Consumer sleep technology for children: A scoping review

Authors:
Craig Canapari MD
Monica Ordway APRN PhD
Ambrose Chiang MD
Judith Owens MD

Contact: Melissa C Funaro, Harvey Cushing/John Hay Whitney Medical Library, Yale University, 333 Cedar St., New Haven, CT 06520-8014

Resources for format
JBI

Abstract
Sleep is a critically important biological function for children and adults. Public interest in sleep has increased considerably in the last decade which has resulted in a rise in consumer sleep technology (CST). CST is a broad category of technology which includes wearables, so-called "nearables" (technology adjacent to the sleeper), and software. Although there has been a proliferation of CST focused on children, the majority of published research and reviews have been on CST use in adults. The goal of this scopng review protocol is to assess the current state of CST in children in terms of a) types of technology b) quality and quantity of evidence and c) potential utility and limitations of CST in assessing and improving the sleep of children.

Introduction: (~1000 words)

Sleep is a critically important biological function for both children and adults. Sleep health, and good sleep habits begin early in life("The Foundations of Lifelong Health Are Built in Early Childhood," n.d.). Multiple studies have demonstrated the importance of sleep for physical and mental health, learning, and growth in children(Agostini and Centofanti, 2021). Moreover, sleep interventions to prevent sleep problems in young children may prevent mental health issues in adolescents(Tochigi et al., 2016). Public interest in sleep has increased considerably in the last decade, which has been reflected in the proliferation of consumer sleep technology (CST).CST is a broad category of technology which includes wearables, so-called "nearables" (technology adjacent to the sleeper), and software. Consumer sleep tracking devices have become both more sophisticated and ubiquitous in the last decade, with an estimated market size in the billions of dollars("Wearable Sleep Trackers Market," n.d.). The majority of research on consumer sleep technology in adults has centered on wearable technology. However, wearables are not necessarily appropriate for young children who may not tolerate a device. Devices which monitor sleep by using nearby technology such as cameras and mattress pads (so called "nearables") or even smartphone or web applications have been developed to assess sleep in

children in ages from infancy to adolescence. Thus, the scope of this article has been expanded beyond just wearables. The focus of this article is on providing insight to pediatricians and pediatric sleep providers who often are asked to interpret data provided by parents. For this reason, we are restricting our review to articles on commercially available technologies.

Sleep problems in children are common, prompting one author to call insomnia "the sleeping giant of pediatric public health." (Badin et al., 2016) Sleep problems are common throughout childhood, with parents reporting up to 69% of children have trouble falling and staying asleep several times per week, and more than half of adolescents reporting difficulty with sleep onset at least weekly(Trosman and Ivanenko, 2021). In a recent survey of parents of young children, 35% of parents reported a sleep problem, but over 96% wanted to change something about their child's sleep. Melatonin, a hormone which is naturally produced in the brain prior to sleep onset, also has been shown to reduce sleep onset latency in children when given as a supplement (Claustrat and Leston, 2015; Esposito et al., 2019). It has become the most commonly reported accidental ingestion in children in the last ten years, increasing in prevalence by 530%(Lelak, 2022). This likely reflects growing parental concern about their children's sleep. Thus it is no accident that there has been a proliferation of consumer sleep technology (CST) marketed to parents with the stated goal of measuring and perhaps improving the sleep of their children.

Children's sleep needs are also different than that of adults. Sleep requirements change quite a bit during from infancy until adulthood, both in terms of duration and timing. Newborns have a normal sleep range from 14-17 hours per 24 hour period, whereas adolescents should sleep between 8-10 hours overnight(Hirshkowitz et al., 2015). Napping reduces in frequency from four or more times per day to none during early elementary school (Iglowstein et al., 2003; Staton et al., 2015). Bedtimes naturally shift later as adolescents move through puberty. There are also important differences in sleep patterns between different racial and ethnic groups as well. Moreover, children have less control over their sleep periods than adults do. Younger children go to bed at bedtime and naptime when their parents or caregivers decide that it is appropriate. Adolescents have different challenges, although they also usually do not get to set their own sleep schedules on most days. . School start times are often the primary determinant of sleep duration, and are often inappropriately early

