Original Article

DOI: 10.14235/bas.galenos.2022.57338
Bezmialem Science 2023;11(1):93-9

Investigation of Proprioception and Kinesthesia Sensations in the Upper Extremities of Children with Childhood Cancer

Çocukluk Çağı Kanserli Çocukların Üst Ekstremitelerinde Propriosepsiyon ve Kinestezi Duyularının İncelenmesi

Zeynep KOLİT, Ceren DAVUTOĞLU, Meral HURİ, Sedef ŞAHİN

Hacettepe University Faculty of Health Sciences, Department of Occupational Therapy, Ankara, Turkey

ABSTRACT

Objective: The objective of this study was to examine the proprioception and kinesthesia functions of the upper limbs in children who were undergoing chemotherapy treatment and hospitalized with various cancer diagnoses.

Methods: Two hundred thirteen (101 females, 112 males) children with childhood cancer participated in this study. The proprioception and kinesthesia senses of the upper extremities were evaluated within the hospital setting. The sense of position, which was a clinical assessment, was used to assess proprioception. The kinesthesia subtest of Sensory Integration and Praxis Test was used to evaluate the kinesthesia sense. Kruskal-Wallis test was used to compare mean values according to diagnostic criteria. Spearman's coefficient of correlation was used for bivariate correlations and the statistical significance was accepted as $p<0.05$.

Results: There was no significant difference in proprioception scores and kinesthesia averages according to diagnosis types ($p>0.05$). In proprioception scores, according to diagnosis types, the lowest score was in the carcinoma group, while the highest score was seen in lymphoma group. In terms of kinesthesia, the most affected was the lymphoma group, while the leukemia group was least. In addition, no significant relationship was found between proprioception and kinesthesia scores ($p>0.05$). However, a significant correlation was found between right and left extremity proprioception scores ($p<0.01$, $r=0.50$).

Conclusion: This study revealed the existence of proprioception and kinesthesia deficiencies in children who received chemotherapy. Planning intervention programs for these areas and evaluating sensory parameters in detail will be useful for future studies.

Keywords: Cancer, child, proprioception, kinesthesia

ÖZ

Amaç: Bu çalışmanın amacı hastanede yatan ve kemoterapi tedavisi gören farklı tanılı kanserli çocukların üst ekstremitelerinin propriosepsiyon ve kinestezi fonksiyonlarını incelemektir.

Yöntemler: Bu çalışmaya çocukluk çağı kanserli 213 (101 kadın, 112 erkek) çocuk katılmıştır. Üst ekstremitelerin propriosepsiyon ve kinestezi duyuları hastane ortamında değerlendirilmiştir. Klinik bir değerlendirme olan pozisyon hissi propriyosepsiyonu değerlendirmek için kullanılmıştır. Kinestezi duyusunu değerlendirmek için Duyu Bütünleme ve Praksis Testlerinin kinestezi alt testi kullanılmıştır. Tanı kriterlerine göre ortalama değerleri karşılaştırmak için Kruskal-Wallis testi kullanıldı. İki değişkenli korelasyonlar için Spearman korelasyon katsayısı kullanıldı ve istatistiksel anlamlılık $p<0,05$ olarak kabul edildi.

Bulgular: Tanı tiplerine göre propriosepsiyon skorları ve kinestezi ortalamaları arasında anlamlı fark yoktu ($p>0,05$). Propriosepsiyon puanlarında tanı türlerine göre en düşük puan karsinoma tanı grubunda iken en yüksek puan lenfoma tanı grubunda görülmüştür. Kinestezi açısından en fazla etkilenen lenfoma tanı grubu iken en az lösemi tanı grubu etkilenmiştir. Ayrıca propriosepsiyon ve kinestezi skorları arasında anlamlı bir ilişki bulunamamıştır ($p>0,05$). Ancak sağ ve sol ekstremite propriosepsiyon skorları arasında anlamlı bir ilişki bulunmuştur ($p<0,01$, $r=0.50$).

Sonuç: Bu çalışma kemoterapi alan çocuklarda propriosepsiyon ve kinestezi sorunlarının varlığını ortaya koymuştur. Bu alanlara yönelik müdahale programlarının planlanması ve duyusal parametrelerin detaylı olarak değerlendirilmesi ileride yapılacak çalışmalar için faydalı olacaktır.

