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INITIAL COMPARISON OF VITAL SIGNS MONITORING ON THE WRIST WITH THE ANKLE AND BICEP

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ABSTRACT

Kangaroo care is a vital component of infant care that can lead to reduced morbidity and mortality amongst infants born prematurely. While it is known that kangaroo care, or more simply, skin-to-skin contact, can lead to better health outcomes for both the infant and the mother, the correlation between duration of kangaroo care and positive health outcomes remains a mystery. Not all mothers are able to perform kangaroo mother care, or 24-hour kangaroo care, so it is important to know how much kangaroo care is necessary to achieve positive health outcomes for infants born prematurely. To determine the relationship between maternal-infant interactions, a system of health monitoring devices is presented to measure the duration and frequency of kangaroo care, along with the effects of kangaroo care before, during, and after the act. One specific parameter of interest is the heartrate of the mother and infant. The maternal heartrate can be measured with a commercially available Garmin Venu® Sq smartwatch, but it typically cannot be worn on the wrist in NICUs due to their infection control guidelines. The viability of wearing a Garmin® smartwatch to measure maternal heartrate on the ankle or bicep compared to the wrist was determined by wearing three smartwatches simultaneously on the specified locations. It was found that the smartwatch located at the ankle undercounted the heartrate by an average of 0.5 bpm and the smartwatch located at the bicep overcounted by an average of 0.05 bpm. From statistical analysis, it was determined that the smartwatch worn at the bicep would be an acceptable alternative to wearing a smartwatch on the wrist to gather maternal heartrate data for use in the complete kangaroo care monitoring system.

Keywords: kangaroo care, smartwatch, vitals monitoring

NOMENCLATURE

KC	Kangaroo Care
KMC	Kangaroo Mother Care

1. INTRODUCTION

The parental bond forged between an infant and their mother is powerful and improves both premature infants' and their mothers' physical and mental health with effects lasting for years [1]. Kangaroo care (KC), or skin-to-skin contact, is a method of care that promotes the bond between an infant and mother to reduce mortality and morbidity due to low birthweight [3]. KC is performed by the mother holding the infant next to their bare skin: chest to chest. KC benefits may extend to all adult caregivers holding their infants: a dearth of information can be found in literature about how other family adult caregivers besides mothers are impacted, particularly fathers [3].

KC has many benefits for both the infant and the mother. KC benefits the infant and mother physiologically and psychologically, especially when infants are born prematurely, typically underweight, and are cared for primarily in an incubator, where contact between the mother and infant is limited. Physiological benefits for the infant include improved weight gain for low birthweight infants, improved acid-base control, and improved breathing control [4,8]. KC promotes more frequent and easier breastfeeding, and increased milk volume, which promotes growth in NICU infants, particularly those with low birthweight [2]. KC leads to more cycles of deep sleep for infants [5], which helps maintain neural pathways and clear toxins from the brain [6]. The mother (or other KC caregiver) also plays a key role in temperature regulation of the infant, which is key to positive health outcomes in premature infants who may not yet be able to regulate their own temperature [8]. KC also leads to more mental stability for the mother. This is attributed to the release of oxytocin associated with skin-to-skin contact, which promotes further positive interactions between the mother and the infant [7]. The mother is able to digest and use calories better due to the release of gastrointestinal hormones [8].

Kangaroo mother care (KMC) is an extreme version of KC where the kangaroo position is held for 24 hours a day and the infant is fed exclusively on breastmilk from the mother. If the infant cannot feed by mouth and the mother can only express or pump milk, KMC is not possible and basic maintenance of milk supply is extremely challenging. Additionally, the level of care required by KMC is not always attainable and encouraging mothers to perform KC for long periods of time can put an increased amount of stress on mothers, especially if asked to be present 24 hours a day, 7 days a week [9]. This is also not always an option for a mother, so determining how much KC is necessary would be instrumental in making KC a more widely prescribed form of care for premature infants and making it more accessible for those who may not have time to perform KMC.