Due to these factors, determining what is "normal" is more challenging for CSTs in children when compared with adult subjects. Moreover, the audience for the information provided for CST may be different. Obviously the parents of infants and young children will be the primary audience, although school age children may be interested. Adolescents may be interested in information from CSTs, but they may also cause conflict with parents or caregivers, for example if the data provided show that the adolescent is going to bed later than their caregivers thought they were.

Although many commercial devices purport to detect sleep staging, trials in adults have suggested that they are best suited to detecting sleep vs wake, as opposed to determining sleep staging(Chinoy et al., 2022, 2021), similar to actigraphy. **Data from such devices is now**

often brought by parents to the primary care or specialty clinic, although their potential utility is unclear.

Another potential issue is how accurate these devices may be in the assessment of children with known or suspected sleep issues such as obstructive sleep apnea.. As pointed out in the review by Chiang et al, a subset of people using consumer wearables may be trying to independently assess and improve sleep when occult sleep disorders are present(Chiang and Khosla, 2023).

This is not to discount the potential utility of CST. Systematic reviews of the literature suggest that consumer wearables may be helpful additions to behavioral sleep interventions in adults(Baron et al., 2021; Lai et al., 2023), but the application of consumer technology to sleep problems in children is unclear.

The objective of this review is to investigate the evidence around consumer devices and applications currently being marketed and sold to families for the express purpose of monitoring children's sleep. The specific questions we hope to answer are:

Questions to answer
1. What kinds of sleep technology have been examined in this patient population?
2. What sleep outcomes are being measured by these technologies?
3. How accurate consumer sleep technology compared with gold standard technologies (PSGs, actigraphy)?
4. What specific behavior change strategies are being used to improve sleep duration and quality in association with these technologies, if any?
5. Does consumer sleep technology improve sleep in healthy children?
6. Does consumer sleep technology increase parental satisfaction with their children's sleep?
7. Are underrepresented groups included in the body of literature? Including racial and ethnic minorities, as well as children with syndromes or developmental disabilities?
7a. For wearable technology, have the authors assessed the utility of included pulse oximetry on different skin tones?
8. Have consumer sleep technology been validated for children with health issues (such as obstructive sleep apnea)?

A preliminary search for existing scoping and systematic reviews on this topic wasn conducted on August 8, 2023 and no reviews were identified at that time.

This scoping review protocol is informed by the framework described by the Joanna Briggs Institute (JBI)(Peters et al., 2020). In addition, the protocol is being reported in accordance with the PRISMA Extension for Scoping Reviews (PRISMA-ScR)(Tricco et al., 2018).

Inclusion criteria

Any studies including children from ages 0 to 18 years of age were included for review. The decision was made to exclude studies specifically on young adults in the 18-24 years of age range so as to focus specifically on children. All published sources were eligible for Inclusion provided that they were peer-reviewed and that the full protocol and results were available. Thus conference abstracts will be excluded.

Devices were defined as “commercially available” if they are available to consumers, either for free or via purchase, at the time of publication.

Exclusion criteria
Conference abstracts and reviews will be excluded. Studies in languages other than English will be excluded due to time and lack of funds for translation.

Search strategy
To identify relevant literature, the following databases will be searched: MEDLINE (Ovid), Embase (Ovid), Psycinfo (Ovid), CINAHL, and Web of Science. No date limit will be imposed on the search. Databases will be limited to English language articles.
An experienced medical librarian (MCF) will be consulted on methodology. A medical subject heading (MeSH) analysis of known key articles provided by the research team [mesh.med.yale.edu] will be done and scoping searches will be done in each database. An iterative process will be used to translate and refine the searches. To maximize sensitivity, the formal search will use controlled vocabulary terms and synonymous free-text words. The search strategy will be peer reviewed by a second librarian, not otherwise associated with the project, using the PRESS standard(McGowan et al., 2016). A draft MEDLINE search strategy is included in Appendix 1. Reviewers will check for additional relevant cited and citing articles using included studies. To capture recently published articles, a second database search will be rerun before publishing the paper.