Anahtar Sözcükler: Kanser, çocuk, propriosepsiyon, kinestezi

Address for Correspondence: Zeynep KOLİT, Hacettepe University Faculty of Health Sciences, Department of Occupational Therapy, Ankara, Turkey
E-mail: zeynepkolit_1903@hotmail.com **ORCID ID:** orcid.org/0000-0003-4172-8666

Received: 17.05.2022
Accepted: 28.09.2022

Cite this article as: Kolit Z, Davutoğlu C, Huri M, Şahin S. Investigation of Proprioception and Kinesthesia Sensations in the Upper Extremities of Children with Childhood Cancer. Bezmialem Science 2023;11(1):93-9

Introduction

Childhood cancers are examined under 12 main groups according to the international classification of pediatric cancers. These include leukemia, nervous system tumors, lymphoma, bone tumors, neuroblastoma, Wilms' tumor and soft tissue sarcomas. Leukemia, nervous system tumors and lymphoma are the most common types (1). Detection of cancer and related treatments (eg, chemotherapy) cause undesirable physical (eg, pain, fatigue), and psychological (eg, anxiety, depression, and irritability) complications for children (2). Significant decreases occur in children's functional capacity and physical fitness compared to pre-disease period. Furthermore, multiple and sometimes prolonged hospitalizations lead to limitations and reduced quality of life of children in performing their daily activities (eg, self-care, play, social participation and educational activities) (3,4).

Sensory deficits occur in cancer due to the infestation of the nerve tissue by the tumor or the treatment received. It has been stated that the occurrence of these sensory damages in pediatric cancers may adversely affect somatosensory development (5). Proprioception, which is one of the subsystems in the somatosensory system, is defined as the awareness of the position and movement of the body and its extremities. This feeling also includes the feeling of heaviness. Proprioception allows the person to interact with the environment by regulating muscle tone, revealing voluntary movement and, giving the person the sense of where he/she is in space (6). Proprioception is generally assumed to consist of two modalities: joint position sensation (kinesthesia) and limb movement sensation. The ability to be aware of the position of body parts in space, consciously or unconsciously, defines proprioception, while kinesthesia is defined as the proprioceptive stimulation reaching the central nervous system and resulting in conscious awareness of joint position (7).

It has been shown that proprioceptive awareness is necessary to coordinate multiple joints, maintain muscle contraction, and even perform complex finger movements with vision. Functionally, individuals who have problems with the proprioceptive system have been reported to have difficulty in fine motor skills such as fastening buttons or writing (8). It has been shown that poor proprioception is associated with more activity limitations (9).

Many people diagnosed as having cancer are inevitably treated with chemotherapy despite its neurotoxic side effects (10). Since chemotherapy affects all body systems, carrying on with daily life becomes difficult for individuals. Due to the suppression of the bone marrow in the early period of the chemotherapy treatment, various side effects emerge including but not limited to leukopenia, thrombocytopenia, anemia, infection, fatigue, gastrointestinal complaints, pain, tingling, numbness, etc. (11). Studies have shown that these side effects correspond approximately to the time of the patient receiving the third cure of chemotherapy (12,13). It was observed that as the number of cures increased, the physical symptoms experienced by individuals also increased as well (14).

Correct processing of proximal sensory stimuli such as proprioception, tactile and vestibular stimuli is important in the normal neurodevelopmental period. In particular, disturbances in the somatosensory system signal processing will cause problems in postural control, movement coordination, motor development and adaptive response. These would negatively affect the child's participation in all life activities in the future (15). Assessing how a child reacts to proprioceptive signals for regulation and modulation is substantial for characterizing a child's skill to participate in activities of daily life (8).

Identified somatosensory deficits in proprioception and kinesthesia might provide clinicians for rehabilitation with information about many factors (16). It has been reported that ignoring these parameters means missing critical opportunities for interventions to enhance the children's development. Therefore, it is important to assess the child's ability to process and use proprioceptive and kinesthesia information with a comprehensive assessment (17). In many pediatric populations, such as cerebral palsy, developmental coordination disorder and children with obesity, sensory problems that negatively affect motor behavior and motor development have been reported to be associated with proprioceptive or kinesthesia deficits (18-20).

It has been shown that poor upper limb proprioception is associated with difficulties in handwriting and poor coordination (21). It has been reported that those with proprioceptive and kinesthesia deficits in the upper extremities exhibit spatially inefficient hand movements, poor spatial reference for movements, and difficulty in timing of movements (19). It has been reported in the literature that deficiencies in upper extremity proprioceptive and kinesthesia functions negatively affect quality of life and functional independence (22-24). In the light of this information little data is available on how somatosensory involvement in children with childhood cancer changes. Studies show that clinical sensory and motor changes need to be determined. This study focuses on proprioception and collectively used kinesthesia with it. The aim of the study was to examine proprioception and kinesthesia function of the upper limbs in children who were undergoing chemotherapy treatment and hospitalized with various cancer diagnoses.