KC reduces infant mortality rates and improves the health outcomes for both the infant and the mother [3], but there is no known minimum duration and frequency of KC to achieve these improved health outcomes. Some barriers to performing KC include (1) a reluctance by healthcare professionals to adopt a 'less advanced' form of neonatal care compared to incubation chambers, (2) a perceived increase in workload to healthcare professionals to help mothers perform KC for critical condition premature infants, and (3) cultural barriers where the performance of KC may be deemed inappropriate due to skin exposure [10].

To make KC a more standardized form of healthcare, monitoring KC duration and frequency could help establish minimum recommendations needed for providing health benefits to the infant-mother dyad so that they can be implemented for all dyads, including those being treated in NICUs. Vital sign monitoring systems that incorporate synced maternal data as part of the mother-infant dyad are necessary to determine the optimal KC duration and frequency to achieve consequential positive health goals for the mother and infant.

Methods and devices for measuring the duration and effects of KC and KMC exist and vary in approach. These methods may include wearable devices, sensors, manual recording, or some combination. A study by Joglekar *et al.* developed a wearable device that measures the duration, temperature and position of the infant during KC [11]. While this device was able to measure the desired parameters, the location of the wearable was in between the mother and the infant, which may be a barrier to comfortable KC implementation. El-Farrash *et al.* used prescribed lengths of time to determine how length of KC affected the infant's health [12]. The results indicated that longer lengths (2 hours per day) as compared to shorter lengths (1 hour per day) of KC led to improvements in health for some outcomes but no change for others; the longer KC duration resulted in better health outcomes for neurodevelopmental tests but not for reducing infant salivary cortisol [12]. Adversely, by performing the test with prescribed lengths of time, some infants received