Source of evidence selection
Search results will be pooled in EndNote 21 [endnote.com] and de-duplicated using the Yale Reference Deduplicator [library.medicine.yale.edu/reference-deduplicator]. This set will be uploaded to Covidence [covidence.org] for screening.

To pilot test source selection, a random sample of 25 titles and abstracts will be selected. The entire team will screen these using the eligible criteria, then meet to discuss discrepancies and make modifications to the eligibility criteria and definitions/elaboration document. The team will only start screening when >= 75% agreement is achieved.

Three reviewers will complete title and abstract screening independently, and selected studies will be assessed against the predefined inclusion criteria. Each record will be reviewed by two of the three reviewers, with each reviewer assessing two-thirds of all the identified articles.

Potentially relevant papers will be retrieved in full and uploaded into Covidence. The full text will then be assessed in detail against the inclusion criteria by two of the three independent reviewers. Reasons for excluding full-text papers will be recorded and reported in the scoping review. Any disagreements that arise between the reviewers at each stage of the selection process will be resolved by a third reviewer or through discussion. The results of the search will be reported in full in the final scoping review, according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR),28 and presented in a PRISMA flow diagram.29

Data extraction

Data will be extracted from studies included in the scoping review by one reviewer using a data extraction tool developed by the reviewers and based on methods recommended by(Aromataris and Munn, 2020). Data extracted will then be verified by a second reviewer. Any disagreement that arises between the reviewers will be resolved through discussion or with a third reviewer. The draft extraction tool (see Appendix II) will be tested on five studies and may be subsequently refined depending on the data available for extraction; any modifications to the extraction tool will be detailed in the full scoping review. Extracted data will include authors, publication year, source, study or article type, description of sleep technology reported, population, setting, outcomes reported, determination of accuracy relative to gold-stand technologies, length of data collection, assessment of parental satisfaction, and strategies used to promote sleep health behaviors. Where relevant, authors of included studies will be contacted for clarification or missing information. Depending on the characteristics of included studies, extracted results may be grouped according to age to support a subgroup for analysis. We anticipate that there could be three main subgroup (ages 0-5, 6-12, and 13-18 year olds, respectively).

Analysis of the evidence

As this is a scoping review, the analysis will primarily be descriptive. A description of the frequency and type of studies of various technologies in the age group will be included as part of the review. Furthermore Included studies will be categorized by quality as determined by study methodology.

Presentation of the results

The extracted data will be presented in tabular format and will address the review questions and quality assessment. A narrative summary will accompany the charted results and will include a comprehensive overview of the types of sleep technology (mobile, wearable, nearable), the context of how the sleep technology is used, sleep outcomes measured, and, if present, any behavioral or medical changes measured. Results will be presented according to age groups and comparisons may be made of the wearable/mobile technology used, behavior strategies

implemented, and sleep outcomes measured during the different ages (early childhood 0-5 yo, school age 6-12 yo, and adolescence 13-18 yo) if possible.

Bibliography

Agostini, A., Centofanti, S., 2021. Normal Sleep in Children and Adolescence. Child Adolesc. Psychiatr. Clin. N. Am. 30, 1–14. https://doi.org/10.1016/j.chc.2020.08.011

Aromataris, E., Munn, Z. (editors), 2020. JBI Manual for Evidence Synthesis. JBI.

