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REGULAR ARTICLE

Accurate and fast neonatal heart rate assessment with a smartphone-based application – a manikin study

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ABSTRACT

Aim: This study determined the accuracy and speed of the NeoTapLifeSupport (NeoTapLS), a free smartphone application that aims to assess a neonate's heart rate.

Methods: We asked 30 participants with a variety of backgrounds to test the NeoTapLS, which was developed by our own nonprofit organisation Tap4Life, to determine a randomly selected heart rate by auscultation or palpation. The study was carried out in 2014 at Sachs' Children and Youth Hospital, Sweden, using a Laerdal SimNewB manikin that simulates true values. The NeoTapLS calculates the heart rate based on the user's last three taps on the smartphone screen.

Results: A total of 1200 measurements were carried out. A high correlation was found between measured and true values by auscultation (correlation coefficient 0.993) as well as by palpation (correlation coefficient 0.986) with 93.5% of the auscultations and 86.3% of the palpations differing from the true value by five beats or fewer. The mean time to the first estimated heart rate was 14.9 seconds for auscultation and 16.3 seconds for palpation.

Conclusion: Heart rates could be accurately and rapidly assessed using the NeoTapLS on a manikin. A globally accessible mobile health system could offer a low-cost alternative to expensive medical equipment.

INTRODUCTION

Intrapartum-related complications, labelled as birth asphyxia, account for up to 0.66 million deaths per year (1). Successful resuscitation could prevent a large proportion of early neonatal deaths, defined as death during the first seven days of life, and improve the number of neonates surviving asphyxia (2,3). In many low- and middle-income countries, neonatal resuscitation is frequently performed by health personnel with limited experience of airway management and a lack of reliable monitoring equipment. To improve the outcomes of delivery in these settings, all birth attendants, including physicians, midwives and nurses, should have the knowledge, tools and skills required to perform proper neonatal resuscitation.

The Helping Babies Breathe curriculum aims to implement basic skills in newborn resuscitation in resource-limited settings (4,5). The cornerstone of this training is to teach appropriate ventilation. An accurate assessment of heart rate provides further essential feedback on the quality of ventilation and is an important clinical indicator (6). Heart rate assessment is part of the Helping Babies Breathe training and flow chart, and it can be determined by auscultating the precordium or palpating the umbilical cord. Improved ventilation and further assistance are recommended if the heart rate is slow, defined as <100 beats per minute. Further heart rate assessment and advanced resuscitation is recommended if no improvements in heart rate and breathing are seen after improved ventilation.

Both the assessment of simulated heart rate on a manikin and the clinical assessment of heart rate in the delivery

Abbreviations
CI, Confidence interval; ECG, Electrocardiography; ILCOR, International Liaison Committee on Resuscitation; NeoTapLS, NeoTapLifeSupport; r, Correlation coefficient.

Key notes
- We asked 30 participants to test the NeoTapLifeSupport (NeoTapLS), a free smartphone application that aims to assess a neonate's heart rate.
- A total of 1200 measurements were carried out, and 93.5% of the auscultations and 86.3% of the palpations differed from the true value by five beats or fewer.
- The mean time to the first estimated heart rate was 14.9 seconds for auscultation and 16.3 seconds for palpation.

room are time-consuming, intermittent and often inaccurate (7,8). Electrocardiography (ECG) is fast and accurate, but is typically unavailable in resource-limited settings (9). Pulse oximetry displays both pulse and saturation. In neonatal resuscitation, the most important parameter is the pulse of the newborn infant. Using pulse oximetry to assess an infant's heart rate can identify, with high sensitivity and specificity, those infants who require interventions based on current recommendations, but the procedure is slow and is also often unavailable in resource-limited settings (10). In one simulation study, where study participants assessed heart rates by registering the heart rate tapped out by an examiner using his or her finger, the estimated heart rates showed little accuracy, especially at rates of <60 beats per minute (11). The need to develop a rapid and accurate method for determining heart rate during newborn resuscitation has been highlighted (12–14).

