monitored. Training can be targeted and adjusted to the student’s current skill status. Ultimately, such tests could contribute to assessing clinical competence, where an ability is compared to a predetermined level based on measurements from clinicians. Those students with inadequate skill would be identified and further training provided.

The present study is only the beginning of many exciting studies where psychophysical methods are used to gain a better understanding of veterinary palpation. As mentioned earlier in this section, two promising future directions include the investigation of motor strategies used in palpation, and the discovery of factors other than stiffness judgment that contribute to better palpation performance. In terms of motor behavior, our previous work has shown that displacements and force magnitudes differ considerably in relation to stiffness levels during palpation [26]. Veterinarians often relate different stiffness levels to different clinical scenarios which further confound their motor behavior. For example, if a veterinarian imagines palpating bone (high stiffness but little or no risk of causing damage), s/he could safely use a high level of force. However, if a veterinarian imagines palpating a cat’s blocked bladder (high stiffness and high risk of serious damage caused by excess force), s/he would be extremely gentle. The challenge, therefore, is to design psychophysical experiments that are clinically relevant but avoid potentially confounding factors.

Other elements involved in palpation can be illustrated with the task of bovine pregnancy diagnosis. During palpation, the haptic properties of the pregnant uterus can be assessed by comparing the two horns (sides) of the uterus in order to reach a diagnosis (the fetus implants in one uterine horn, which is larger and softer than the other non-implanted horn). This process can be likened to the task of identifying the pitch of a musical note whilst being able to hear a note of a known pitch - for example the middle C. The task itself is still of identification in nature, although with the availability of a reference signal. We are now designing a relative (as opposed to absolute) identification paradigm where the participant will always have access to a reference stiffness. The performance level for relative identification is likely to be higher than that measured by the absolute identification paradigm that the present study followed. This might help explain why the experts’ measured information transfer is lower than expected in the present study. Further research will be undertaken to determine how the use of this relative identification procedure would affect the information transfers of the expert and novice groups.

In conclusion, we have shown that stiffness perception is an important skill for a veterinarian which veterinary students do not necessarily possess innately. We have demonstrated the potential of applying the scientific methods of psychophysics to the art of palpation. By quantifying expert ability, student training can be improved and targets set. Also, using the same methods, student ability can be monitored and assessed throughout the learning process. It would also be interesting to undertake further work to investigate other component skills, such as perceiving subtle differences in size or texture, to identify those skills that characterize the expert. This would then in turn provide metrics against which to assess competence and target training. Our research approach can be generalized to the analysis, training and assessment of other medical tasks, or in general any manual task, where experts attain a superior level of performance after an extended period of time on the job.

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