

Mutual correlations between regulation disorders of sensory processing (RDSP) in school-age children

Wzajemne współwystępowanie poszczególnych zaburzeń regulacji procesów sensorycznych (RDSP) u dzieci w wieku szkolnym

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Medical Studies/Studia Medyczne 2022; 38 (2): 89–94

DOI: <https://doi.org/10.5114/ms.2022.117710>

Key words: cognitive attention, nervous system, neurodevelopment, sensorimotor, sensory integration.

Słowa kluczowe: uwaga poznawcza, układ nerwowy, neurorozwoj, sensomotoryka, integracja sensoryczna.

Abstract

Introduction: A very important element in the development of the nervous system is sensory integration, i.e. organizing and interpreting sensory stimuli and using processed information in a deliberate action. Disruption of the processes of sensory integration at any stage of its formation may result in dysfunctions in the development of complex motor functions as well as self-regulation of behaviour and concentration of cognitive attention.

Aim of the research: To investigate the coexistence and correlation between regulation disorders of sensory processes (RDSP) in school-age children.

Material and methods: The study was conducted on a group of 104 children aged 6–15 years using a standardized sensorimotor questionnaire completed by their parents or legal guardians in compliance with all the principles consistent with Good Clinical Practice. Then, the correlation between the occurrence of individual RDSPs was analysed.

Results: Correlation analysis showed that many RDSPs are statistically significantly correlated with each other, which is also confirmed in other publications. A special relationship has been demonstrated between individual RDSPs and disturbances in motor coordination and disturbances in cognitive attention and behaviour (self-control).

Conclusions: The study, by showing significant correlations between individual RDSPs, may contribute to better control over the neurodevelopment of children and adolescents, as well as helping to support their psychomotor development through psychologists, physiotherapists, or educators, as well as by parents/guardians. Correlations between RDSP and impaired coordination skills and cognitive functions indicate the integrity of the nervous system and the links between the motor and mental spheres that are important for a child's development.

Streszczenie

Wprowadzenie: Bardzo ważnym elementem rozwoju układu nerwowego jest integracja sensoryczna, czyli organizowanie i interpretowanie bodźców sensorycznych oraz wykorzystywanie przetworzonych informacji w celowym działaniu. Zaburzenie procesów integracji sensorycznej na którymkolwiek etapie jej kształtowania może skutkować dysfunkcjami w zakresie kształtowania złożonych funkcji motorycznych oraz autoregulacji zachowania i koncentracji uwagi poznawczej.

Cel pracy: Zbadanie współwystępowania lub współzależności pomiędzy poszczególnymi zaburzeniami regulacji procesów sensorycznych (RDSP) u dzieci w wieku szkolnym.

Materiał i metody: Badanie przeprowadzono w grupie 104 dzieci w wieku 6–15 lat za pomocą standaryzowanego kwestionariusza sensomotorycznego wypełnianego przez ich rodziców lub opiekunów prawnych z zachowaniem wszelkich zasad zgodnych z *good clinical practice*. Następnie dokonano analizy korelacji pomiędzy występowaniem poszczególnych RDSP.

Wyniki: Analiza korelacji wykazała, że wiele RDSP jest ze sobą skorelowanych istotnie statystycznie, co znajduje potwierdzenie również w innych publikacjach. Stwierdzono związek pomiędzy poszczególnymi RDSP a zaburzeniami koordynacji ruchowej oraz zaburzeniami uwagi poznawczej i zachowania (autokontroli).

Wnioski: Przeprowadzone badanie, poprzez wskazanie na istotne korelacje pomiędzy poszczególnymi RDSP, może się przyczynić do lepszej kontroli nad neurorozwojem dzieci i młodzieży, a także do wspomagania ich rozwoju psychomotorycznego przez psychologów, fizjoterapeutów czy pedagogów, a także przez rodziców lub opiekunów. Korelacje pomiędzy RDSP a zaburzeniami zdolności koordynacyjnych oraz funkcji poznawczych wskazują na integralność układu nerwowego oraz istotne dla rozwoju dziecka powiązania pomiędzy sferą motoryczną a psychiczną.

Introduction

Sensory integration is the processing of sensory stimuli, in which the nervous system receives information from the receptors of all senses and then organizes and interprets them. It enables them to be used at a higher level of the central nervous system in a targeted and effective action. Sensory integration is based on assumptions about neurology and the theory of behaviour: neural plasticity (the brain's ability to modify), sequential development of sensory integration processes (complex behaviours are built on basic behaviours), integrity of the nervous system (brain development occurs gradually), adaptive reactions (the organism reacts optimally to the requirements of the environment), as well as the child's internal drive for development [1, 2].

