For cited: *Turgut, B. (2023). Wearables for Babies. Journal of Current Researches on Health Sector, 13 (1), 1-10.*

Year: 2023
Volume: 13
Issue: 1

Journal of Current Researches on Health Sector
(J o C R e H e S)
www.jocrehes.com
ISSN: 2547-9636

Review/Derleme

Crossref doi: 10.26579/jocrehes.13.1.1

Wearables for Babies

Begumhan TURGUT[1]

Keywords
Baby monitoring systems, Wearable Technologies, Smart Textile, Sensor Technologies, Baby Monitor.
Article History
Received
25 Dec, 2022
Accepted
15 Mar, 2023

Abstract
Wearable technologies for babies are increasing in popularity as physical biosensors are now able to be integrated into a baby's clothing. These clothes can then be used to both monitor the baby's critical biological signs such as heart and respiratory rate, blood oxygenation and pressure, core body temperature and position, and can notify parents or other care givers when critical situations occur. This study summarizes the latest developments in wearable technologies used to monitor an infant early development.

Bebekler için Giyilebilir Ürünler

Anahtar Kelimeler
Bebek izleme sistemleri, Giyilebilir Teknolojiler, Akıllı Tekstil, Sensör Teknolojileri, Bebek Monitörü.
Makale Geçmişi
Alınan Tarih
25 Aralık 2022
Accepted
15 Mart 2023

Özet
Fiziksel biyosensörler artık bir bebeğin giysisine entegre edilebildiğinden, bebekler için giyilebilir teknolojilerin popülaritesi artıyor. Bu giysiler daha sonra hem bebeğin kalp ve solunum hızı, kan oksijenasyonu ve basıncı, vücut ısısı ve pozisyonu gibi kritik biyolojik belirtilerini izlemek için kullanılabilir hem de kritik durumlar meydana geldiğinde ebeveynleri veya diğer bakıcıları bilgilendirebilir. Bu çalışma, bir bebeğin erken gelişimini izlemek için kullanılan giyilebilir teknolojilerdeki en son gelişmeleri özetlemektedir.

1. Introduction

Interest in wearable technology started in the 1960's worldwide with a particular concentration in the United States. When this research was combine with the inventions and rise of the internet, smart hardware and big data, wearable technology research expanded rapidly in the health monitoring space (Lu et al., 2020). Some of these technologies were geared towards the consumer market and have now seen regular use in the daily lives of individual people. These wearables are mainly worn on various locations on the arm and include smart watches,

[1] Corresponding Author. ORCID: 0000-0001-8635-7198. Dr., Artvin Çoruh Üniversitesi, bturgut@gmail.com

armbands, and smart wristbands that facilitates the continuous monitoring and analysis of vital data points during wear. First, we will provide a summary of medical wearables for function, form, and challenges and then examine how these are being addressed as the market starts to focus on babies.

2. Wearables for Health Monitoring

The world is coming to the realization that the next driver of human technological improvement will come from wearable devices (HappiestMinds, 2023). Wearable devices normally serve a specific purpose, such as collecting biofeedback (Rutherford, 2015) and can be subdivided into wearable technology for health monitoring, medical devices, and consumer products for home use. For health monitoring and medical devices, the definition and regulation for these devices are evolving and fall under different classifications around the world. In the United States wearable devices fall under the Food and Drug Administration's (FDA) definition for Digital Health which they have defined as "tools for users to make more informed decisions about their own health enabling the prevention, early decision of life-threatening diseases, or the management of chronic conditions outside of traditional care settings". Digital Health tools encompass telemedicine, health information technology, and personalized medicine (FDA, 2020). In its 2017 report, the European Commission defined smart wearable devices as "body-borne computational and sensory devices that can sense the wearer and/or the environment". This report also states that wearables could have "control, communication, storage and operation capabilities" (Directorate Generate for Communications Networks, 2017) making wearables a primary tool in healthcare use cases such (Harte et al., 2014). So why are regulators and consumers so interested in this space?