Methods

The study was carried out in the inpatient clinic of the University Hospital, Department of Pediatric Oncology. Inclusion criteria for children diagnosed as having childhood cancer were as follows: (a) being between the ages of 6 and 14; (b) receiving at least three curing of chemotherapy (12); (c) not having a central or peripheral nervous system disease or disorder; (d) scoring 1.65-2.83 according to the Semmes-Weinstein Monofilament Test and scoring 7 correct answers in 10 trials for superficial pain assessment; (e) having scores higher than 28, 30 and 35 in the mini-mental state exam devised for children of ages 6-8, 9-11 and 12-14, respectively (25); and (f) not having metastases. The exclusion criteria for children were: (a) having relapsed disease or being in palliative care; (b) not speaking Turkish fluently; (c); being diagnosed as having brain tumor.

Children who received inpatient treatment during the study were included as potential participants. The sample size was calculated as a result of the power analysis performed with 80% power and 5% error rate. According to the inclusion criteria, 244 children were initially eligible. However, 31 of these children later met the exclusion criteria: Not speaking Turkish fluently enough (n=5), having relapsed disease (n=3), being diagnosed as having brain tumor (n=10), having metastases (n=7) and having a peripheral nervous system disease (n=6). Before the study procedure, an informed written consent was taken from each child and legal guardian, which was approved by the University's Ethics Committee (decision number: 677-25, date: 28.02.2017).

Assessments

In order to avoid distraction, each child was evaluated separately in their own room in a quiet environment. Demographic data (i.e. age, gender, number of cures and cancer type) were obtained during the interview. Later, proprioception and kinesthesia assessments were performed in the children. The first author evaluated kinesthesia, and the third author scored. The second author evaluated proprioception, and the last author scored. Tests were administered with dominant and non-dominant hands in an appropriate setting. Total evaluation time was approximately 15 minutes.

Proprioception (Sense of Position)

Common proprioception clinical assessments investigate the determination of the position or direction of motion in which a finger or more proximal joint passively places or moves (8). Proprioception was evaluated by evaluating the sense of motion in the elbow, wrist, thumb and index finger. The therapist moved different joints in small widths in flexion-extension and the child was instructed to say 'yes' when movement was felt. Proprioception was scored as normal (2), impaired (1), or absent (0). (2= Normal: Movement is felt in a small width with all three attempts. 1= Impaired: Movement is only felt over a greater breadth. 0= Absent: The movement is not felt in great breadth with any attempt). The test took about 5-10 minutes. The child was asked to close his/her eyes with this assessment and the therapist did not give any feedback on the accuracy of their estimates to eliminate a learning effect (17).

Kinesthesia

The kinesthesia subtest of Sensory Integration and Praxis Tests (SIPT) was used to evaluate the kinesthesia discrimination of the children under consideration. The kinesthesia test is one of 17 subtests included as part of the SIPT, developed by Ayres (26) as a standard measure of sensory integration and praxis functions in children aged 4-8 years and 11 months. The test most directly measures proprioceptive function, namely sense of movement. Therapists who have a practitioner certificate can apply this test. The child with closed eyes was asked to hold her/his fingers and move from one predetermined point to the other on the paper, and then the child was asked to repeat this movement according to her/his own sense of movement. The test took about 5 minutes. The distance to the correct point was recorded in centimeters. The mean distances of both upper limbs to the correct point were calculated. Low mean score was interpreted as good kinesthetic perception (27).

Statistical Analysis

Statistical analysis was executed by SPSS (Statistical Package for Social Sciences version 22). Data distribution normality was examined using visual and analytical methods. Outcome measurements were defined using mean and standard deviations for continuous variables and frequencies and ratios for categorical variables. Descriptive statistics were reported using medians and interquartile range for the non-normally distributed and ordinal variables. Proprioception and kinesthesia values were not normally distributed and the Kruskal-Wallis tests were conducted to compare them based on diagnosis criteria. Spearman's coefficient of correlation was used for bivariate correlations between proprioception scores and kinesthesia averages. An overall 5% type-I error level was used to infer statistical significance.

Results

Two hundred thirteen children with childhood cancer participated in this study. The demographic characteristics of the participants are shown in Table 1.

