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DEVELOPMENTAL COORDINATION DISORDER (DCD) AND THE ROLE OF ICTS AND NEUROFEEDBACK (NF) FOR TRAINING AND INTERVENTION

TRANSTORNO DA COORDENAÇÃO DO DESENVOLVIMENTO (TDC) E O PAPEL DO TCI E NEUROFEEDBACK (NF) PARA TREINAMENTO E INTERVENÇÃO

EL TRASTORNO DE LA COORDINACIÓN DEL DESARROLLO (DCD) Y EL PAPEL DE LAS TIC Y LA NEUROFEEDBACK (NF) PARA EL ENTRENAMIENTO Y LA INTERVENCIÓN

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ABSTRACT
DCD is a neurodevelopmental disorder that affects many levels of a person's functioning, displaying a multitude of features that persist throughout the person's life. Neurofeedback is a widely used form of non-invasive intervention that is implemented worldwide in non-DCD populations and is presented to be effective targeting a lot of difficulties and common features of DCD. The purpose of this literature review is to highlight the impact of NF showcasing several studies of its effectiveness to several populations with main key characteristics that are found to be presented also in DCD. In the introduction, the basic definitions concerning the concepts of DCD and neurofeedback are described and in the main part, an analysis of DCD is made to further investigate its key characteristics that aligns with other populations (especially ADHD) in which further investigation using neurofeedback is proposed due to its effectiveness.

KEYWORDS: Neurofeedback. NF. NFT. EEG. Biofeedback. DCD

RESUMO
DCD é um distúrbio do neurodesenvolvimento que afeta muitos níveis de funcionamento de uma pessoa, exibindo uma infinidade de características que persistem ao longo da vida da pessoa. O neurofeedback é uma forma amplamente utilizada de intervenção não invasiva que é implementada em todo o mundo em populações não DCD e é apresentada como eficaz para abordar muitas dificuldades e características comuns do DCD. O objetivo desta revisão da literatura é destacar o impacto do NF, apresentando vários estudos de sua eficácia para várias populações com principais características-chave que também se apresentam no TDC. Na introdução são descritas as definições básicas sobre os conceitos de DCD e neurofeedback e, na parte principal é feita uma análise do DCD para investigar suas principais características que se alinham com outras populações (especialmente TDAH) nas quais uma investigação mais aprofundada usando neurofeedback é proposta devido à sua eficácia.

PALAVRAS-CHAVE: Neurofeedback. NF. NFT. EEG. Biofeedback. DCD

RESUMEN
DCD es un trastorno del neurodesarrollo que afecta muchos niveles del funcionamiento de una persona, mostrando una multitud de características que persisten a lo largo de la vida de la persona. Neurofeedback es una forma de intervención no invasiva ampliamente utilizada que se implementa en todo el mundo en poblaciones sin DCD y se presenta como eficaz para abordar muchas dificultades y características comunes de DCD. El propósito de esta revisión de la literatura es resaltar el impacto de NF mostrando varios estudios de su efectividad en varias poblaciones con características clave principales que también se presentan en DCD. En la introducción, se describen las definiciones básicas sobre los conceptos de DCD y neurofeedback y, en la parte principal, se realiza un análisis de DCD

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para investigar más a fondo sus características clave que se alinean con otras poblaciones (especialmente el TDAH) en las que se requiere una mayor investigación con neurofeedback. propuesta por su eficacia.

PALABRAS CLAVE: Neurorretroalimentación. NF. NFT. EEG. Biorretroalimentación. DCD

1. INTRODUCTION

1.1 NEUROFEEDBACK AND CLINICAL APPLICATION

For many conditions, including brain-based disorders, neurofeedback (NF) is a non-invasive intervention technique. It is primarily employed in the management of attention deficit disorders and the enhancement of academic performance.

