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Motorized Percussion: A comparative Evaluation to Foster Telemedicine

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Abstract:

Purpose The demand for telemedicine is continuously increasing. However, many medical examination techniques such as auscultation are based on manual execution and subjective assessment by each individual doctor. For the increasing trend of telemedicine, we have developed an electric percussion device that examines in a standardized way.
Methods This study evaluated the new approach of using motorized percussion against the gold standard of manual percussion. An examination was carried out on a healthy volunteer using both techniques. Thereby, occurring sounds from both pulmonary and non-pulmonary areas were recorded as the primary goal of percussion is to assess the size of the lung. Recordings were cut into individual samples and randomized within each examination variant.
Results When discriminating between ventral and dorsal, and manual and motorized percussion, the outcome of the 28-participant anonymous survey showed that the noise-suppressed ventral motorized percussion with 93.2% (10.2) correctly identified percussion points surpassed all other conducted percussion techniques.
Conclusion Making a distinction between pulmonary volume and exterior areas is very reliable with the motorized percussion. In order to be able to describe the clinical picture precisely in the future, further evaluations are necessary.

Keywords: Percussion · Auscultation · Telemedicine · Telediagnostics · Clinical Examination

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1 Introduction

Upper thoracic percussion is a fundamental technique in clinical examinations, difficult to learn and highly subjective, but widely used for the initial diagnosis of lung diseases (e.g. Pneumothorax, Pleural Effusion). Therefore, auscultatory percussion is used by tapping the patient on the sternum while listening to the posterior thorax with a stethoscope.[1–4] A key clinical finding from percussion is that the pneumothorax sounds hyper-sonorous and pleural effusion is dulled.[5] To distinguish between empty and filled body cavities – sonorous and tympanic sounds – the percussion was introduced to medicine by Leopold Auenbrugger in 1763. He began tapping the patient's body surface in the affected region to produce sounds of resonance.[6]
Physical examination, the other major established diagnostic method, suffers from several disadvantages, most notably low accuracy and high interobserver error. The accumulation of fluid in the lungs (consolidation), characteristic of pneumonia, cannot be reliably detected.[7] Today, increasingly more techonological devices (e.g. wearables) are being developed for telemedicine and home care systems. However, percussion as a simple inexpensive and fast diagnostic method is still left out, as the examination cannot be performed by a layperson.

2 Methods

2.1 Motorized Percussion Setup

To overcome the challenges of a manual percussion, we developed a device for an automatic percussion. As described in [8], three working principles were evaluated in a previous comparative study, resulting in the motorized approach being the most favorable. We therefore improved the first prototype of the mechanical approach, resulting in the new overall dimensions of 230 mm x 170 mm x 160 mm (Fig. 1). Core of the system is a HSR-2645 CR continuous drive servo motor (HITEC, Sand Diego, USA), placed on a conventional manufactured aluminum plate. All further parts are designed for additive manufacturing and were printed with a Form 3B (Formlabs, Somerville, USA). A transmission rotor with three

strokes causes a continuous prestress on a torsion spring with each stroke in form of a short interlock power transmission. This causes an intermittent knocking on an aluminum plate plessimeter.

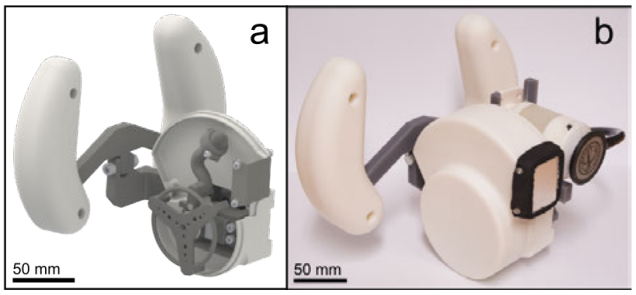

Fig. 1: a) CAD-Model of the motorized percussion applicator with an inside view; b) Prototype with adapted stethoscope

The entire device is designed to be handheld and therefore includes a stethoscope mounting option using a custom stethoscope mount in conjunction with a silicone spacer to isolate vibrations.