Sensory systems develop at individual stages, from those responsible for somatognosia, through those related to praxia, targeted activity, and concentration, to the cooperation of individual senses, manifested, among others, in the form of coordination skills or executive functions. In sensory integration, special attention is paid to the cooperation and interdependence of sensorimotor development with emotional-cognitive development. If, at a certain stage, a child does not achieve the skill set for that period, the basis for their development in the next levels may not be appropriate. In such a situation, the child may show disturbances in certain skills or behaviour [2, 3].

Aim of the research

Responsible for the proper functioning of the nervous system, among others sensory integration, i.e. organizing the stimuli and sensory impressions delivered to the body, and then processing them for use in the executive control of purposeful action. Sensory integration is treated as the basis for proper functioning in terms of movement, posture, coordination, perception, and even emotions and cognitive attention. In this study, however, it is predicted that individual sensorimotor disorders or the resulting dysfunctions will be correlated with each other.

The research topic was undertaken because the research conducted in the group of children with cerebral palsy showed a significant relationship between regulation disorders of sensory processing (RDSP) and gait parameters, motor coordination, and the process of motor learning [4]. It was found that the selection of a research group without identified neurological diseases and neurodevelopmental disorders

allows for a closer look at the coexistence of individual RDSP and related disorders. The study was also extended to examine disorders related to cognitive attention and self-control, to take into account the complexity of the psychomotor development of the child [5]. It was found that the multifaceted examination of the interdependencies between the sensorimotor and psychomotor systems may allow for more effective programming of rehabilitation as well as physioprophylactic and psychoprophylactic programs to support the proper development of the child.

The aim of the study was to assess the mutual correlations between particular RDSPs in school-age children, including answering the following research questions:

1. Will there be cross-correlations between different RDSPs?
2. Will RDSPs most associated with motor coordination dysfunctions be identified?
3. Will RDSPs most associated with cognitive attention dysfunctions be identified?
4. Is there a mutual correlation between movement coordination disorders and disorders of cognitive attention?

Material and methods

The study concerned school-age children and adolescents and was conducted in the form of a questionnaire filled in by parents or legal guardians. The approval of the Bioethics Committee was not necessary because the study did not bear the hallmarks of an experiment. Participation in the study was voluntary. In accordance with the principles of Good Clinical Practice and the Helsinki Declaration, each of the study participants gave informed and voluntary consent to participate in the study.

The study group consisted of 104 children ($F = 56$; $M = 48$) aged 6 to 15 years ($M = 10.08$; $Me = 10$; $SD = 2.39$; $V = 23.7\%$). The only inclusion criteria were being of school age and obtaining the voluntary consent of the parents/guardians. School age was considered to be the age of late childhood (6–12 years old) and the sub-period of early adolescence (13–15 years old); hence, the age range was 6–15 years old. Among the exclusion criteria were diagnosed severe neurological diseases, because they may be characterized by coupled sensorimotor disorders. Study participants attended standard educational establishments on a daily basis.

Parents/guardians completed a questionnaire assessing the presence of sensorimotor disorders. For

Table 1. Questionnaire results – descriptive statistics

| Variable | Max. possible | Max. achieved | Me | V |
|----------------|---------------|---------------|----|--------|
| Tactile | 9 | 6 | 2 | 72.1% |
| Balance | 9 | 8 | 4 | 51.4% |
| Proprioception | 6 | 5 | 2 | 63.8% |
| Auditory | 9 | 7 | 1 | 102.5% |
| Sight | 11 | 8 | 1 | 129.7% |
| Olfactory | 3 | 2 | 1 | 107.13 |
| Coordination | 6 | 5 | 3 | 70.4% |
| Attention | 5 | 4 | 1 | 95.5% |
| Total | 58 | 39 | 13 | 59.4% |

this purpose, a standardized Sensorimotor Questionnaire by Balzer-Martin was used, containing questions about the child's sensory profile in terms of the standardized test scale of sensorimotor disorders. The questionnaire was divided into domains that corresponded to individual RDSPs (touch, balance, muscle tone, hearing, vision, and smell) and dysfunctions related to sensorimotor disorders (motor coordination and attention and behaviour). Based on the results, it was possible to assess the level of RDSPs in terms of individual sensory systems – the higher the score on the scale (more “YES” answers), the more advanced the sensorimotor dysfunction.