Despite the fact that it can be used in conjunction with medication, it does not contain any medication. Electroencephalographic (EEG) biofeedback and neurotherapy are other terms used to describe neurofeedback (NF). The neurofeedback apparatus consists of NF hardware, such as a Brain Computer Interface (BCI), an EEG cup, and peripheral devices, as well as NF software[34].

By measuring brain waves and sending a feedback signal to the individual, neurofeedback is a type of biofeedback that teaches people how to control their own brain functions. Typically, audio and/or visual feedback is provided by neurofeedback. Brain activity that is desirable or undesirable is accompanied by positive or negative feedback, respectively[21].

Neurofeedback has many clinical applications and has been used to reduce the symptoms caused by various diseases and conditions. Some of them concern neurodevelopmental disorders such as ADHD[25, 30, 32, 34], ASD[16, 23] and specific and non-specific learning difficulties[23]. It has also been reported to target mental and neurological disorders such as anxiety, depression, epilepsy, insomnia, drug addiction, schizophrenia[21]. Finally, it has been used in neurorehabilitation in various neurological and neurodegenerative diseases[19]. The above studies have proven the effectiveness of the use of neurofeedback in the aforementioned populations and conditions.

1.2 DEVELOPMENTAL MOTOR COORDINATION DISORDER (DCD) DEFINITION AND HISTORICAL REVIEW

Developmental motor coordination disorder (DCD) is a common childhood disorder that presents a wide range of severity and can often be underestimated by healthcare professionals. It is characterized by basic motor learning difficulties, such as learning fine and/or gross motor skills and is a condition in which a person's autonomy and functionality in activities of daily living are significantly affected[5, 10].

The term DCD was used for the first time in 1994 in an international convention which was held with the aim of jointly agreeing on an official definition that would characterize this category of children with the specific characteristics. Until then, these children were referred to with the definitions of

developmental dyspraxia, reduced brain function, physical clumsiness, cognitive-motor disorder, and as clumsy child syndrome[26].

The concept of DCD has evolved over time and the diagnostic criteria for the disorder have been refined through successive editions of the Diagnostic and Statistical Manual of Mental Disorders (DSM). In DSM-III-R (1987), DCD was referred to as “developmental dyspraxia” and was included in the category of “perceptual motor disorder”. In DSM-IV (1994), DCD was renamed “developmental coordination disorder” and included in the “movement disorders” category. In DSM-V (2013), DCD is still included in the category of “movement disorders,” but the criteria for diagnosis have been revised to better reflect current understanding of the disorder. In DSM-V (2013), DCD is defined as a “persistent difficulty planning, executing, and coordinating skilled movements that is not due to a lack of intelligence, sensory problems, or other medical conditions”[3]. It is diagnosed based on the presence of specific symptoms and functional impairment in activities of daily living and academic or occupational performance.

According to the DSM V for the diagnosis of the person the following diagnostic criteria must be met for the person to be diagnosed with DCD which are as follows:

A. Given the person's chronological age and opportunities for skill learning, the acquisition and application of coordinated motor skills is significantly below what is predicted.

B. From criterion A the deficit in motor skills presented must significantly affect and persist in performing activities of daily living that are appropriate for the child's age such as self-care and self-maintenance, academic and productive skills, leisure time and play.

C. Symptoms must begin in the early developmental period.

D. These deficits in motor skills must not be the result of an intellectual disability or neurological conditions that may affect movement[3].

1.3 DEVELOPMENTAL MOTOR COORDINATION DISORDER (DCD) AND COMORBIDITY

According to the systematic review by Blank et al (2019) prevalence estimates range from 5% to 6% of children aged 5 to 11 years, most commonly reported in the literature and boys appear to be more affected, with reported analogies of boys and girls to be from 1.9:1 to 7.3:1[15]. In Greece the rate of occurrence seems to reach 8% of the population[33].

DCD is a disorder with an increased rate of comorbidity. Many of the children who receive this diagnosis also receive at least one other different diagnosis.