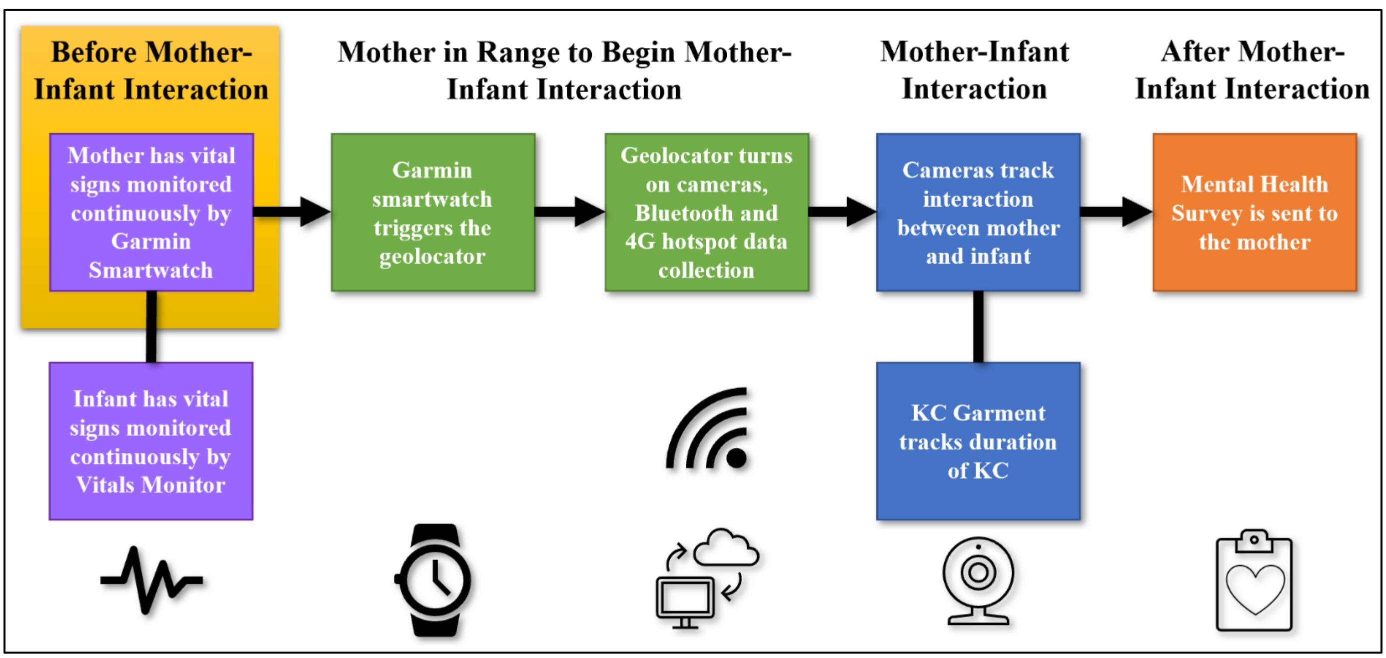

FIGURE 1: SYSTEM CONFIGURATION FOR MONITORING THE MOTHER-INFANT DYAD WHERE THE CURRENT COMPONENT OF INTEREST IS HIGHLIGHTED IN YELLOW.

less KC than others, which may not have happened had there not been a specific prescribed duration of KC. They may have received more KC, and thus had better health outcomes. Other measures of duration may be manual recording, which is more prone to human error than previously mentioned methods. Parents of neonates are busy and under high stress, so the expectation of dutiful recording is both inappropriate and unlikely.

A system of sensors and devices needs to be developed to measure the duration and effects of KC to determine how much KC is necessary to improve an infant's health outcomes without being burdensome to the mother. There are several criteria that need to be met by the monitoring system to maximize the accuracy of measurements, along with the comfort of both the infant and the mother. Monitoring systems should not interfere with the caregiver-infant bonding, and if possible, assist during KC to provide support and comfort to the dyad. Data collection should occur without the mother's or health care professional's direct effort and with minimal interference. In addition, the monitoring system needs to have secure, HIPAA compliant data protection, to protect the information of both the mother and infant.

In order to meet these criteria, a new KC monitoring system was designed to measure the duration of KC, vital signs of both the mother and the infant before, during, and after KC and video monitoring of the interaction between the mother-infant dyad (Figure 1). Not only will this system automatically monitor the duration of KC, but it will monitor how mother-infant interactions such as touch, talking, singing, and eye contact affect the mental health and physical health of the dyad.

One component of importance in this system is the monitoring of the mother's vital signs before, during and after KC. Monitoring before during and after the action of KC will give insight into how the mother-infant dyad affects the autonomic nervous system of both individuals. This component needs to independently record maternal vital signs, and not interfere with the day-to-day activity of the mother, nor the act of KC itself. One option for the mother's vital signs monitoring is a commercially available smartwatch. Not only can a smartwatch measure the vital signs of interest, additionally, using its Bluetooth pairing capability with a smartphone it can act as a signal trigger to begin the KC monitoring process once the smartwatch is in range and begins pairing with the geolocator in the smartphone.

There is one barrier to the usage of a smartwatch as a vital signs monitor: watches cannot be worn on the wrist in many NICUs due to infection control concerns. Smartwatches on the wrist can carry bacteria and other infectious material straight to an infant during handling, which poses a great danger to the fragile health of premature infants. An alternative method to using the smartwatch to measure vital signs is to wear it on a location permitted by the NICU other than the wrist.

One possible smartwatch for use is a Garmin® Smartwatch. Garmin® smartwatches use a system of devices along with a patented method to measure heart rate, sleep, exercise, breathing rate, and 'body battery', an all-encompassing metric of a person's energy level. The Garmin® system is composed of a LED emitter, a receiving photodiode, and a processor to read the light intensity signal [13]. Since the Garmin® smartwatch is worn on the wrist, where the skin is thinner and offers less resistance to light, there may be differences in the vital signs measurements if the smartwatch is to be worn on a different body location.

This poses the question of whether the measurement of vital signs at a location other than the wrist, such as the ankle or bicep is comparable to the wrist measurement. The main goal of this study is to determine whether a Garmin Venu® Sq smartwatch worn on a location other than the wrist can output vital signs with acceptable agreement with the data gathered at the wrist. The secondary goal is to test the software that records the vital signs from the smartwatch and transfers it to online Box Secure Storage for later evaluation automatically.