Due to the multifaceted nature of the Sensorimotor Questionnaire by Balzer-Martin, no other tools were used in the study, because the above-mentioned questionnaire examines not only the risk of RDSP, but also other disorders resulting from it (in terms of motor coordination, attention, and behaviour). The results of the questionnaire for the individual domains were combined to investigate the interrelationships between the various RDSPs and the coordination disorders and attention and behaviour dysfunctions.

Statistical analysis

To perform the statistical analysis, the Statistica software package (version 13.3) was used. Spearman's rank correlation coefficient was used to investigate the correlation between the results of the questionnaire domains, and they were statistically assessed using correlation tests when determining the significance based on the verified value p of 0.05. Due to the lack of normality of the distribution, a non-parametric test was used.

Results

The results of the questionnaire on sensorimotor disorders showed that the most common problem of the respondents are imbalances ($N = 60$), and to a lesser extent, impaired proprioception ($N = 48$), touch ($N = 44$), hearing ($N = 32$), smell ($N = 24$), and eyesight ($N = 22$). There was also a high frequency of disorders

resulting from RDSPs, i.e. coordination ($N = 48$) as well as attention and self-regulation of behaviour ($N = 44$). The highest score achieved was 39 and the lowest 3 points. No domain was observed where at least one child would not score 0 (no abnormality). No children scored the maximum in any of the domains. The basic statistical descriptive parameters of the results for individual domains are presented in Table 1.

The W-Shapiro-Wilk test was performed for all results; however, for each domain of the questionnaire, the result was $p < 0.05$, which indicates that non-parametric tests should be used for further analysis. In order to investigate the correlation between particular variables, the analysis of Spearman's rho correlation was used. The results of the compilation are presented in Table 2.

All the presented correlation values have a positive value and turned out to be statistically significant ($p < 0.001$); therefore, it is worth taking a closer look at each of them. The lowest value of the correlation occurred between the disturbances of smell and coordination disorders ($r_s = 0.42$ – average correlation according to Guilford), and the highest correlation was between visual disturbances and coordination disorders ($r_s = 0.80$ – high correlation according to Guilford). Particularly high results of the correlation analysis were recorded for the domain of motor coordination and the domain of attention and behaviour.

Positive correlation values indicate that the sensorimotor disorders are positively related to each other, suggesting that certain RDSPs increase, rather than decrease, the likelihood of identifying other RDSPs or related disorders.

Discussion

The highest correlations of specific RDSPs were identified between touch and balance ($r_s = 0.62$), hearing and sight ($r_s = 0.62$), and between touch and smell ($r_s = 0.60$). It turns out that these relationships are supported in the literature, because exteroceptive tactile stimuli are important for maintaining static balance

Table 2. Analysis of Spearman's rho correlation between individual sensorimotor domains

| | Tactile | Balance | Proprio. | Auditory | Sight | Olfactory | Coord. | Attention |
|----------------|---------|---------|----------|----------|-------|-----------|--------|-----------|
| Tactile | | 0.62 | 0.53 | 0.45 | 0.50 | 0.60 | 0.48 | 0.60 |
| Balance | 0.62 | | 0.43 | 0.47 | 0.43 | 0.51 | 0.61 | 0.57 |
| Proprioception | 0.53 | 0.43 | | 0.47 | 0.49 | 0.43 | 0.76 | 0.53 |
| Auditory | 0.45 | 0.47 | 0.47 | | 0.62 | 0.54 | 0.63 | 0.70 |
| Sight | 0.50 | 0.43 | 0.49 | 0.62 | | 0.45 | 0.80 | 0.63 |
| Olfactory | 0.60 | 0.51 | 0.43 | 0.54 | 0.45 | | 0.42 | 0.60 |
| Coordination | 0.48 | 0.61 | 0.76 | 0.63 | 0.80 | 0.42 | | 0.61 |
| Attention | 0.60 | 0.57 | 0.53 | 0.70 | 0.63 | 0.60 | 0.61 | |

[6], and telereceptor auditory stimuli are almost automatically and naturally integrated with telereceptor visual stimuli in order to build an image of the world, and this integration is highlighted, among others, in the context of shaping consciousness [7]. On the other hand, the analysis of psychophysiological interactions in functional magnetic resonance showed a significant cross-modal interaction between tactile centres and centres of olfactory sensations [8].