Some of them are receive the diagnosis of ADHD in which the comorbidity rate in studies seems to reach 50%[9, 35]. Learning disorders, including developmental dyslexia, specific language impairment, behavioral problems, and autism spectrum disorder are also common in children with DCD with co-occurrence of these disorders to be as high as 30 to 50%[15].

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2. CHARACTERISTICS OF DEFICITS OF INDIVIDUALS WITH DEVELOPMENTAL COORDINATION DISORDER (DCD)

Several categories are presented regarding the findings and diversity of characteristic deficits prevalent in DCD.

According to the literature review by Zwicker et al., 2018 in their research on the description and impact of DCD on the quality of daily life of these children, children with DCD have difficulty coping with a variety of functional abilities, making them difficult to performing activities such as dressing, tying shoes and using utensils, with these issues persisting into adolescence and adulthood. Children with DCD may also experience secondary psychosocial issues, including issues arising in their social relationships, reduced sense of self-worth, depressive disorders, and emotional/behavioral disorders[11, 14, 22]. Compared to their peers, children with DCD may have a lower quality of life.

According to Cousins and Smith (2003) in a survey of adults aged 18-65 years to further investigate DCD in adulthood, the participating sample consisted of 19 individuals who formed pairs with typical and gender-specific and age control samples. Individuals with DCD or suspected DCD were given tests that included tasks of fine motor skills, writing, construction, obstacle avoidance, dynamic and static balance, divided attention, ball skills, response time, movement time and succession. It appeared from the findings that the DCD group showed lower performance in all tasks. Some of the features they presented were problems related to delay and variety of movements with many of the participants showing considerable problems in sequencing and dividing attention.

This is also confirmed in the systematic review by Wilson et al, 2017 to provide a synthesis of data and evidence that will include recent research processes to provide consistency in theory about DCD and direction for new research work. For the purpose of this research, the data collection was done through the PICO framework, the analysis of 106 final articles from 7 electronic databases for the years 2011-2016. The researchers concluded that the nature of the task underlies motor control deficits in DCD. Also, these deficits are evident and more pronounced when dual tasks are produced and tasks that require greater motor precision in both temporal and spatial demands, more developed planning and adaptation and compensation at the perceptual-motor level to maintain stability.

Additional difficulties are found in issues related to executive functions and attention. According to Lechambre et al, 2021 in a systematic review of the literature conducted according to pre-specified eligibility criteria, 41 studies were used using the PubMed/Medline and PsycINFO databases, whose findings summarize that children with DCD have problems with inhibitory control, working memory, planning, non-verbal fluency and general executive function.

In addition to this, for the purpose of examining a synthesis of recent experimental studies of motor control, cognitive, and neural underpinnings of DCD, Zukic et al. 2022 conducted a systematic review and meta-analysis that included one hundred papers with a DCD control comparison from published work carried out from September 2016 up to April of 2021. According to the study's findings, the most difficulties were related to voluntary gaze control while moving, cognitive-motor integration,

practice- and context-dependent motor learning, internal modeling, more variable kinematics and kinetics, as well as greater safety margins when moving.

2.1 DEVELOPMENTAL MOTOR COORDINATION DISORDER (DCD) AND NEUROLOGICAL BASIS

DCD according to several studies that have been done with the use of neuroimaging present findings that correlate it with problems of neuronal transmission of messages. More specifically, evidence is presented about basic brain structures such as the mesencephalon, the basal ganglia, the cerebellum, the parietal lobe and the thalamus, as well as their connections. Additional atypical images have been identified regarding the functions of the frontal cortex and the composition and maturation of the brain's white and gray matter[6, 12, 17, 28, 37].