2. MATERIALS AND METHODS

To collect data from each of the Garmin Venu® Sq smartwatches located on a participant's wrist, bicep and ankle simultaneously, software was developed to work in conjunction with the existing Garmin® data collection software to transfer data in a readable manner to Box Secure Storage, a HIPAA compliant online file.

Once the software development was complete, heartrate data was collected from one participant over 5 hours with heartrate sampled every 15 seconds for a total of 1201 data points (per smartwatch), and a statistical comparison was performed.

2.1 Software for Data Collection

Garmin® collects data securely on their website for users to peruse at their convenience. A software was developed to securely transfer the data gathered by Garmin® to Box Secure Storage via a secured server at the University of Minnesota Duluth's server.

To collect the data from Garmin®, Garmin® was provided a link to where the software was running. Garmin® sends the recorded data to the link, where the data was then redirected by Heroku, a cloud application platform. Heroku redirects the data to the server at the University of Minnesota Duluth, where it was stored in a database engine called SQLite. The server then converts the data from JSON format, which is JavaScript specific, to the generic CSV format. Once the conversion is made, the data is uploaded to the Box Secure Storage and can be opened by researchers in the data analysis software MS Excel.

2.2 Smartwatch Data Collection

One participant cooperated in the Garmin Venu® Sq smartwatch optical heartrate monitor body location readout comparison to quantify any differences noted in the sensor location.

Three Garmin Venu® Sq smartwatches were worn at 3 different locations, wrist, bicep and ankle, simultaneously. Each watch was color coded and assigned to a body location: red was worn on the bicep, blue was worn on the wrist and white was worn on the ankle. and the readings were synced based on time.

The Garmin Venu® Sq smartwatches sampled heartrate every 15 seconds. The 3 Garmin Venu® Sq ® smartwatches were worn for 5 hours for a total of 1201 data points per watch. The participant followed their average routine, attending work and school, where walking was the predominant mode of travel. All data from the activities was taken sequentially and transferred to the data Box for later evaluation.

2.3 Statistical Data Comparison

To analyze the agreement between the three measurements, a Bland-Altman plot analysis was performed. Two Bland-Altman plot analysis were created: Wrist-Bicep, and Wrist-Ankle. The wrist is taken as the actual value for heartrate that the bicep and ankle measurements are being compared to. The mean between the measurement taken at the actual value and the comparison value is displayed on the x-axis. The y-axis is the difference between the value measured at the wrist, and the value measured at the bicep or ankle. The 95% confidence interval between measurements (indicated by the solid black lines) is displayed along with the average difference between the measurements (indicated by the dashed orange lines).

A direct comparison between the readings at the wrist, bicep and ankle was performed and the Pearson's correlation coefficient was determined between the wrist and bicep, and the wrist and ankle via MS Excel's Data Analysis Tool.

3. RESULTS AND DISCUSSION

The Bland-Altman plot analysis revealed that the Garmin Venu® Sq smartwatch located at the bicep overcounted the heartrate by 0.05 bpm on average and the smartwatch located at the ankle undercounted the heartrate by 0.53 bpm on average as compared to the smartwatch located on the wrist.

The Bland-Altman plot comparing the bicep to the wrist is shown in Figure 2 and the Bland-Altman plot comparing the ankle to the wrist is shown in Figure 3. It is worthy to note that the 95% confidence interval is fairly large, with ranges of 14.04 bpm and 26.32 bpm for the Wrist-Bicep and Wrist-Ankle comparison respectfully. About 95% of the differences between the wrist and the bicep or ankle are contained within the confidence interval limits, and since the measurement at the bicep has a much smaller range of 14.04 bpm, it is reading values much closer to those measured at the wrist as compared to those measured at the ankle. While the watches on the bicep and ankle follow the trend of the watch worn on the wrist, which is an important component that needs to be monitored during KC, there are large differences of 14.0 and 26.32 bpm. These large differences in heartrate between the wrist and ankle could falsely indicate changes in heartrate when in reality none exist.