The correlations of individual RDSPs with dysfunctions of motor coordination (actually: coordination abilities) and attention and behaviour (more precisely: self-regulation and concentration of attention) seem to be of particular interest. RDSPs of vision ($r_s = 0.80$), proprioception ($r_s = 0.76$), hearing ($r_s = 0.63$), and balance ($r_s = 0.61$) most strongly correlate with motor coordination disorders. Most likely, this is due to the important role of vision, proper muscle tone, and cortico-cerebellar cooperation in building hand-eye coordination [9]. According to other studies, the balance resulting from the proper functioning of the vestibular system is also important for the formation of coordination abilities [10] and rhythmization resulting from the correct processing of auditory stimuli [11, 12].

As shown in Table 2, the autoregulation and attention focus disorders are highly correlated with all sensorimotor disorders on a scale from $r_s = 0.53$ to $r_s = 0.70$. The correlation between auditory disorders and attention disorders is explained by the fact that auditory integration minimizes the risk of distractions and disorders of other cognitive functions [13]. Other authors pay attention to significant links between sensory processing disorders and disorders of cognitive attention [14, 15], also in the case of disturbances related to movement – proprioception or balance [16, 17]. The presented study indicates a relationship between the occurrence of RDSP and attention disorders, as well as an indirect relationship between movement and cognitive functions, which is mentioned many times in the literature [18–20]. The limitation of the study, however, is that only questionnaire tools were used. Psychological tests would allow for a more adequate measurement of attention and other cognitive func-

tions, and a more detailed clinical examination would allow for an objective examination of the actual disturbances in the regulation of sensory processes in school children and adolescents. Another limitation of the study may be the significant age discrepancy of the respondents (6–15 years); however, we had hoped to include participants representing the entire school age spectrum. The presented study may not be sufficient to draw clinical conclusions for particular age subgroups (e.g. early school age).

It should also be noted that the level of individual disorders in the questionnaire results is relatively high. However, this may be due to the fact that the study was performed during the SARS-CoV-2 coronavirus pandemic, when most children and adolescents had significantly reduced physical activity [21, 22]. Many hours of using cell phones and computers related to among others distance learning, combined with limitation of motor activity, is a significant factor in the increased level of sensorimotor disintegration [23–25] and could have been a cause of the high levels of individual RDSPs, but verification of this would require an extended study, including, inter alia, characteristics of the use of electronic devices by the child.

Despite the presented limitations of the study, the presented work points to an important problem, which is the coexistence of various disturbances in the regulation of sensory processes and disorders of motor coordination, as well as concentration of attention and self-regulation of behaviour. This work may contribute to a more effective control of the child's neurodevelopment and may sensitize parents and guardians of school children and adolescents to support their sensorimotor and cognitive-emotional development through physical activity and reduction of excessive sensory stimulation (e.g. distracting effects of smartphones). Above all, however, the work pays special attention to the significant relationship between inappropriate sensory processing and dysfunctions in complex motor skills and cognitive functions, which is important for the development of rehabilitation, education, and development programs for children and adolescents with RDSP. It is possible that in the long run, determining

the child's sensory profile will allow for the prediction of their progress in learning or in shaping their motor skills. This research may also contribute to the development of personalized medicine, particularly in the field of physical rehabilitation and psychomotor therapy.

Conclusions

The results of the research carried out allow us to draw the following conclusions:

The study identified many cross-correlations between different RDSPs, e.g. between touch and balance, hearing and sight, and between touch and smell. 5. RDSP of vision, proprioception, hearing, and balance most strongly correlate with motor coordination disorders. 6. The autoregulation and attention focus disorders are highly correlated with all examined sensorimotor disorders.

A high correlation has been demonstrated between movement coordination disorders and disorders of cognitive attention, which may indirectly result from the multifaceted nature of psychomotor development.

The presented research conclusions may directly translate into clinical practice. Knowledge about the correlation between individual RDSPs and between motor functions and cognitive functions indicates not only the multifaceted nature of psychomotor development, but also the fact that disorders related to sensorimotor development often coexist with other disorders, which may translate into multimodal RDSPs. The awareness of the coexistence of RDSP and related executive function disorders (praxia and self-control of behaviour) can also be used in the development of rehabilitation programs based on methods such as sensory integration, bilateral integration, shantala massage, neurotactile therapy, and other integrative, neurodevelopmental, and psychomotor methods. The results can also serve as a theoretical basis for studies on the indirect influence of unimodal and bimodal therapeutic methods on other sensorimotor modalities, e.g. whether massage can be used to treat sensory disorders other than touch and proprioception [26]. The conclusions from the presented study can also be used to plan preventive programs aimed at the fastest possible detection of RDSP symptoms and, consequently, the implementation of extended diagnostics and the necessary therapeutic interventions.

Conflict of interest

The authors declare no conflict of interest.

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