According to Wilson et al, 2017 multiple brain regions (across association cortex, primary, parasympathetic and subcortical regions) have been studied in 15 studies conducted as part of neuroimaging research on DCD. In these, the cingulate frontal cortex was shown to have a thinner cortex, according to structural MRI. Diffusion MRI also reveals changes in white matter networks, particularly in sensorimotor pathways such as the corticospinal tract, posterior thalamic radiation, and the parietal subregion of the corpus collosum. In addition, mapping of the linker segment using graph theoretical analyzes reveals weaker segregation and integration of the structural linker in DCD.

These findings are enriched in recent related research that was done to investigate the cerebellar differences found in children with DCD compared to children with typical brain development. Voxel-based morphometry was used to measure cerebellar morphology and investigated using high-resolution T1 images. The population included children aged 8 to 12 years and the sample consisted of 46 children of which 12 had typical development and 34 had DCD.

The research results showed reduced gray matter volume related to connections presented in the brainstem. In a measurement made using the motor assessment tool MABC, with tests that activate the specific affected areas of the brainstem, a significant positive correlation was shown in that the reduced volume of the gray matter is also associated with reduced motor skills that explain the motor learning difficulties that are presented[8].

This confirms that a variety of DCD symptoms, including motor skills, attention, and executive function, are related to the processing of motor and cognitive functions provided by the cerebellum. The findings of the present research lend credence to this idea because fronto-parietal, sensorimotor, ventral attention, and default functioning networks, all of which have been found to be reduced in children with DCD, are linked to cerebellar regions associated with impaired motor performance[8].

2.2 ADHD AND DEVELOPMENTAL COORDINATION DISORDER (DCD)

ADHD is characterized as a highly comorbid condition that can reach up to 80% of people who have already received the diagnosis. ADHD is dominated by a triplet of core symptoms characterized

by inattention, impulsivity and hyperactivity. Something that is still observed are deficits concerning motor coordination as well as planning in movement.

In addition, ADHD is considered by research to be a neurodevelopmental disorder that exhibits the greatest and most common associations with DCD, as well as individuals with DCD exhibiting to a large extent problems related to inhibition and impulsivity. The scientific community has focused its attention on investigating the cause of these two phenomena to be able to provide answers through the study and identification of problems that arise in the development and maturation of the brain.

Recent studies using neuroimaging methods to examine the two populations revealed that there are significant differences in the way they manifest the motor deficit from a neurophysiological as well as a neurofunctional point of view[18].

What is observed in the systematic review by Wilson et al, 2017 is that several of the studies conducted on DCD population did not include as exclusion criteria population with ADHD, which can cause confusion in the interpretation of the results and understanding of the core mechanism of DCD. This need is also highlighted in the more recent reviews by Irie et al, 2021 and Zukic et al, 2022.

2.3 DEVELOPMENTAL MOTOR COORDINATION DISORDER (DCD) AND THE NEED FOR FUTURE RESEARCH USING NEUROFEEDBACK

Neurofeedback as a treatment method for children with DCD and its research presents a vast research gap. As mentioned above, DCD is a neurodevelopmental disorder that can significantly affect a person's functionality throughout their life. A person with DCD can show many and varied disorders that affect the cognitive domain (executive functions and attention), motor functions as well as have a serious impact on their psychosocial functions, causing significant problems in their participation in daily activities and necessary experiences for them. Neurofeedback is an emerging choice as a therapeutic modality with ever-increasing studies supporting its effectiveness in various ailments and conditions.

In some studies, it has been mentioned and investigation has been suggested, due to the complexity of this specific condition and the increased comorbidity it presents, especially with ADHD. The research of Noroutzi et al, 2018 proved the effectiveness regarding the improvement of motor skills. This particular study investigated whether using neurofeedback (NFT), compared to a control group, could improve bilateral coordination in children with ADHD.

The sample consisted of twenty children with ADHD (mean age: 7:9, SD, 2:11) who were divided into two groups: the group that received NFT and a control group. The two groups completed a bilateral coordination test at three different time points as well as after the 12-session intervention. Participants in the control group underwent sham NFT conditions while those in the NFT group received training to increase Sensory Motor Rate (SMR) in C3 and C4.