2.2 Experimental setup

For capturing produced percussion sounds in this evaluation, a Master Classic II™ stethoscope (3M™ Littmann®, St. Pauls, USA) picked up the sound directly from the patient's skin. Audio signals were digitized by a microphone and converted into 24-bit/192 kHz recordings using a UR824 interface (Steinberg Media Technologies GmbH, Hamburg, Germany). The experiment was performed on one healthy testperson, sitting upright. To compare multiple variants and verify with the gold standard of a manual percussion[9], 6 spots within and 6 spots outside of the pulmonary area, corresponding to the points in Fig. 3, were defined. The four tested variants differ between ventral percussion (V) – where the sternum was targeted – with a dorsal auscultation, and a dorsal percussion (D) with a dorsal auscultation; both performed with the motorized device and manual tapping.

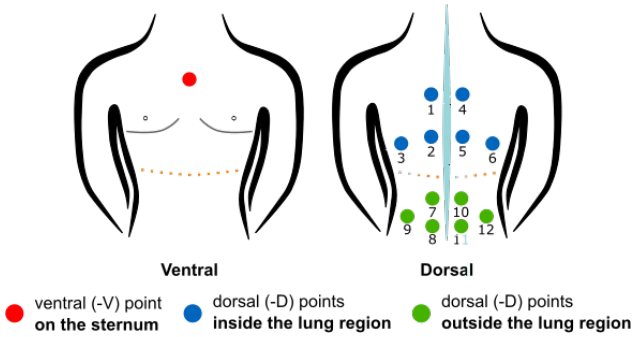

Fig. 3: Considered points for percussion and auscultation on the ventral (left) and dorsal (right) patient side; Auscultation was always carried out dorsal (D)

2.3 Sound pattern editing

Volumes of recordings were normalized and each examination was split into 12 individual samples corresponding to the anatomical points as shown in Figure 3. While recordings of the manual percussion sounds were not further processed, sounds of the automatized percussion were filtered additionally. Since the sound of the motor is mixing up with the biosignals, a noise reduction (NR) filter based on the technique of spectral noise gating (parameters: 42 dB noise reduction, 12.5 sensitivity, 12 tapes of frequency smoothing) was applied using the software *Audacity* (version 3.0.0) to clear up the tapping sound. When an unwanted sound region is selected, Audacity identifies a profile. Then, by selecting the entire region of the waveform to which noise reduction is to be applied, the unwanted noise is reduced using the previously created pro-

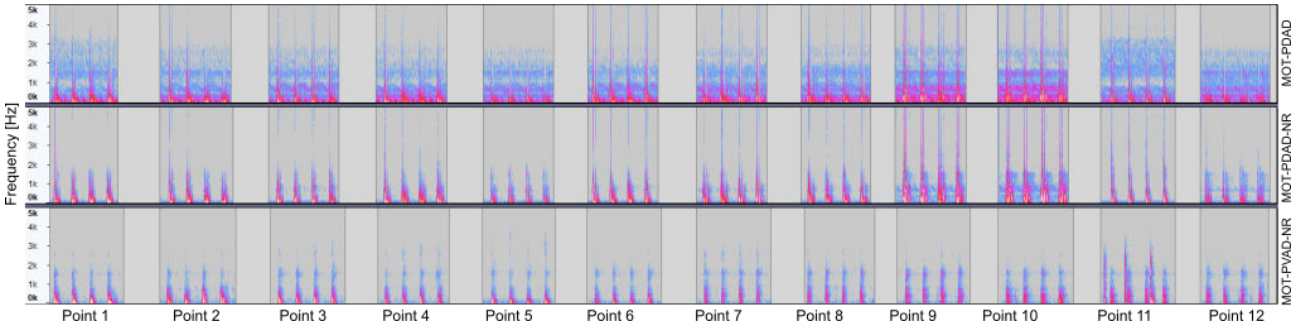

Fig. 2: Comparison of the spectral audio tracks of three different motorized examinations. Top to bottom: MOT-PD/AD; MOT-PD/AD-NR; MOT-PV/AD-NR; Especially noticeable, ventral percussion shows no yellow spectral colors outside the lung border (pt. 7 - 12); Inoperable point 11: MOT-PV/AD-NR with adverse interfering noise – a negative example