A systematic review, published in 2017, explored the accuracy of seven new technologies for monitoring the heart rates of newborn infants and compared them to current reference standards (13). The authors suggested that pairing digital stethoscopes with a smartphone might improve global assessments of heart rate, including resource-limited settings. However, they concluded that the seven new technologies tested could not be recommended as suitable for widespread clinical use at that stage (13).

The 2015 International Liaison Committee on Resuscitation (ILCOR) guidelines state that progress beyond the initial steps of newborn care, namely position of the airway, suction if needed, drying and stimulation, is determined by the simultaneous assessment of two vital characteristics: respiration and a heart rate of <100 beats per minute. Furthermore, chest compressions should be initiated if the heart rate is <60 beats per minute, after having ensured that the patient has adequate ventilation. ILCOR suggest that an ECG should be used to evaluate heart rates in newborn infants who need resuscitation, but an ECG does not replace the need for pulse oximetry to evaluate the newborn infant's oxygenation (15). Compared to the 2010 ILCOR guidelines, the new guidelines place less emphasis on auscultation (6,15). However, when ECG and pulse oximetry are not available, auscultation is still recommended. The current ILCOR guidelines do not provide other alternative heart rate monitoring methods. Given that a great majority of neonatal deaths occur in resource-limited settings, there is an urgent need for a reliable, inexpensive and readily available tool to assess heart rates under these conditions.

NeoTapLifeSupport (NeoTapLS) is a new free-of-charge smartphone application that is designed to evaluate neonatal heart rates and was developed by our own nonprofit organisation (Tap4Life, Stockholm, Sweden). The development of this application responded to the demand identified in our previous study for a method to assess the heart rate of newborn infants in a fast and accurate way in a resource-limited setting where no other reliable monitoring equipment was available (16).

The user listens to the heart beat, or feels the pulse, of the newborn infant and then taps the pace of the heart rate at least three times on the screen of the smartphone. The NeoTapLS then displays the heart rate as a number on the screen. The interface is designed to be visible and functional even when the smartphone is placed in a latex glove for protection, which is useful in healthcare service in resource-limited settings. The heart rate is also colour-coded: red for a heart rate of <60, yellow for a heart rate of 60–99 and green for a heart rate of 100 or more. The NeoTapLS is downloadable free of charge at Google Play.

The aim of this manikin study was to determine the accuracy and speed when participants with a range of professional and educational backgrounds assessed a simulated heart rate using the NeoTapLS.

METHODS

Study participants

This observational study was conducted in 2014 at the Centre for Education in Paediatric Simulation at Sachs' Children and Youth Hospital in Stockholm, Sweden. It tested the NeoTapLS, a new free-of-charge android application. To cover a wide range of clinical resuscitation skills, we recruited participants who were unfamiliar with the NeoTapLS and came from a variety of professional and educational backgrounds. All the people we approached agreed to take part in the study, and any prior experience in smartphone management was disregarded. We included 30 participants: eight doctors, six nurses, three nurse assistants, six nurse students, two medical students, three secretaries and two web designers.

The simulated heart rate, auscultated over the precordium or palpated by the pulse, was simultaneously tapped onto the smartphone screen. After three taps, a colour-coded number indicating the heart rate was displayed (Fig. 1).

A neonatal patient simulator, the Laerdal SimNewB manikin (Laerdal Medical, Stavanger, Norway), was used for the tests. This manikin is capable of generating heart tones as well as umbilical and brachial pulsations. Before starting the simulation, 20 heart rates, within the range of 20–140, were chosen using a random number generator (17). As the manikin could only present in multiples of tens, the numbers from the random number generator were rounded to the nearest ten. The 20 heart rates were presented to the participants in two orders, one for auscultation and one for palpation. Participants were not informed that the manikin could only present numbers in tens. The participants were blinded to the selected heart rates.