Badin, E., Haddad, C., Shatkin, J.P., 2016. Insomnia: the Sleeping Giant of Pediatric Public Health. Curr. Psychiatry Rep. 18, 47. https://doi.org/10.1007/s11920-016-0687-0

Baron, K.G., Duffecy, J., Reutrakul, S., Levenson, J.C., McFarland, M.M., Lee, S., Qeadan, F., 2021. Behavioral interventions to extend sleep duration: A systematic review and meta-analysis. Sleep Med. Rev. 60, 101532. https://doi.org/10.1016/j.smrv.2021.101532

Chiang, A.A., Khosla, S., 2023. Consumer Wearable Sleep Trackers: Are They Ready for Clinical Use? Sleep Med. Clin. https://doi.org/10.1016/j.jsmc.2023.05.005

Chinoy, E.D., Cuellar, J.A., Huwa, K.E., Jameson, J.T., Watson, C.H., Bessman, S.C., Hirsch, D.A., Cooper, A.D., Drummond, S.P.A., Markwald, R.R., 2021. Performance of seven consumer sleep-tracking devices compared with polysomnography. Sleep 44, zsaa291. https://doi.org/10.1093/sleep/zsaa291

Chinoy, E.D., Cuellar, J.A., Jameson, J.T., Markwald, R.R., 2022. Performance of Four Commercial Wearable Sleep-Tracking Devices Tested Under Unrestricted Conditions at Home in Healthy Young Adults. Nat. Sci. Sleep 14, 493–516. https://doi.org/10.2147/NSS.S348795

Claustrat, B., Leston, J., 2015. Melatonin: Physiological effects in humans. Neurochirurgie 61, 77–84. https://doi.org/10.1016/j.neuchi.2015.03.002

Esposito, S., Laino, D., D'Alonzo, R., Mencarelli, A., Genova, L.D., Fattorusso, A., Argentiero, A., Mencaroni, E., 2019. Pediatric sleep disturbances and treatment with melatonin. J. Transl. Med. 17. https://doi.org/10.1186/s12967-019-1835-1

Hirshkowitz, M., Whiton, K., Albert, S.M., Alessi, C., Bruni, O., DonCarlos, L., Hazen, N., Herman, J., Katz, E.S., Kheirandish-Gozal, L., Neubauer, D.N., O'Donnell, A.E., Ohayon, M., Peever, J., Rawding, R., Sachdeva, R.C., Setters, B., Vitiello, M.V., Ware, J.C., Hillard, P.J.A., 2015. National Sleep Foundation's sleep time duration recommendations: methodology and results summary. Sleep Health J. Natl. Sleep Found. 1, 40–43. https://doi.org/10.1016/j.sleh.2014.12.010

Iglowstein, I., Jenni, O.G., Molinari, L., Largo, R.H., 2003. Sleep Duration From Infancy to Adolescence: Reference Values and Generational Trends. PEDIATRICS 111, 302–307. https://doi.org/10.1542/peds.111.2.302

Lai, M.Y.C., Mong, M.S.A., Cheng, L.J., Lau, Y., 2023. The effect of wearable-delivered sleep interventions on sleep outcomes among adults: A systematic review and meta-analysis of randomized controlled trials. Nurs. Health Sci. 25, 44–62. https://doi.org/10.1111/nhs.13011

Lelak, K., 2022. Pediatric Melatonin Ingestions — United States, 2012–2021. MMWR Morb. Mortal. Wkly. Rep. 71. https://doi.org/10.15585/mmwr.mm7122a1

McGowan, J., Sampson, M., Salzwedel, D.M., Cogo, E., Foerster, V., Lefebvre, C., 2016. PRESS Peer Review of Electronic Search Strategies: 2015 Guideline Statement. J. Clin. Epidemiol. 75, 40–46. https://doi.org/10.1016/j.jclinepi.2016.01.021

Peters, M., Godfrey, C., McInerney, P., Tricco, A., Khalil, H., 2020. Chapter 11: Scoping reviews - JBI Manual for Evidence Synthesis - JBI Global Wiki, in: JBI Manual for Evidence