The proprioception scores of the right and left upper extremities of the participants according to the types of cancer shown in Figure 1. Proprioception scores reveal that that the carcinoma group is the most affected cancer type in the sense of proprioception.

The average of kinesthesia scores with respect to cancer types are shown in Figure 2. The lowest averages of the kinesthesia are in the leukemia group and the highest averages are in the lymphoma group. According to these results, the most affected cancer type in terms of kinesthesia sensation is lymphoma group.

The mean proprioception scores according to their cancer types is shown in Figure 3. The childhood cancers when sorted from the least affected group to the most affected group according to mean proprioception scores were lymphoma, leukemia, ewing sarcoma, osteosarcom and carcinoma.

The differences between the means of proprioception and kinesthesia according to cancer types are shown in Table 2. There were no statistically significant differences between the proprioception scores and kinesthesia averages of children with childhood cancer according to the diagnosis groups ($p>0.05$). Considering that the maximum possible proprioception score was 8, both right and left extremities average scores were low.

While standard deviations (SD) between +1 and -1 in kinesthesia scores were accepted as normal perception (27). The calculated standard deviations of kinesthesia scores were more than +1 SD among children with childhood cancer. Therefore, it was observed that the kinesthetic perceptions of children were negatively affected with cancer.

The relationship between right and left extremity proprioception scores and means of kinesthesia values are shown in Table 3. A

significant moderate positive correlation was found between right and left extremity proprioception scores (RSpearman=0.50, p<0.01). No correlations were detected proprioception scores between with mean of kinesthesia scores (p>0.05).

Discussion

The aim of this study was to examine proprioception and kinesthesia functions of the upper limbs in children with childhood cancer undergoing chemotherapy treatment who were hospitalized according to different diagnosis groups. It was observed that the average proprioception levels of children with childhood cancer were low. The carcinoma group showed the lowest, while the lymphoma group showed the highest proprioception scores among various types of cancer. In terms of kinesthesia scores, the lymphoma group was the most affected types of cancer. Also, no difference was detected in proprioception (both right and left limb) and kinesthesia values according to cancer types. In addition to these, a significant relationship between right and left proprioception values was found. However, there was no relationship between kinesthesia and proprioception values.

Table 1. The demographic characteristics of childhood cancer with children

Mean ± SD n=213	
Age (year)	11.16±3.03
Number of cures	3.73±0.73
Type of cancer	n (%)
Osteosarcoma	46 (21.6)
Ewing sarcoma	54 (25.4)
Lymphoma	37 (17.4)
Leukemia	37 (17.4)
Carcinoma	39 (18.3)
Gender	
Female	101 (47.4)
Male	112 (52.6)
Dominant hand	
Right	137 (64.3)
Left	76 (35.7)
SD: Standard deviation	

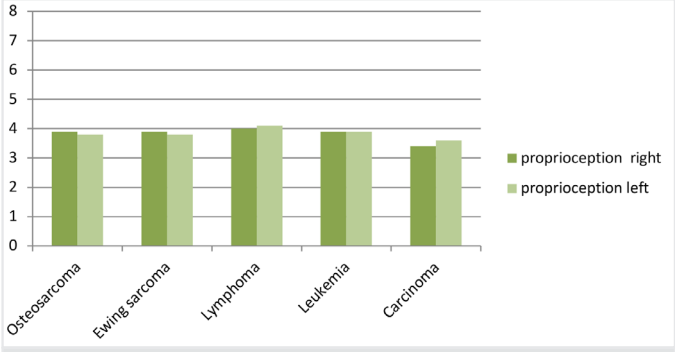

Figure 1. Proprioception scores according to types of childhood cancer

It is emphasized that a sedentary lifestyle accelerates the loss of proprioceptive acuity (6). Wang et al. (20) examined the proprioception of knee and ankle joints in pre-pubertal obese and non-obese boys. The study concluded that obese boys showed deficit proprioception in knee flexion (20). In another study evaluating the proprioception of children with cerebral palsy, proprioceptive deficit was found in all limbs of children (16). Most childhood cancers are more common in boys, and this is even more evident in developing countries (28). In the light of this information, the high number of boys in our study is similar to the literature. Considering that we had a higher number of boys in our study, it was not surprising that their proprioception levels were low. Cancer treatment usually requires repeated and/or prolonged hospitalization (29). It has been stated that in children with cancer who are hospitalized for a long time, the opportunity to establish an active relationship with environment decreases and the ability to process and use sensory information to organize, direct and regulate behavior in the future is negatively affected (30). The results of our study showed that considering the maximum possible score in proprioception was 8, the scores of children with childhood cancer were quite low. We claim that this is because the treatment of cancer in childhood takes months and children often stay in hospitals for a long time. According to the results in our study, the lowest proprioception scores belong to the carcinoma group. Our study demonstrated that although the evaluation of the sense of proprioception was very important in all cancer types, children with carcinoma who had the lowest proprioception scores should especially be focused on during related evaluations and interventions.