All users were introduced to the NeoTapLS and the Laerdal SimNewB, and they familiarised themselves with the set-up for three to five minutes prior to the simulation. They were instructed to determine the heart rate by auscultation of the precordium or palpation of the brachial pulse of the Laerdal SimNewB manikin and simultaneously tap the same pace on the screen of a smartphone, with the NeoTapLS app installed. The simulation began by the researcher telling the participants to start. As soon as

Figure 1 (A, B, C) How the NeoTapLS is displayed on the smartphone screen. Tap to register the infant's heart rate. (A) Heart rate at 32 seconds <100, prepare for ventilation. (B) Heart rate at one minute <100, ventilate now! (C) Heart rate at one minute 45 seconds >100, newborn resuscitation is going well.

the participants were sure of the heart rate, they said stop and reported the number. The acquisition time, defined as the time from start to stop, was noted for all scenarios. Each of the 30 participants carried out 20 estimations for auscultation and 20 for palpation of the brachial pulse of the Laerdal SimNewB, resulting in a total of 1200 readings. Auscultation of the precordium was performed using a 3M Littman Classic II Infant Stethoscope (3M, Minnesota, USA). In all scenarios, the Laerdal SimNewB manikin was lying on an open resuscitation table, without respiratory frequency (Fig. 2).

Sachs' Children and Youth Hospital, Stockholm, Sweden, approved the study. Further ethical approval was not considered necessary for this study as it focused on the accuracy and speed of the method and not on comparing performance between individual participants or groups of participants, similar to a previously published manikin study (18). The participants gave oral consent to participate and could decline participation at any time during the study.

Statistical analysis

The analyses were performed using Stata Statistical Software version 14.0 (StataCorp LP, College Station, Texas, USA). Numerical variables were summarised with means, ranges and standard deviations, and categorical variables were summarised using frequencies. To compare correlations between numerical variables, Pearson correlation coefficients (r) were estimated. Results were presented with 95% confidence intervals (CI). All the inferential analyses were adjusted to take into account the clustered nature of the data, as the data clustered within individuals. P values of <0.05 were considered significant.

RESULTS

The estimated heart rates were arranged into three categories: very low (<60), low (60–99) or normal (≥100). The simulated heart rates were categorised into very low (20–50), low (60–90) or normal (100–140). The heart rate of the manikin, which was equal to the true value, will henceforth be called the simulated heart rate.

Auscultation

The correlation between the estimated and simulated heart rates was high (r = 0.993). It was lower in the normal range (r = 0.920) compared to the very low (r = 0.974) and low range (r = 0.974). Overall, 93.5% of all auscultations differed by five beats or less from the true value (Fig. 3).

In all, 18/600 (3.0%) estimations of simulated heart rate by the 30 participants were placed in a category that was different to the actual category of the simulated heart rate

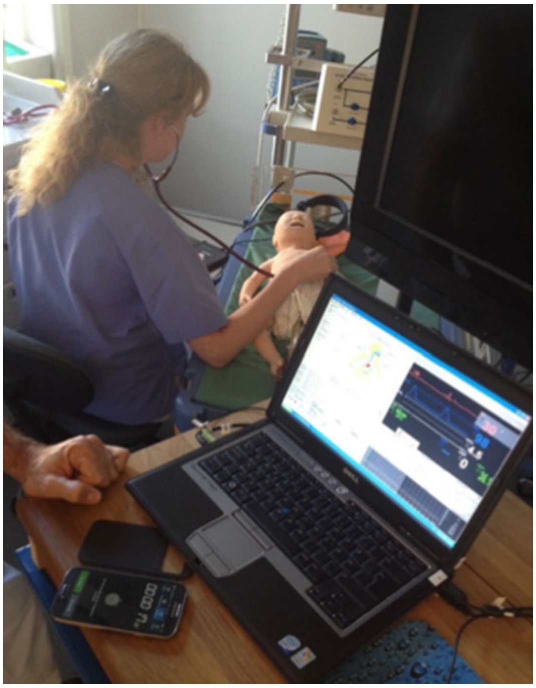

Figure 2 A simulation in which a participant, who agreed to be photographed, auscultated the precordium of the manikin and at the same time tapped the screen of the smartphone with the NeoTapLS application.