These devices are convenient vital system monitors which can easily be worn on wrists to provide data on blood oxygenation (Lochner et al., 2014) or woven into fabric enabling electrocardiograms (Marozas et al., 2011). Further these devices can both help hospitals with efficiency, reducing costs, while improving patient outcomes through increased quality of medical care received. For example by allowing the sensors to remain on a patient the transfer time between ambulances and emergency services can remove complexity and therefore reduce complications that may arise during these transitions (Metcalf et al., 2016). They can also be used during surgical procedures reducing the size and interconnections of wires between the patient and the external equipment reducing distractors and physical barriers for the surgical teams.

The future of wearables will come from e-textiles (Gokey, 2016) as e-textiles have the promise of both generating signals and biomechanical data but also the power charge to operate them. The physical flexibility and fabric integration has led to improved comfort and has led to the potential for smart textiles to dramatically increase the usage of these monitors (Kumar & Vigneswaran, 2015). Technological advances can be expected to continue this pattern making electronics smaller and more powerful further increasing user mobility and comfort (Libertino et al., 2018). While this class of wearable hold the most promise for the monitoring for children, they do not prevent some of the challenges presented by wearables.

Wearables provide two major concerns for humans. The first is the electromagnetic radiation that is generated by their communications. This concern has been addressed in multiple ways as there is no direct link between electromagnetic radiation at the power levels used by wearables and adverse events in children. This makes sense as a larger power draw of a wearable device would either require a larger power source, battery etc, or require more frequent external charging. This has resulted in wearables that are designed around lower power radios which results in a lower Specific Absorption Rate, which is the electromagnetic energy absorbed in the body, than mobile phones. Fortunately this can also be tested as “electronic engineers can simulate electromagnetic fields in the body and, in collaboration with people with medical backgrounds, determine the power levels absorbed in the head and adjust them to safe levels” (Caddy, 2015). Another concern around wearables is the value of the data these devices are tasked with collecting and there are methods for limiting this privacy impact (Telecommunications, 2019). When this turns to children the monitoring and dissemination of the information is occurring voluntarily by care givers and can even be seen as expected (Leaver, 2017).

3. Wearables for Babies

Development of smart health monitoring systems has progress over several years. Those monitoring systems that are wearable technology can be exchange traditional human monitoring methods and with electronic self-monitoring allowing medical staff to focus on the care of patients instead of these mundane tasks (Memon et al., 2020). Usage of these devices in hospitals for the monitoring of a patient’s psychological, non-psychological, and vital signs such as respiratory and pulse rate, body temperature, blood pressure, and blood oxygen saturation (Rimet et al., 2007) and can also be embedded into socks, buttons, coveralls, diaper clips, and leg bands enabling home use by sending data to family members' smartphones using Bluetooth technology (Callahan, 2017; Ul Hasan & Negulescu, 2020). With these devices being available for both hospital and home use we will now focus on the form and function of devices currently on the market.

Sensors that wrap around the body, consisting of multiple electrodes, enables the continuous recording of biological tissue internal to the body such as the lungs and heart (Salman et al., 2014). Wearable sensors for health monitoring tend to have specific medical criteria for each function. In order to be widely adopted, a wearable sensor system’s design needs to incorporate multiple criteria for wearability. As an example, its external appearance must be considered aesthetic while also ensuring that it’s form is located in such a position and shape that it does not hinder the user's movements, especially in when designed for infants (Pantelopoulos & Bourbakis, 2010). Sensor system for infants typically includes five modules: data acquisition or detection module, data processing, health status detection, wireless communication, and power that all must be contained in a wearable package (Wei et al., 2008; Yu, 2008). Smart textiles can now be integrated into a suit for electrocardiogram and respiration monitoring with data wireless transmission (Catrysse et al., 2004; Nicholas, 2014). Video monitors provide care givers with access to live audio and video streamed into a dedicated monitor or personal smart phones (Cartwright, 2022). Other monitoring products are equipped with sensors for temperature or under-bed movement (Angelcare, 2023). Baby monitors designed to be overalls, socks, stockings, buttons, leg straps, and diaper clips regularly occur on the market. Monitors that can measure the biological signals such as heart and respiration rate, blood oxygen levels, and remind parents of sleep times are also popular (Bonafide et al., 2017; Dangerfield et al., 2017; Sportelli, 2017).