file. Figure 2 shows a section of the processed audio tracks. Differences in noise reduction are shown in blue.

2.4 Survey Design

For the survey, five individual examination versions were compared:

i manual ventral percussion with dorsal auscultation (MAN PV/AD)
ii manual dorsal percussion with dorsal auscultation (MAN PD/AD)
iii motorized dorsal percussion with dorsal auscultation (MOT PD/AD)
iv motorized ventral percussion with dorsal auscultation and noise reduction (MOT PV/AD NR)
v motorized dorsal percussion with dorsal auscultation and noise reduction (MOT PD/AD NR)

Evaluators had to listening five sound tracks of each examination and identify which were samples of within the lung area. For this purpose, using *Kdenlive* (version 21.12.3), short videos of the audio recordings combined with images for each numbered point were edited. Participants were informed about the 50:50 split of lung and non-lung samples and were able to listen to two reference samples for each examination. In all videos the audio track was played to the listener with randomized percussion points, deviating from the order in figure 3. Finally, the respondents answered questions about the possible use of an AI in combination with the motorized percussion mechanism. The survey was aimed to approbated physicians and medical students, who are already familiar with the use of percussion, and in addition also at laypersons, who have not yet had contact with everyday medical practice.

3 Results

In total, 28 participants (9 approbated physicians / 6 medical students / 13 laypersons – average age: Mdn = 28.5 yrs (8.5)) show a significant superiority of the ventral (V) percussion. Even though results for the manual ventral and motorized ventral percussion can be compared to one another, results for motorized sounds (MOT PV/AD NR: 93.2% (10.2)) are even slightly better than those for manual tapping (MAN PV/AD: 87.5% (18,8)). In general, ventral percussion and dorsal auscultation sounds were quieter than the rest, which is why participants were not shown the ventral audio sample of the device without previous noise reduction. All results, including Table 1 are provided as median (Mdn) values (%) and interquartile ranges (IQR). Statistical methods conform with Friedman and Wilcoxon Ranksum tests within a Bonferroni correction, using the statistical software *R* (version 4.2.0).

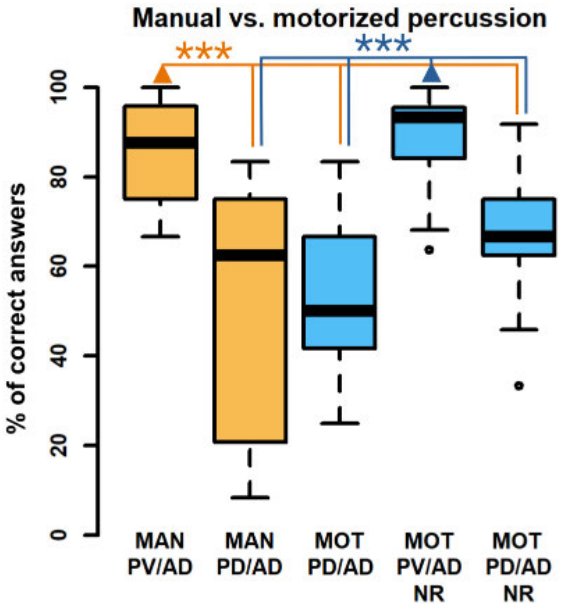

Fig. 4: Comparison between manual (MAN) and motorized (MOT) percussion (P); Distinguished between percussion from ventral (V) and dorsal (D); Further noise reduction is indicated as (NR); Auscultation (A) in all cases from dorsal (D); Statistical significance: *** = $p < 0.001$