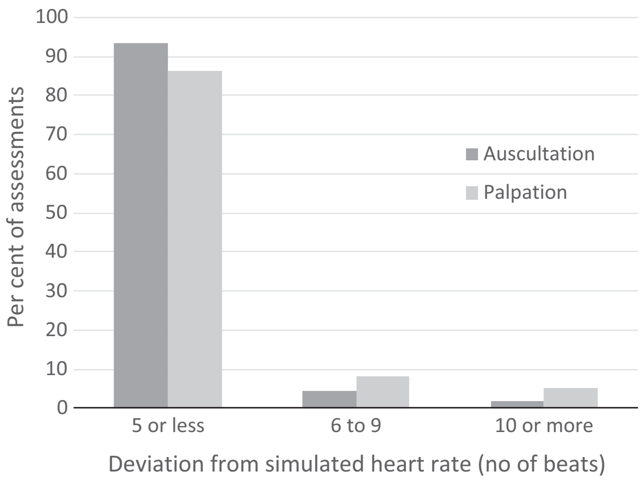

Figure 3 Deviation from simulated heart rate by auscultation and palpation.

(Table 1). In the very low range, none were misclassified. Misclassifications were more likely to happen in the estimations of simulated heart rates at 60 and 100 as they were cut-offs for the three categories. We found that 2/30 were misclassified at 60 and 1/30 differed by five beats or less from the simulated heart rate 60. Furthermore, 15/90 were misclassified at 100 and 12/90 differed by five beats or less from the simulated heart rate of 100. If the 120 simulated heart rates of 60 and 100 were excluded, because just a difference of one beat could lead to the wrong categorisation, only one of the 480 (0.2%) estimations was misclassified.

The mean difference between the estimated and simulated heart rate was 0.79 beats per minute (95% CI −0.11 to 1.68). There was a slight, but constant, overestimation, and this occurred more frequently in the normal range than in the lower ranges. In the very low range, it was 0.39 beats per minute (95% CI −0.03 to 0.81); in the low range, it was 0.68 beats per minute (95% CI 0.07 to 1.28); and in the normal range, it was 1.14 beats per minute (95% CI −0.73 to 3.02). The prevalence of correct estimations increased in a similar way from the normal range to the very low range (p value < 0.001) (Fig. 4A).

The mean acquisition time for the estimated heart rate was 14.9 seconds (95% CI 13.42 to 16.40), ranging from two to 80 seconds. The mean acquisition time was longer in the very low range at 17.8 seconds (95% CI 16.5 to 19.2), compared to 13.1 seconds in the low range (95% CI 11.5 to 14.6) and 13.4 seconds in the normal range (95% CI 11.6 to 15.3) (p value < 0.001).

Palpation

The correlation between the estimated and the simulated heart rate for palpation was high ($r = 0.986$), as it was for auscultation. The correlation was highest in the very low range ($r = 0.956$) and lower in the low range ($r = 0.906$). The normal range had the lowest correlation ($r = 0.840$). Overall, 86.3% of all palpations differed by five beats or less from true value (Fig. 3).

In all, 39/600 (6.5%) estimations of simulated heart rate by the 30 participants were placed in a category that was different to the actual category of the simulated heart rate (Table 1). We found that 7/30 were misclassified at 60 and 6/30 differed by five beats or less from the simulated heart rate of 60. Furthermore, 23/90 were misclassified at 100 and 18/90 differed by five beats or less from the simulated heart rate of 100. If the 120 simulated heart rates of 60 and 100 were excluded, again because just a difference of one beat could lead to the wrong categorisation, 9/480 (1.9%) estimations were misclassified.