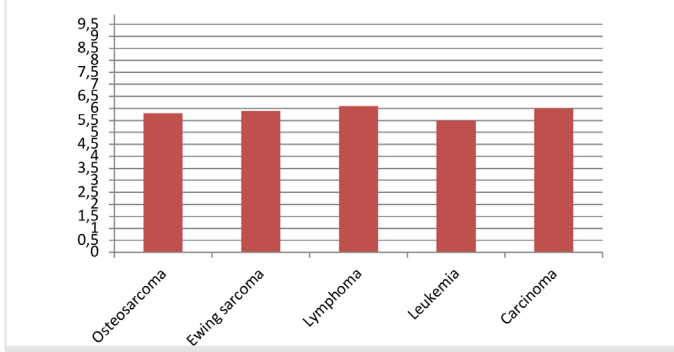

Figure 2. Averages of kinesthesia considering types of childhood cancer

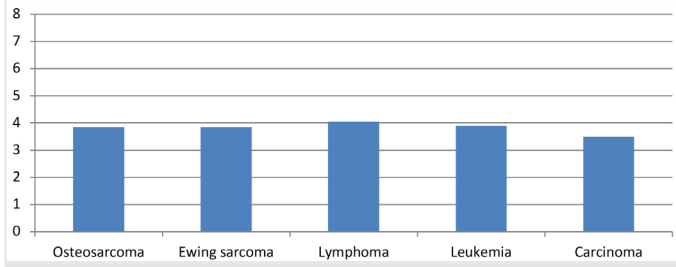

Figure 3. The mean of proprioception scores considering types of childhood cancer

A study conducted to measure and compare kinesthetic sensitivity in children who were typically developing and in children with Developmental Coordination Disorders (DCD) showed that children with DCD were significantly less sensitive to the sense of kinesthesia (18). In another study examining the kinesthesia sense of children with specific language disorders, it was reported that these children performed poorly in kinesthesia tasks (31). In our study, it was found that the distance of the average of the kinesthesia scores to the target point was quite high. Hence, we can state that the kinesthesia senses are also affected in children with cancer. In a study conducted on the writing analysis of children receiving leukemia treatment, it was stated that children could overcome problems other than the constantly increasing drawing pressure and this increased drawing pressure might be related to the children's attempt to obtain sufficient kinesthetic information (32). In a study of fine motor and tactile-perceptual functions in children with cancer, they found transient problems in children treated for leukemia and more persistent problems in children treated for solid tumors (33). It was stated that children who experienced the side effects of cancer treatment or who were hospitalized for a long time due to illness had difficulty in learning and participating in play activities and therefore lost opportunities to improve in their physical, problem-solving and social-interactive skills (34). Based on the findings in the literature, we think that children with cancer will experience more problems in their playing, fine motor skills, academic performance and social relationship skills if their sensory deficiencies are left unidentified and untreated. According to our study, it was shown that the leukemia group was better than other diagnostic groups in terms of kinesthesia, and the lymphoma group was the most affected of childhood cancer types. For this reason, it would especially be useful to evaluate children with lymphoma in the early period and to plan interventions in this area.

Table 2. The differences between the means of proprioception and kinesthesia according to cancer types

Variable	Cancer types	Mean ± SD	p
Proprioception right (0-8)	Osteosarcoma	3.97±1.08	0.10
	Ewing sarcoma	3.98±0.99	
	Lymphoma	4.05±1.02	
	Leukemia	3.94±1.02	
	Carcinoma	3.48±0.75	
Proprioception left (0-8)	Osteosarcoma	3.86±0.95	0.44
	Ewing sarcoma	3.81±0.93	
	Lymphoma	4.10±0.87	
	Leukemia	3.94±0.88	
	Carcinoma	3.74±0.78	
Kinesthesia (cm)	Osteosarcoma	5.89±1.39	0.79
	Ewing sarcoma	5.94±1.20	
	Lymphoma	6.19±1.06	
	Leukemia	5.51±0.90	
	Carcinoma	6.06±0.98	