4. Temperature

Fever needs to be taken very seriously, usually in babies aged 2 to 3 months, as fever in infants is an indicator of a very important infection that can spread very quickly throughout the body. Smart thermometers in a wearable form factor could aid new care givers who can then customize the amount of notifications they receive from a baby-monitoring app or tech linked to these wearables. Products are available that can help parents monitor an infant's heart rate, temperature, feeding, and sleep cycle, however, caution is currently being urged when using these technologies for medical information or diagnostics experts (Howard, 2017).

5. Respiration

The respiratory rates of babies are generally faster than that of older children and also can exhibit a pattern known as periodic breathing. While this is usually a normal occurrence in healthy babies this sudden change in respiratory pattern can be scary for a parent as monitoring respiratory rate can provide important information about diseases such as chronic obstructive pulmonary disease, asthma, sleep disturbance and anemia (Ul Hasan & Negulescu, 2020). Wearable sensors can determine the respiratory rate through direct detection of airflow during breathing or measure the expansion and contraction of the chest and abdomen. While it is currently inappropriate to utilize textile sensors for direct measurement indirect measurements of breath flow can be found with placement close to the nose or mouth and there are rapid developments occurring (Zhu et al., 2015). Conductive knitted fabric based has been used for indirect measurement (Lochner et al., 2014) and for extended monitoring of respiration rate, there are clothing covered with piezoresistive sensors participating in part of a wearable sensing system (Zhou, 2016). These sensors can then also be utilized as monitoring devices for sleep quality, cardiac events or heart disease syndrome, and sudden death (Lokavee et al., 2012).

6. Blood Oxygenation

Hypoxemia is a widely distributed cause of human death across the world derived from a non-specific balance of blood oxygen levels. The measurement of oxygen levels is typically through tissue oxygenation (StO2), peripheral oxygenation (SpO2) and venous oxygenation (SvO2). SpO2 is a non-invasive method and the most common method employed by wearable devices for this measurement. Pulse oximetry occurs with an optical approach that includes two LEDs, one that emits a visible light through a translucent part of the body such as the fingertip, earlobe, wrist, or forehead area, and the other is infrared. This light is then absorbed by the oxy-hemoglobin in a based on it's volume and concentration in the blood. A photodiode located on the opposite side of the translucent body part collects the non-adsorbed light resulting in a pulse oxygenation measurement that can be calculated based on the Beer-Lambert law (Folke et al., 2003; Herbert et al., 2020; Schwartz et al., 2013). Advancements in organic optoelectronics, or flexible organic LEDs and organic photodetector OPDs (Lochner et al., 2014) enables wearable devices to overcomes the need for measurement to occur only on a fingertip or earlobes only that occurred from inorganic optoelectronics. Measurement of oxygenation through these organic sensors has enabled the placement of monitors constructed with an OLED light source and photodiode on the forearm using a flexible bandage or garment (Zhou, 2016).

7. Heart Rate

The measurement of heat rate can be obtained by either an optional strain or electrical sensor. A myocardium, or electrocardiogram (ECG), measurements the level of electrical activity of the heart from the direct measurement of its level on the skin. As the electrical potential of the body varies based on the measurement point different types of ECG leads are needed. Researchers are now trying to design and develop textile electrodes that are integrated into clothing and provide an ECG. This focus should allow for further research into the detection and prevention sudden infant death (SIDS). A babywear prototype utilizing Textrodes has integrated a flexible printed circuit and embroidered on an elastic belt has been developed with wireless power and data communication (Coosemans et al., 2006) towards this end.