The mean difference between the estimated and simulated heart rate was −0.02 beats per minute (95% CI −1.08 to 1.04). In the very low range, it was 0.68 beats per minute (95% CI 0.20 to 1.16); in the low range, it was −0.29 beats per minute (95% CI −1.61 to 1.03); and in the normal range, it was −0.44 beats per minute (95% CI −2.21 to 1.36). The estimated heart rates were not significantly lower or higher than the simulated heart rates (p value 0.94), meaning that there was no consistent over- or underestimation (Fig. 4B).

The mean acquisition time for the estimated heart rate was slightly longer than for auscultation, at 16.3 seconds (95% CI 14.7 to 17.9), and it ranged from 5 to 62 seconds. The mean acquisition time was 18.7 seconds in the very low range (95% CI 17.3 to 20.1), 14.6 seconds in the low range (95% CI 12.9 to 16.2) and 15.1 seconds in the normal range (95% CI: 13.1;17.1) (p value < 0.001).

Table 1 Estimated heart rate and simulated heart rate by auscultation and palpation, divided by categories, according to the 2015 ILCOR guidelines

		Very low simulated heart rate 20–50 N = 210 n (%)	Low simulated heart rate 60–90 N = 120 n (%)	Normal simulated heart rate 100–140 N = 270 n (%)
Estimated heart rate <60	By auscultation	210 (100)	2 (1.7)	0 (0)
	By palpation	209 (99.5)	8 (6.7)	0 (0)
Estimated heart rate 60–99	By auscultation	0 (0)	117 (97.5)	15 (5.6)
	By palpation	1 (0.5)	111 (92.5)	29 (10.7)
Estimated heart rate 100 or higher	By auscultation	0 (0)	1 (0.8)	255 (94.4)
	By palpation	0 (0)	1 (0.8)	241 (89.3)

DISCUSSION

This study showed that assessment of a simulated heart rate in a manikin using a newly developed application for smartphones, the NeoTapLS, was fast and accurate. Overall, 93.5% of the assessments made by auscultations and 86.3% of the assessments made by palpations differed by five beats or less from the heart rate simulated by the manikin.

Prior to our study, auscultation and palpation had repeatedly been shown to lead to incorrect management, even in manikin studies. One study found that up to 28% of simulated heart rates obtained by auscultation led to incorrect management (7), while another reported that heart rates below 60 beats per minute were inaccurate and overestimated simulated heart rate (11). A third study stated that errors in initial heart rate determination occurred in 26–48% of the time (19). A clinical study reported poor agreement between the assessments of heart rate in newborn infants when both auscultation and palpation were used (20). In healthy newborn infants, brachial and femoral pulses are not reliable for determining heart rates (19,20) and umbilical pulsations must not be relied upon whether they are low or absent (20). Two reviews have pointed out problems with the inaccuracy of existing methods (13,14).

In contrast, our study showed that very few heart rate estimations fell on the wrong side of the cut-off levels at 100 beats per minute (2.7% of auscultations and 5.0% of palpations) and 60 beats per minute (0.3% of auscultations and 1.5% of palpations). If simulated heart rates of 60 and 100 were excluded, because just a difference of one beat could lead to the wrong categorisation, an even smaller number would be misclassified (0.2% of auscultations and 1.9% of palpations).

As 93.5% of the NeoTapLS-assisted auscultations and 86.3% of the NeoTapLS-assisted palpations differed by five beats or less from the true value, it is unlikely that the results would lead to major differences in the management of cardiopulmonary resuscitations. A heart rate of 100 is the cut-off for the definition of normal heart rate and guides the resuscitator to re-evaluate ventilation and <60 is the cut-off for initiating heart compression, according to the ILCOR guidelines. This means that incorrect estimations when the heart rate is near these cut-off points could eventually lead to wrong assumptions about the status of the newborn infant. Our findings are encouraging and may prevent incorrect management in the resuscitation of newborn infants (15).