SD: Standard deviation, min: Minimum; max: Maximum. The significance of differences for means of the proprioception and kinesthesia was compared using the Kruskal-Wallis test.
P-values of <0.05 were considered significant

Table 3. Correlation between the proprioception scores and kinesthesia

Variable	n	Mean ± SD	1.	2.	3.
1. Proprioception right	213	3.90±1.08	-	0.001*	0.28
2. Proprioception left	213	3.69±0.92		-	0.15
3. Kinesthesia	213	5.92±1.15			-

SD: Standard deviation; min: Minimum; max: Maximum. P-values of <0.05 were considered significant *p<0.001

Childhood cancers vary according to the type of the disease, the organ in which it is located, and the individual characteristics of the patient (35). Carcinoma is the name given to the tumoral mass that occurs in the skin or in the epithelial cells surrounding the internal organs (36). The skin, muscles, and joints of limbs are richly innervated by a variety of sensory receptors that convey proprioceptive information to all levels of the nervous system. It is known that loss or impairment of sensation in the limbs can lead to serious movement disorders and sensory input plays a critical role in controlling movement (37). Carcinoma tumors can also arise in cutaneous cells that are associated with proprioception (38). In the results of our study, it was revealed that the carcinoma group was more affected in the proprioceptive area, which was in line with this information in the literature. Lymphomas are malignant diseases originating from lymphoreticular cells. These types of cells are found mainly in the lymph nodes, and the leading clinical symptom is tumoral enlargement of the lymph nodes (39). Lymphedema can be seen as a secondary symptom in lymphoma (40). It has been reported in the literature that loss of kinesthetic sensation is associated with upper extremity lymphedema (41,42). In the results of our study, it was seen that the lymphoma group was most affected in the sense of kinesthesia. However, we think that it will be valuable to reveal whether this condition is associated with lymphedema in future studies.

Proprioception contributes to body image, and the development of motor control when learning new skills (43). Chancel et al. (44), emphasized that proprioceptive afferents were bilaterally integrated during bimanual tasks. Several studies have highlighted strong interactions between the muscle proprioceptive afferents for the two arms (45,46). In our study, a moderately significant correlation was found between right and left proprioception scores. Our finding is in line with the results in the literature. According to our results, we can state that approaches involving the coordination of extremities and bilateral activities are needed in children with childhood cancer due to low proprioception mean scores and a significant relationship between the two extremities.

Study Limitations

There were some limitations to this study. Primarily, these findings could not be generalized for age and childhood cancer types not included in our study, depending on the heterogeneous population. Secondly, there was no control group of same aged

healthy children. Another limitation of our study was that we only evaluated the upper extremity and not the lower extremity in our study.

Conclusion

This study provides valuable information on the proprioception and kinesthesia senses of children with childhood cancer, an area which has not yet been explored adequately in an early phase of pediatric oncological aftercare. Early identification of sensory impairment is especially relevant in pediatric populations as sensory dysfunction is occurring during somatosensory development (47). The studies in the literature conducted in children with similar chronic or neurological diseases show that sensory impairments closely affect the development of motor skills. Thus, considering our study results, we think that sensory deficits may also affect motor skills in children with cancer. Sensory problems can potentially be critical, as proprioceptive transmitters are required for strong motor behaviors such as fine motor skills and balance. In this respect, it will be important to include sensorimotor interventions, which are an important component of long-term care, in the treatment protocol, together with early detection of proprioception and kinesthesia deficits in children with childhood cancer. Sensory assessments may also be useful for identifying and monitoring other patient populations with known or potential sensory dysfunction, such as other pediatric cancers and individuals with adult cancers. Further investigation and analysis of sensory skills of children with cancer are recommended.

Acknowledgments: We would thank to all participants.

Ethics

Ethics Committee Approval: Before the study procedure, an informed written consent was taken from each child and legal guardian, which was approved by the University's Ethics Committee (decision number: 677-25, date: 28.02.2017).

Informed Consent: Before the study procedure, an informed written consent was taken from each child and legal guardian.

Peer-review: Externally peer reviewed.

Authorship Contributions

Concept: M.H., Design: S.Ş., Data Collection or Processing: Z.K., C.D., Analysis or Interpretation: M.H., S.Ş., Literature Search: Z.K., C.D., writing: Z.K., C.D.

Conflict of Interest: No conflict of interest was declared by the authors.

Financial Disclosure: The authors declared that this study received no financial support.