The Pearson's correlation coefficients between the readings at the wrist and the readings at the bicep and ankle were determined to be 0.84 and 0.63 respectively. The coefficients were determined by inputting the smartwatch data into MS Excel's Data Analysis Tool for determining the Pearson coefficient of correlation. The correlation between the readings is shown in Figure 4, where the agreement indicating a correlation coefficient of 1 is shown as a solid black line, which

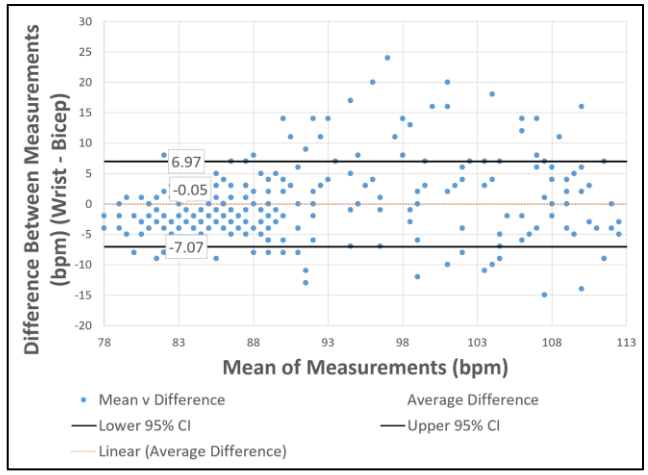

FIGURE 2: BLAND-ALTMAN PLOT COMPARING THE VALUE MEASURED AT THE WRIST TO THE VALUE MEASURED AT THE BICEP.

is a perfect agreement. While both the wrist-bicep comparison and the wrist-ankle comparison both have a positive correlation coefficient, the wrist-bicep correlation coefficient is much higher than the wrist-ankle comparison.

From visual analysis of the Bland-Altman plots (Figures 2 and 3) and the direct comparison plot (Figure 4), it is apparent that outside the range of 75-95 bpm, the readings start to diverge much more. This follows a trend noted by Pasadyn *et al.* where they concluded that commercially available smartwatches decrease in accuracy as intensity increases [14]. This increase in intensity is not expected during KC, which is a relaxed activity.

In light of the results, it is suggested that if the Garmin Venu® Sq smartwatch needs to be worn on a location other than the wrist, the bicep is an acceptable alternative. The bicep has a smaller average difference between the measurement at the wrist and the bicep of 0.05, it has a much narrower confidence interval of 14.04 bpm, and it has a higher positive correlation coefficient of 0.84 than the ankle.

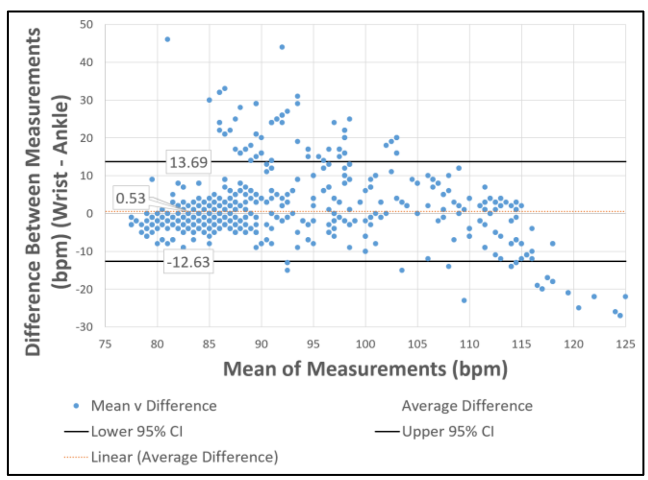

FIGURE 3: BLAND-ALTMAN PLOT COMPARING THE VALUE MEASURED AT THE WRIST TO THE VALUE MEASURED AT THE ANKLE.