Time is an extremely important factor in neonatal resuscitation. ECG monitoring in the delivery room can be time-consuming (8) and may be difficult to apply due to the infant's wet skin. Pulse oximetry is also time-consuming, it needs an extra pair of hands, and it is often unreliable in the delivery room, because it is sensitive to the excessive motion and low blood perfusion displayed by newborn infants. One study showed that it took a median of 68 seconds to obtain a heart rate by pulse oximetry (10). Another study showed that the time interval from attaching the pulse oximetry unit to the first heart rate value appearing on the monitor was 84 seconds (range 35–132 seconds) (21). In fact, neither ECG nor a conventional pulse oximetry is fast enough to enable delivery room staff to follow the international resuscitation guidelines for newborn infants. In our study, simulated heart rate assessment was possible within one minute, with few exceptions, and in most of the assessments, it took <20 seconds. This means that, at least under simulation conditions, it is possible to use the heart rate information to guide the management of the infant.

Furthermore, both ECGs and pulse oximetry are expensive and are rarely available in resource-limited settings. With the number of mobile phone users in the world expected to pass the five billion mark in 2019, wireless technology is expanding even in the most remote parts of the world (22). The widespread use of mobile phones highlights a significant opportunity to have a global impact on health behaviours (23). Low-cost smartphones are readily available and used at the patient's bedside by an increasing number of health workers (23). Free-of-charge mobile health tools, like NeoTapLS, can be available for all health workers who have access to a smartphone. In addition, the smartphone can easily be protected by a glove.

A manikin study is close to an ideal situation for assessing heart rate, or, in fact, simulated heart rate. There is little stress, no interfering sounds, no dirt and none of the movement seen in a real newborn infant. This is a limitation of any manikin study (7). However, a manikin study can be used to prove a concept that can then be tested further in