8. Conclusion

Wearable systems have also undergone significant development in recent years to monitor an infant vital signs in order to prevent premature death especially when they are born prematurely or infant death (Vanhaesebrouck et al., 2004). Wearable devices and sensors are essential for monitoring babies' physical activity as care providers, unlike wearable devices, will not be able to continuously monitor a baby's condition at all times and notify the care provider as soon as an alert condition is met. While these systems each have unique functionality they operate under the following general pattern:

- Detection of vital statistics through the wireless sensor integrated wearable device;
- wirelessly transmission of collected health-related information to a base station and relayed to parents' mobile phone and internet cloud;
- cloud storage for accessibility from any internet end point;
- Instant notifications delivered directly to care givers from their base station and mobile phones in case of unexpected drop in baby vitals (Ul Hasan & Negulescu, 2020).

If we think of Sudden Infant Death Syndrome (SIDS), as a leading causes of death in infants, monitors for this condition can greatly sooth parental anxiety during a baby's vulnerable sleep cycle through constant monitoring. The wearable system can now continually monitor conditions and detect an unexpected drop in respiratory rate, heart rate and oxygen level. This then can alleviate Sudden Infant Death Syndrome anxiety by reporting sudden critical situations. The value and potential provided by wearable technology designed for a baby's health will be a critical factor in improving the quality of a baby's life.

References

Angelcare. (2023). Angelcare Baby Monitoring. [Erişim: 21.03.2023, https://angelcarebaby.com/us_en/monitoring].

Bonafide, C. P., Jamison, D. T. & Foglia, E. E. (2017). The Emerging Market of Smartphone-Integrated Infant Physiologic Monitors. JAMA, 317(4), 353. [Erişim:21.03.2023, https://doi.org/10.1001/jama.2016.19137].

Caddy, R. (2015). *Quantified Babies: Is Wearable Tech for Your Newborn Really Safe?* [Erişim: 11.03.2023, https://www.wareable.com/health-and-wellbeing/wearable-tech-babies-newborn-safe].

Callahan, A. (2017). New Type of Baby Monitors Offers 'Peace of Mind' But May Deliver Just the Opposite. *The Washington Post*. [Erişim: 21.03.2023, https://www.washingtonpost.com/national/health-science/new-type-of-baby-monitors-offers-peace-of-mind-but-may-deliver-just-the-opposite/2017/05/05/8d31a07e-09b7-11e7-93dc-00f9bdd74ed1_story.html].

Cartwright, G. (2022). *10 of the Best Baby Monitors – Tried and Tested*. Made for Mums. [Erişim: 21.03.2023, https://www.madeformums.com/reviews/10-of-the-best-baby-monitors/].

Catrysse, M., Puers, R., Hertleer, C., Van Langenhove, L., van Egmond, H., & Matthys, D. (2004). Towards the Integration of Textile Sensors in a Wireless Monitoring Suit. *Sensors and Actuators A: Physical*, *114*(2-3), 302-311. [Erişim: 21.03.2023, https://doi.org/10.1016/j.sna.2003.10.071].

Coosemans, J., Hermans, B., & Puers, R. (2006). Integrating Wireless ECG Monitoring in Textiles. *Sensors and Actuators A: Physical*, *130-131*, 48-53. [Erişim: 21.03.2023, https://doi.org/10.1016/j.sna.2005.10.052].

Dangerfield, M. I., Ward, K., Davidson, L., & Adamian, M. (2017). Initial Experience and Usage Patterns With the Owlet Smart Sock Monitor in 47,495 Newborns. *Global Pediatric Health*, *4*, 2333794X1774275. [Erişim: 21.03.2023, https://doi.org/10.1177/2333794X17742751].

Directorate Generate for Communications Networks, C. a. T. (2017). *Smart Wearables Reflection and Orientation Paper Including Feedback from Stakeholders*. Brussels: European Commission

FDA. (2020). *What is Digital Health?* FDA. [Erişim: 21.03.2023, https://www.fda.gov/medical-devices/digital-health-center-excellence/what-digital-health].

Folke, M., Cernerud, L., Ekström, M., & Hök, B. (2003). Critical Review of Non-invasive Respiratory Monitoring in Medical Care. *Medical & Biological Engineering & Computing*, *41*(4), 377-383. [Erişim: 21.03.2023, https://doi.org/10.1007/BF02348078].