References

1. American Academy of Pediatrics Section on Hematology/Oncology Children's Oncology Group. Long-term follow-up care for pediatric cancer survivors. Pediatrics 2009;123:906-15.
2. Stubblefield MD. Cancer rehabilitation: principles and practice: Springer Publishing Company; 2018.
3. Mohammadi A, Mehraban A. Play-based occupational therapy for hospitalized children with cancer: A short communication. Iran Rehabil J 2020;18:17-22.
4. Rankin J, Murtagh N, Robb K, Cooper J, Lewis S. Rehabilitation in cancer care: John Wiley & Sons; 2009.
5. Moore RJ, Groninger H. Chemotherapy-induced peripheral neuropathy in pediatric cancer patients. Cureus 2013;5:e124.
6. Suetterlin KJ, Sayer AA. Proprioception: where are we now? A commentary on clinical assessment, changes across the life course, functional implications and future interventions. Age Ageing 2014;43:313-8.
7. Mourcou Q, Fleury A, Diot B, Franco C, Vuillerme N. Mobile phone-based joint angle measurement for functional assessment and rehabilitation of proprioception. Biomed Res Int 2015;2015:328142.
8. Findlater SE, Dukelow SP. Upper extremity proprioception after stroke: bridging the gap between neuroscience and rehabilitation. J Mot Behav 2017;49:27-34.
9. Scheper M, Rombaut L, de Vries J, De Wandele I, van der Esch M, Visser B, et al. The association between muscle strength and activity limitations in patients with the hypermobility type of Ehlers–Danlos syndrome: the impact of proprioception. Disabil Rehabil 2017;39:1391-7.
10. Neil EC, Hanmantgad S, Khakoo Y. Neurological complications of pediatric cancer. J Child Neurol 2016;31:1412-20.
11. Monfort SM, Pan X, Loprinzi CL, Lustberg MB, Chaudhari AM. Impaired postural control and altered sensory organization during quiet stance following neurotoxic chemotherapy: a preliminary study. Integr Cancer Ther 2019;18:1534735419828823.
12. Beser N. Öz F. Kemoterapi alan lenfomalı hastaların anksiyete-depresyon düzeyleri ve yaşam kalitesi, CÜ Hemşirelik Yüksekokulu Dergisi. 2003;7:47-58.
13. Norum J, Wist EA. Quality of Life in Survivors of Hogkins' Disease. Qual Life Res 1996;5:257-67.
14. Yeşilbalkan ÖU, Akyol AD, Çetinkaya Y, Altın T, Deniz Ü. Studying the Symptoms that are Being Experienced due to Treatment by the Patients who Receive Chemotheraphy and Their Effects on the Quality of Life. Ege Üniversitesi Hemşirelik Yüksek Okulu Dergisi. 2005;21:13-31.
15. Gardner E, Johnson K. The somatosensory system: receptors and central pathways. Principles of neural science. 2013;5:475-95.
16. Wingert JR, Burton H, Sinclair RJ, Brunstrom JE, Damiano DL. Joint-position sense and kinesthesia in cerebral palsy. Arch Phys Med Rehabil 2009;90:447-53.
17. Chu VWT. Assessing proprioception in children: A review. J Mot Behav 2017;49:458-66.
18. Li KY, Su WJ, Fu HW, Pickett KA. Kinesthetic deficit in children with developmental coordination disorder. Res Dev Disabil. 2015 Mar;38:125-33.
19. Goble DJ, Lewis CA, Hurvitz EA, Brown SH. Development of upper limb proprioceptive accuracy in children and adolescents. Hum Mov Sci 2005;24:155-70.
20. Wang L, Li JX, Xu DQ, Hong YL. Proprioception of ankle and knee joints in obese boys and nonobese boys. Med Sci Monit 2008;14:CR129-CR35.