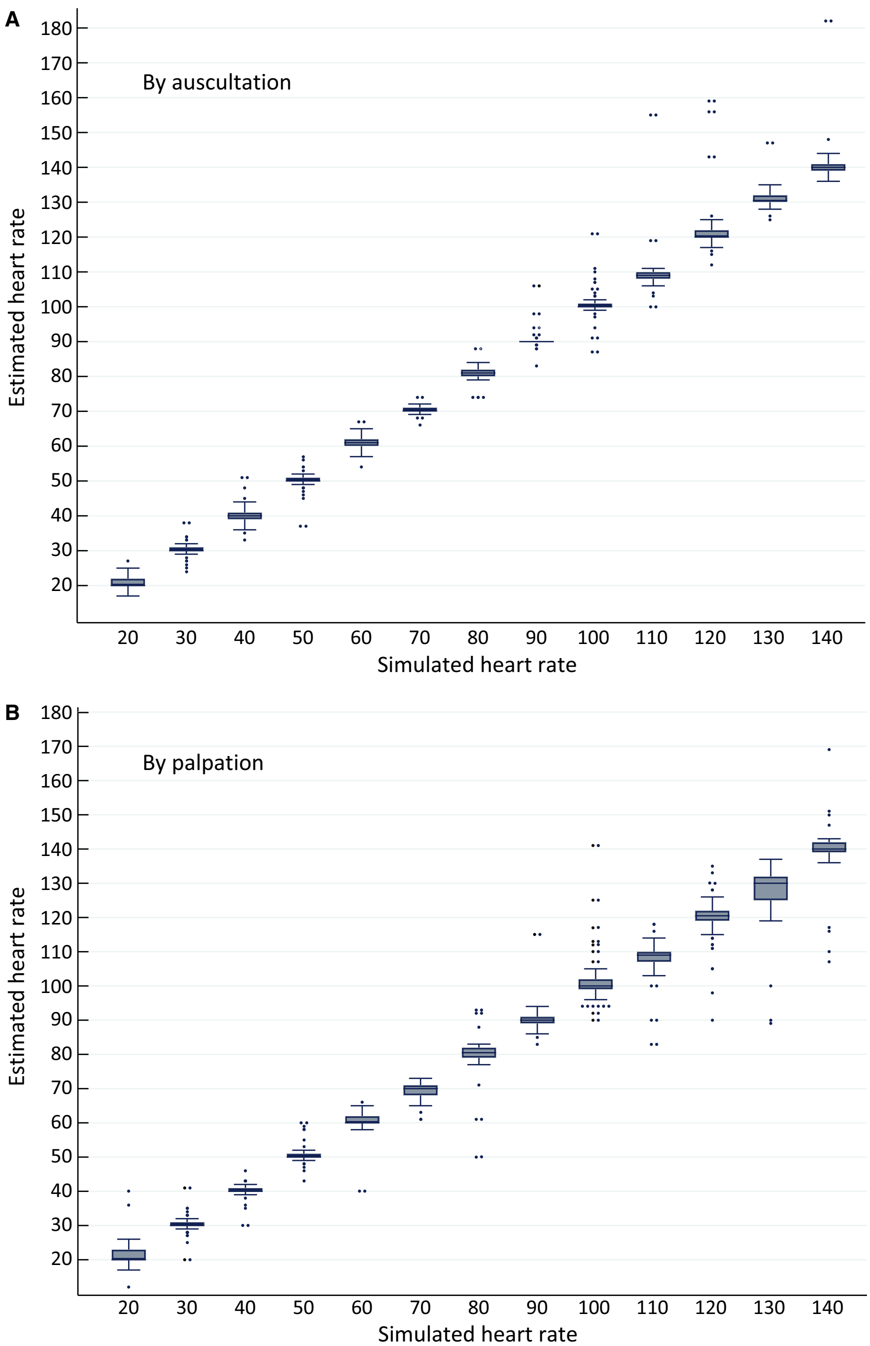

Figure 4 (A, B) Boxplot and whiskers showing all estimated heart rate assessments with NeoTapLS versus simulated heart rate of the manikin (A) by auscultation and (B) by palpation.

clinical environments. The manikin we used, the Laerdal SimNewB, could only present numbers in multiples of 10, but as the participants were not aware of this, it should not have affected the results. Furthermore, as the 30 participants were from a number of different professions, and the results were accurate, swift and significant for the entire group, the results indicate that the application is user-friendly and that it is possible to learn the required method with just a few minutes training.

The results from our study are encouraging and suggest that healthcare staff could avoid erroneous and delayed estimations of heart rate if they used the NeoTapLS in clinical practice. Our results also indicate that auscultation, with a stethoscope over the precordium of the newborn, should be a preferred method to palpation. In the absence of a stethoscope, palpation combined with NeoTapLS may be an alternative method for accurately and quickly assessing the heart rate. The NeoTapLS could also be used as a backup if monitoring equipment fails or in the absence of any other equipment. The ILCOR guidelines advocate auscultation for initial heart rate assessment and ECG or pulse oximetry if the baby needs neonatal resuscitation and/or continuous respiratory support. The ILCOR does not provide recommendations for other alternative methods of evaluating heart rates, when expensive medical devices are unavailable. Mobile health tools such as the NeoTapLS could fill this gap.

CONCLUSION

Our study showed that heart rates were accurately and rapidly assessed using the NeoTapLS on a manikin. The operators can start the NeoTapLS at the time of birth, and it keeps track of the time and reminds them to start ventilation at 60 seconds. NeoTapLS makes it possible to evaluate the heart rate with a minimum interruption of ventilation, even when only one resuscitator is in attendance. A globally accessible mobile health system offers a low-cost alternative to expensive medical equipment. Future studies, including clinical trials that compare smartphone-assisted heart rate estimations to ECG or pulse oximetry, could provide more data on the potential of NeoTapLS prior to clinical use.

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CONFLICT OF INTERESTS

Four of the five authors are cofounders of the nonprofit organisation Tap4Life, which produces the free-of-charge NeoTapLS application.

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