Synthesis. JBI.
Staton, S.L., Smith, S.S., Thorpe, K.J., 2015. “Do I really need a nap?”: The role of sleep science in informing sleep practices in early childhood education and care settings. Transl. Issues Psychol. Sci. 1, 32–44. http://dx.doi.org/10.1037/tps0000011
The Foundations of Lifelong Health Are Built in Early Childhood, n.d.
Tochigi, M., Usami, S., Matamura, M., Kitagawa, Y., Fukushima, M., Yonehara, H., Togo, F., Nishida, A., Sasaki, T., 2016. Annual longitudinal survey at up to five time points reveals reciprocal effects of bedtime delay and depression/anxiety in adolescents. Sleep Med. 17, 81–86. https://doi.org/10.1016/j.sleep.2015.08.024
Tricco, A.C., Lillie, E., Zarin, W., O’Brien, K.K., Colquhoun, H., Levac, D., Moher, D., Peters, M.D.J., Horsley, T., Weeks, L., Hempel, S., Akl, E.A., Chang, C., McGowan, J., Stewart, L., Hartling, L., Aldcroft, A., Wilson, M.G., Garritty, C., Lewin, S., Godfrey, C.M., Macdonald, M.T., Langlois, E.V., Soares-Weiser, K., Moriarty, J., Clifford, T., Tunçalp, Ö., Straus, S.E., 2018. PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation. Ann. Intern. Med. 169, 467–473. https://doi.org/10.7326/M18-0850
Trosman, I., Ivanenko, A., 2021. Classification and Epidemiology of Sleep Disorders in Children and Adolescents. Child Adolesc. Psychiatr. Clin. N. Am. 30, 47–64. https://doi.org/10.1016/j.chc.2020.08.002
Wearable Sleep Trackers Market [WWW Document], n.d. URL https://www.futuremarketinsights.com/reports/wearable-sleep-trackers-market (accessed 9.8.23).

Appendix 1. Ovid MEDLINE Draft search strategy

1	exp Sleep wake disorders/ or exp Sleep/ or (circadian or insomnia* or dyssomnia* or hypersomn* or narcolep* or parasomnia* or rapid eye movement* or REM or restless leg* or sleep or bruxism or somn* or wake or wakefulness).tw,kw.
2	exp Child/ or Adolescent/ or exp Infant/ or Pediatrics/ or (adolescen* or babies or baby or child* or infancy or infant* or kid or kids or neonatology or newborn* or new-born* or paediatric* or pediatric* or preadolescen* or pubescence or pubescent or schoolchild* or teen or teenager* or teens or toddler*).tw,kw.
3	((sleep or circadian or insomnia* or dyssomnia* or hypersomn* or narcolep* or parasomnia* or rapid eye movement* or REM or restless leg* or sleep or bruxism or somn* or wake or wakefulness) adj2 (device* or technolog* or app or application* or apps or computer or electronic or gamificat* or internet or m health or mhealth or mhealth or online or smart phone* or smartphone* or tablet* or text delivered or text messag* or text-based or web or website*)).tw,kw.
4	Wearable Electronic Devices/ or Fitness Trackers/ or (autovideosomnograph* or "auto videosomnograph*" or "automatic videosomongraph*" or Actiwatch or SMartSleeve or Apple Watch or Fitbit* or Hexoskin or Jawbone or Micromini or nearable* or Nanit* or

	nearable* or OMRON or OURA ring or Owlet or Polar electro or Sleep tracker* or fitness tracker* or wearable* or ScanWatch or wrist device* or Xiaomi mi band* or responsive bassinet* or SNOO or responsive soothing or Mechanical Soothing).tw,kw. or (smart adj2 (bassinet* or device* or monitor* or sock* or sleeper* or wristband* or headband* or headgear)).tw,kw.
5	((app or application* or apps or computer or electronic or gamificat* or internet or m health or mhealth or mhealth or online or smart phone* or smartphone* or tablet* or text delivered or text messag* or text-based or web or website*) adj2 (intervention or program* or assess*)).tw,kw.
6	3 or 4 or 5
7	1 and 2 and 6