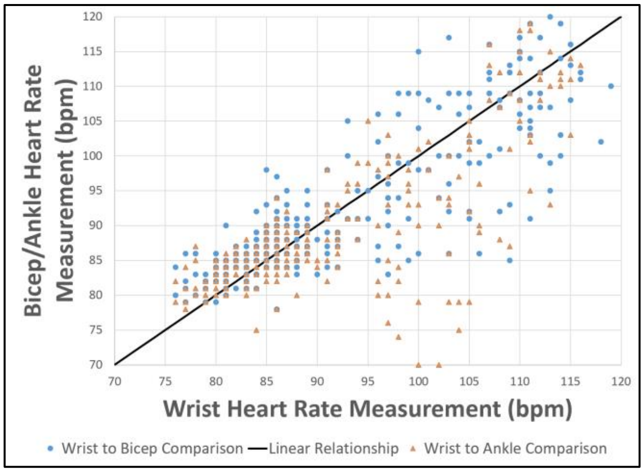

FIGURE 4: CORRELATION PLOT COMPARING THE HEART RATE MEASURED AT THE WRIST TO THE BICEP (BLUE CIRCLES) AND THE ANKLE (ORANGE TRIANGLES).

While this preliminary trial using the Garmin Venu® Sq smartwatch revealed that the watch worn at the bicep would be an acceptable alternative to wearing the watch at the wrist, more trials need to be performed to verify these results. A broader pool of participants is needed to verify that the watch can perform precisely across different ages, sexes, and skin types. Once it is further verified that the watch can be used on the bicep as an accurate measure of heartrate, the Garmin Venu® Sq can be implemented into the KC monitoring system to monitor the heartrate of the mother or other adult caregiver and transfer it to the HIPAA compliant Box Secure Storage for later analysis. This data can then be used to determine the relationship between mother-infant interactions on the overall physical and mental health of the dyad and give insight to how KC can be used to have a positive impact on the health outcomes of both the mother and the infant.

4. CONCLUSION

Through a comparison trial wearing three Garmin Venu® Sq smartwatches concurrently, it can be determined that wearing the smartwatch on the bicep is comparable to wearing the smartwatch on the wrist.

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REFERENCES

[1] Charpak, Nathalie, Tessier Rejean, Ruiz Juan, Hernandez Jose, Uriza Felipe, Villegas Julieta, Nadeau Line, Mercier Catherine, Maheu Francoise, Marin Jorge, Cortes Darwin, Gallego Juan and Maldonado Dario. “Twenty-year follow-up of kangaroo mother care versus traditional care.” *Pediatrics* (2016). DOI: 10.1542/peds.2016-2063. https://pubmed.ncbi.nlm.nih.gov/27965377/.

[2] Cutland Clare, Lackritz Eve, Mallett-Moore Tamala, Bardají Azucena, Chandrasekaran Ravichandran, Lahariya Chandrakant, Nisar Muhammed, Tapia Milagritos, Pathirana Jayani, Kochhar Sonali, Muñoz Flor and the Brighton Collaboration Low Birth Weight Working Group. “Low birth weight: Case definition & guidelines for data collection, analysis, and presentation of maternal immunization safety data.” *Vaccine* (2017). DOI: 10.1016/j.vaccine.2017.01.049. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5710991/.

[3] Sabnis Animesh, Fojo Sofia, Nayak Sameera, Lopez Elizabeth, Tarn Derjung, and Zeltzer Lonnie. “Reducing parental trauma and stress in neonatal intensive care: systematic review and meta-analysis of hospital interventions.” *J Perinatol* (2019). DOI: 10.1038/s41372-018-0310-9. https://pubmed.ncbi.nlm.nih.gov/30659239/.

[4] Charpak Nathalie, Montealegre-Pomar Adriana, Bohorquez Adriana. “Systematic review and meta-analysis suggest that the duration of Kangaroo mother care has a direct impact on neonatal growth.” *Acta Paediatr* (2021). DOI: 10.1111/apa.15489. https://pubmed.ncbi.nlm.nih.gov/32683720/.