The audio example with the motor noise (MOT PD/AD: 50.0% (25.0)) was less assignable than the other two audio examples (MOT PV/AD NR: 93.2% (10.2); MOT PD/AD NR: 66.7% (12.5)) of motorized percussion with noise filtering. Although, ventral manual percussion (MAN PV/AD: 87.5% (18,8)) was the quietest it achieved a better result than dorsal manual percussion (MAN PD/AD: 62.5% (50.2)). No statistically significant differences were found between the age groups. Gender differences are up to 16.7 %, with women performing better than men. Additionally, 79% of all participants agree and 21% are unsure if artificial intelligence will be able to categorize these sounds in the future (79% / 21% / 0%).

4 Discussion

Percussion and auscultation, are fundamental diagnostic techniques in medical examinations, thus it is surprising that no automatic system for general use is yet available. While results of our system are quite promising, one has to consider for the evaluation, that usually the current percussion and auscultation spot is visible for the physician. Hence, their anatom-

ical knowledge adds additional information to the pure audio feedback. In our setup, timbre was difficult to distinguish when both percussion and auscultation were performed from dorsal. Percussion, during both procedures manual and motorized, was more distinguishable when performed from ventral. However, with a ventral percussion, the increasing distance, between the tapping point and the caudally guiding stethoscope, automatically leads to a softer and also brighter sound. A more compact design and damping of the engine noise are further steps to improve the overall concept. Whether as a multi-functional device in telemedicine, as a tool for practitioners or as an independent self-care application in combination with a robotic arm, the motorized device produces a periodic, reliable sound with a constant impact force.

5 Conclusion

We were able to proof that a motorized percussion can keep up with manual percussion and could bring the traditional examination technique to the 21st century. Digitization and standardization open up new possibilities for future Artificial Intelligence-based classification of the percussion and could lead to substantially more objective decisions without the need for an experienced doctor. Most medical professionals agreed that recordings with a microphone sound different than classic percussions, but the work further shows that the natural timbre does not play an important role in the categorization of the audio recordings. Our developed percussion applicator is low cost build, simple to handle and offers a rapid and inexpensive examination for e.g. pneumothorax/pleural effusions.

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Tab. 1: Correct answers sorted by sex and by medical expertise; Noteworthily, laypersons achieved comparable results to those with a medical background; All groups were able to assign the ventral motorized percussion with noise reduction (MOT PV/AD NR) best; Results in median values (%) and interquartile ranges (IQR); Abbreviations according to Fig. 4

	MAN				MOT					
	PVAD		PDAD		PDAD		PVAD NR		PDAD NR	
	%	IQR	%	IQR	%	IQR	%	IQR	%	IQR
Women (n=17)	**91,7**	**25,0**	**66,7**	**25,0**	**50,0**	**25,0**	**95,5**	**13,6**	**66,7**	**12,5**
Men (n=11)	**83,3**	**12,5**	**50,0**	**54,2**	**58,3**	**20,8**	**90,9**	**9,1**	**62,5**	**4,2**
Physicians (n=9)	**83,3**	**16,7**	**58,3**	**50,0**	**66,7**	**8,3**	**86,4**	**9,1**	**62,5**	**4,2**
Medical Students (n=6)	**91,7**	**6,3**	**37,5**	**31,3**	**41,7**	**6,2**	**86,4**	**20,5**	**66,7**	**15,6**
Laypersons (n=13)	**83,3**	**25,0**	**66,7**	**25,0**	**50,0**	**25,0**	**95,5**	**0,0**	**66,7**	**12,5**
Total (n=28)	**87,5**	**18,8**	**62,5**	**52,1**	**50,0**	**25,0**	**93,2**	**10,2**	**66,7**	**12,5**