Gokey, M. (2016). *Why smart clothes, not watches, are the future of wearables*. DigitalTrends. [Erişim: 21.03.2023, https://www.digitaltrends.com/wearables/smart-clothing-is-the-future-of-wearables/].

HappiestMinds. (2023). *Wearable Technology; What Are Wearables?* Happiest Minds, The Mindful IT Company. [Erişim: 21.03.2023, https://www.happiestminds.com/Insights/wearable-technology/].

Harte, R., Glynn, L., Broderick, B., Rodriguez-Molinero, A., Baker, P., McGuiness, B., O'Sullivan, L., Diaz, M., Quinlan, L.R. and ÓLaighin, G. (2014). Human Centred Design Considerations for Connected Health Devices for the Older Adult. *Journal of Personalized Medicine*, *4*(2), 245-281. [Erişim: 21.03.2023, https://doi.org/10.3390/jpm4020245].

Herbert, A., Pearn, J., & Wilson, S. (2020). Normal Percentiles for Respiratory Rate in Children—Reference Ranges Determined from an Optical Sensor. *Children*, *7*(10), 160. [Erişim: 21.03.2023, https://doi.org/10.3390/children7100160].

Howard, J. (2017). *There Are Health-tracking Wearables for Babies, Too.* CNN. [Erişim: 21.03.2023, https://edition.cnn.com/2017/11/06/health/baby-technology-products-teching/index.html].

Kumar, L. A., & Vigneswaran, C. (2015). *Electronics in Textiles and Clothing: Design, Products and Applications* (0 ed.). CRC Press.

Leaver, T. (2017). Intimate Surveillance: Normalizing Parental Monitoring and Mediation of Infants Online. *Social Media + Society*, *3*(2), 205630511770719. [Erişim: 21.03.2023, https://doi.org/10.1177/2056305117707192].

Libertino, S., Plutino, M. R., & Rosace, G. (2018). Design and Development of Wearable Sensing Nanomaterials for Smart Textiles. In *AIP Conference Proceedings*, 1990(1), 020016. AIP Publishing LLC.

Lochner, C. M., Khan, Y., Pierre, A., & Arias, A. C. (2014). All-organic optoelectronic sensor for pulse oximetry. *Nature Communications*, *5*(1), 5745. [Erişim: 21.03.2023, https://doi.org/10.1038/ncomms6745].

Lokavee, S., Puntheeranurak, T., Kerdcharoen, T., Watthanwisuth, N., & Tuantranont, A. (2012). Sensor Pillow and Bed Sheet System: Unconstrained Monitoring of Respiration Rate and Posture Movements During Sleep. 2012 IEEE International Conference on Systems, Man and Cybernetics - SMC, Lu, L., Zhang, J., Xie, Y., Gao, F., Xu, S., Wu, X., & Ye, Z. (2020). Wearable Health Devices in Health Care: Narrative Systematic Review. *JMIR mHealth and uHealth*, *8*(11), e18907. [Erişim: 21.03.2023, https://doi.org/10.2196/18907].

Marozas, V., Petrenas, A., Daukantas, S., & Lukosevicius, A. (2011). A Comparison of Conductive Textile-based and Silver/silver Chloride Gel Electrodes in Exercise Electrocardiogram Recordings. *Journal of Electrocardiology*, *44*(2), 189-194. [Erişim: 21.03.2023, https://doi.org/10.1016/j.jelectrocard.2010.12.004].

Memon, S. F., Memon, M., & Bhatti, S. (2020). Wearable Technology for Infant Health Monitoring: A Survey. *IET Circuits, Devices & Systems*, *14*(2), 115-129. [Erişim: 21.03.2023, https://doi.org/10.1049/iet-cds.2018.5447].

Metcalf, D., Milliard, S. T. J., Gomez, M., & Schwartz, M. (2016). Wearables and the Internet of Things for Health: Wearable, Interconnected Devices Promise More Efficient and Comprehensive Health Care. *IEEE Pulse*, *7*(5), 35-39. [Erişim: 21.03.2023, https://doi.org/10.1109/MPUL.2016.2592260].