21. Falk TH, Tam C, Schwellnus H, Chau T. Grip force variability and its effects on children's handwriting legibility, form, and strokes. J Biomech Eng 2010;132:114504.
22. Ribeiro F, Oliveira J. Aging effects on joint proprioception: the role of physical activity in proprioception preservation. Eur Rev Aging Phys Act 2007;4:71-6.
23. Hughes CML, Tommasino P, Budhota A, Campolo D. Upper extremity proprioception in healthy aging and stroke populations, and the effects of therapist-and robot-based rehabilitation therapies on proprioceptive function. Front Hum Neurosci 2015;9:120.
24. Adamo DE, Martin BJ, Brown SH. Age-related differences in upper limb proprioceptive acuity. Percept Mot Skills 2007;104:1297-309.
25. Jain M, Passi G. Assessment of a modified Mini-Mental Scale for cognitive functions in children. Indian Pediatr 2005;42:907-12.
26. Ayres AJ. Sensory integration and praxis tests (SIPT): Western Psychological Services (WPS) Los Angeles, CA; 1996.
27. Van Jaarsveld A, Mailloux Z, Herzberg DS. The use of the Sensory Integration and Praxis tests with South African children. S Afr J Occup Ther. 2012;42(3):12-8.
28. Parkin D, Kramarova E, Draper G, Masuyer E, Michaelis J, Neglia J, et al. International incidence of childhood cancer(Volume II). IARC scientific publications. 1998.
29. Speyer E, Herbinet A, Vuillemin A, Briançon S, Chastagner P. Effect of adapted physical activity sessions in the hospital on health-related quality of life for children with cancer: A cross-over randomized trial. Pediatr Blood Cancer 2010;55:1160-6.
30. Lin SH, Cermak S, Coster WJ, Miller L. The relation between length of institutionalization and sensory integration in children adopted from Eastern Europe. Am J Occup Ther 2005;59:139-47.
31. Marton K. Imitation of body postures and hand movements in children with specific language impairment. J Exp Child Psychol 2009;102:1-13
32. Reinders-Messelink H, Schoemaker M, Snijders T, Göeken L, Bökkerink J, Kamps W. Analysis of handwriting of children during treatment for acute lymphoblastic leukemia. Med Pediatr Oncol: The Official Journal of SIOP—International Society of Pediatric Oncology (Societé Internationale d'Oncologie Pédiatrique. 2001;37(4):393-9. https://doi.org/10.1002/mpo.1216
33. Dodzik PA, Fulton R. Neuropsychological outcomes in children with acute lymphoblastic leukemia. In: Mucci GA, Torno LR, editors. Handbook of Long Term Care of The Childhood Cancer Survivor Specialty Topics in Pediatric Neuropsychology. Boston, MA: Springer; 2015. p. 223-47.
34. Keene N. Childhood leukemia: A guide for families, friends & caregivers: Childhood Cancer Guides. United States of America, O'Reilly Media, 2010.
35. Bowen JM, Wardill HR. Advances in the understanding and management of mucositis during stem cell transplantation. Curr Opin Support Palliat Care 2017;11:341-6.
36. Bruix J, Sherman M; American Association for the Study of Liver Diseases. Management of hepatocellular carcinoma: an update. Hepatology 2011;53:1020-2.
37. van der Wal J. The architecture of the connective tissue in the musculoskeletal system—an often overlooked functional parameter as to proprioception in the locomotor apparatus. Int J Ther Massage Bodyw 2009;2:9-23.
38. Gleason JM, Köhler TS, Monga M. Merkel cell carcinoma metastatic to testis. Urology. 2006;67:423-e13- 14.
39. Du J, Zhang Y. Sequential anti-CD19, 22, and 20 autologous chimeric antigen receptor T-cell (CAR-T) treatments of a child with relapsed refractory Burkitt lymphoma: a case report and literature review. J Cancer Res Clin Oncol 2020;146:1575-82.
40. Rymal C. Lymphedema management in patients with lymphoma. Nurs Clin North Am 2001;36:709-34.
41. Hwang R, Kentish M, Burns Y. Hand positioning sense in children with spina bifida myelomeningocele. Aust J Physiother 2002;48:17-22.
42. Karadibak D, Yavuzsen T. Evaluation of kinesthetic sense and hand function in women with breast cancer-related lymphedema. J Phys Ther Sci 2015;27:1671-5.
43. Stillman BC. Making sense of proprioception: the meaning of proprioception, kinaesthesia and related terms. Physiotherapy 2002;88:667-76.
44. Chancel M, Kavounoudias A, Guerraz M. What's left of the mirror illusion when the mirror can no longer be seen? Bilateral integration of proprioceptive afferents! Neuroscience 2017;362:118-26.
45. Brun C, Guerraz M. Anchoring the "floating arm": use of proprioceptive and mirror visual feedback from one arm to control involuntary displacement of the other arm. J Neurosci 2015;310:268-78.
46. Kuehn E, De Havas J, Silkoset E, Gomi H, Haggard P. On the bimanual integration of proprioceptive information. Exp Brain Res 2015;233:1273-88.
47. Holst-Wolf JM, Yeh I, Konczak J. Development of proprioceptive acuity in typically developing children: normative data on forearm position sense. Front Hum Neurosci 2016;10:436.