[5] Bastani Farideh, Rajai Nahid, Farsi Zahra, and Als Heidelise. “The Effects of Kangaroo Care on the Sleep and Wake States of Preterm Infants.” *Journal of Nursing Research* Vol. 25, No. 3(2017): pp. 231–239. DOI: 10.1097/JNR.0000000000000194. https://www.researchgate.net/publication/311989876_The_Effects_of_Kangaroo_Care_on_the_Sleep_and_Wake_States_of_Preterm_Infants.

[6] “*Brain Basics: Understanding Sleep*.” National Institute of Neurological Disorders and Stroke. https://www.ninds.nih.gov/health-information/public-education/brain-basics/brain-basics-understanding-sleep (accessed November 22, 2022).

[7] Venancio Sonia and de Almeida Honorina, “Kangaroo Mother Care: scientific evidences and impact on breastfeeding,” *Jornal de Pediatria* Vol. 80, No. 5 (2004): pp. 8. DOI: 10.2223/JPED.1251. https://www.researchgate.net/publication/239983324_Kangaroo_Mother_Care_Scientific_evidences_and_impact_on_breastfeeding.

[8] Winberg Jan. “Mother and newborn baby: mutual regulation of physiology and behavior--a selective review.” *Dev Psychobiol* (2005). DOI: 10.1002/dev.20094. https://pubmed.ncbi.nlm.nih.gov/16252290/.

[9] Samra Haifa, Dutcher Janet, McGrath Jacqueline, Foster Meghan, Klein Linda, Djira Gemechis, Hansen Julie and Wallenburg Deborah. “Effect of skin-to-skin holding on stress in

mothers of late-preterm infants." *Adv Neonatal Care* (2015): pp 354-364. DOI: 10.1097/ANC.0000000000000223. https://pubmed.ncbi.nlm.nih.gov/26356086/.

[10] Charpak Nathalie and Gabriel Ruiz-Peláez Juan, "Resistance to implementing Kangaroo Mother Care in developing countries, and proposed solutions: Resistance to Kangaroo Mother Care." *Acta Paediatrica* Vol. 95, No. 5 (2007): pp. 529–534. DOI: 10.1111/j.1651-2227.2006.tb02279.x. https://onlinelibrary.wiley.com/doi/10.1111/j.1651-2227.2006.tb02279.x.

[11] Joglekar Ashish, Rawat Alok, Raiaraman Vasanth, Amrutur Bharadwai, Mony Prem, Thankachan Prashanth, Raj Tony, and Rao Suman. "A Wearable Sensor for Monitoring Kangaroo Mother Care Treatment for Premature Neonates." *2018 IEEE Sensors* (2018): pp. 4. DOI: 10.1109/ICSENS.2018.8589633. https://ieeexplore.ieee.org/document/8589633/authors.

[12] El-Farrash Rania, Shinkar Dina, Ragab Dina, Salem Ramy, Saad Wessam, Farag Ahmed, Salama Dina, and Sakr Medhat. "Longer duration of kangaroo care improves neurobehavioral performance and feeding in preterm infants: a randomized controlled trial." *Pediatric Research* (2020): pp.6. DOI: 10.1038/s41390-019-0558-6. https://pubmed.ncbi.nlm.nih.gov/31493775/.

[13] MacDonald P. R. and C.J. Kulach, "Heart rate monitor with time varying linear filtering." United States Patent 9801587B2, October 31, 2017.

[14] Pasadyn Selena, Soudan Mohamad, Gillinov Marc, Houghtaling Penny, Phelan Dermot, Gillinov Nicole, Bittel Barbara, and Desai Milind. "Accuracy of commercially available heart rate monitors in athletes: a prospective study." *Cardiovasc Diagn Ther* (2019). DOI: 10.21037/cdt.2019.06.05. PMID: 31555543; PMCID: PMC6732081. https://pubmed.ncbi.nlm.nih.gov/31555543/.