Nicholas, H. (2014). *Wearable 'Smart' Baby Monitor Provides Parents with Insight*. [Erişim: 21.03.2023, https://www.medicalnewstoday.com/articles/280874].

Pantelopoulos, A., & Bourbakis, N. G. (2010). A Survey on Wearable Sensor-Based Systems for Health Monitoring and Prognosis. *IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews)*, *40*(1), 1-12. [Erişim: 21.03.2023, https://doi.org/10.1109/TSMCC.2009.2032660].

Rimet, Y., Brusquet, Y., Ronayette, D., Dageville, C., Lubrano, M., Mallet, E., Rambaud, C., Terlaud, C., Silve, J., Lerda, O., Netchiporouk, L.I., and Weber, J.-L. (2007). Surveillance of Infants at Risk of Apparent Life Threatening Events (ALTE) with the BBA Bootee: A Wearable Multiparameter Monitor. 29th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, (pp. 4997-5000). IEEE.

Rutherford, Z. (2015). *Wearables: Enhancing or Exploiting Our Personal Data?* UX Booth. [Erişim: 21.03.2023, https://www.uxbooth.com/articles/wearables-enhancing-or-exploiting-our-personal-data/].

Salman, S., Lee, L. Z., & Volakis, J. L. (2014). A Wearable Wrap-Around Sensor for Monitoring Deep Tissue Electric Properties. *IEEE Sensors Journal*, *14*(8), 2447-2451. [Erişim: 21.03.2023, https://doi.org/10.1109/JSEN.2014.2323896].

Schwartz, G., Tee, B. C. K., Mei, J., Appleton, A. L., Kim, D. H., Wang, H., & Bao, Z. (2013). Flexible Polymer Transistors with High Pressure Sensitivity for Application in Electronic Skin and Health Monitoring. *Nature Communications*, *4*(1), 1859. [Erişim: 21.03.2023, https://doi.org/10.1038/ncomms2832].

Sportelli, N. (2017). *Owlet's Smart Sock Makes Millions Selling Parents Peace Of Mind -- But Doctors Are Unconvinced.* Forbes. [Erişim: 21.03.2023, https://www.forbes.com/sites/nataliesportelli/2017/10/03/owlets-infant-health-monitor-is-winning-over-millennial-parents-doctors-are-another-matter/?sh=3612fb897646].

Telecommunications, I. W. G. o. D. P. i. (2019). *Privacy Risks with Smart Devices for Children*.

Ul Hasan, M. N., & Negulescu, I. I. (2020). Wearable technology for baby monitoring: a review. *Journal of Textile Engineering & Fashion Technology*, *6*(4), 15406.

Vanhaesebrouck, P., Allegaert, K., Bottu, J., Debauche, C., Devlieger, H., Docx, M., François, A., Haumont, D., Lombet, J., Rigo, J. and Smets, K. (2004). The EPIBEL Study: Outcomes to Discharge From Hospital for Extremely Preterm Infants in Belgium. *Pediatrics*, *114*(3), 663-675. [Erişim: 21.03.2023, https://doi.org/10.1542/peds.2003-0903-L].

Wei, C., Sonntag, C., Boesten, F., Bambang Oetomo, S., & Feijs, L. (2008). A Power Supply Design of Body Sensor Networks for Health Monitoring of Neonates. 2008 International Conference on Intelligent Sensors, Sensor Networks and Information Processing (ISSNIP), (pp. 255-260). IEEE.

Yu, X. (2008). Approaches and Principles of Fall Detection for Elderly and Patient. HealthCom 2008-10th International Conference on e-health Networking, Applications and Services, (pp. 42-47). IEEE.

Zhou, M. (2016). Electronic Technology in Home Medical Equipment in Chinese Market.

Zhu, Z., Liu, T., Li, G., Li, T., & Inoue, Y. (2015). Wearable Sensor Systems for Infants. *Sensors*, *15*(2), 3721-3749. [Erişim: 21.03.2023, https://doi.org/10.3390/s150203721].