The results showed that the NFT group made fewer errors in both bilateral coordination patterns than the control group. A significant improvement in a bilateral coordination task was observed in

children with ADHD after SMR neurofeedback training (NFT). Thus, it appears that SMR NFT has the potential to enhance and improve motor control in ADHD patients.

This research highlights the need for future investigation using the same protocol in a population with DCD, due to the increased comorbidity that occurs and the fact that the motor deficits in the particular sample obtained may be a consequence of DCD.

In an even more recent study by Seikh et al, 2022 to highlight the effectiveness of NFT on motor function, anxiety and sleep habits in children with ADHD, the authors take for granted the comorbidity of DCD with ADHD as a feature of the condition.

In the present research, a sample of 20 children aged 7 to 9 years was collected and divided into two groups, the group that received NFT and the control group. The experimental group received NFT and physical activity training for 24 sessions of 45 minutes, while the control group followed their normal daily schedule. The results showed that there was a big difference between the two groups regarding the motor functions, anxiety and sleeping habits of the children.

Also, one of the most presented problems associated with DCD is reported to be executive functions[4, 27, 29, 36, 39]. According to Shalkouhli et al, 2022 in their recent study in order to investigate and compare the effectiveness of pharmacotherapy and neurofeedback on improving the executive functions in children with ADHD, they discovered that neurofeedback was more effective than pharmacotherapy on improving overall executive functions. Further findings seem to support those assumptions in another study used in non-DCD populations using neurofeedback combined with computer and cognitive games presenting gains in time perception and working memory[24].

These findings were also enriched in Luo et al, 2022 study in which they applied a combined NFT and computerized cognitive training (CCT) using a randomized control design to compare NFT, CCT and Combined NFT and CCT training approaches in ADHD population. 80 of the 121 ADHD kids who were randomly assigned to the NFT, CCT, or NFT/CCT training groups finished the course. Executive and daily functions, as well as pre- and post-training symptoms, were assessed using questionnaires and resting EEG under both the eyes-closed and eyes-open conditions. Following three months of training, there was a noticeable improvement in the three groups of children's inattentional, hyperactive/impulsive, and inhibitional symptoms, as well as working memory, learning, and life skills.

Including the research mentioned above and in relation to the problems mentioned in motor performance and executive skills which are important pillars of problems in DCD as well it would be worth investigating this population further using neurofeedback as a therapeutic method and with consolidation of exclusion criteria for correct interpretation, validity and reliability of results.

3. DISCUSSION

In conclusion, we emphasize the importance of all digital technologies in the field of education, training and rehabilitation. These technologies are highly effective and productive and facilitate and improve assessment, intervention, and educational procedures through mobile devices that bring

educational and training activities anywhere[45-48], various ICTs applications that are the main supporters of training and education[49-61], and AI, STEM, and ROBOTICS that raise assessment procedures to new performance levels[62-73], and games which transforms the training and rehabilitation in a very friendly and enjoyable interaction[74-76]. In addition, the development and integration of ICTs with theories and models of metacognition, mindfulness, meditation, and the development of emotional intelligence[77-105], as well as with environmental factors and nutrition[41-44], accelerates and improves educational practices, training and rehabilitation results in new levels especially in neurodevelopment domain.

More specifically DCD is a neurodevelopmental disorder of childhood that affects the overall functioning and participation of the individual in basic and necessary activities for them (productivity, socialization, work, leisure) throughout their life. The dominant problems observed in it are related to difficulties in the individual's motor learning and executive functions. Although the concept of DCD has been consolidated since 1994 in the DSM, researchers are trying to identify its cause through the use of mainly neuroimaging methods, studying deviations arising from typically developing brains, as well as differences from other neurodevelopmental disorders (ADHD and ASD). The large comorbidity that occurs with other diseases especially with ADHD and the incomplete exclusion criteria regarding the research procedures that are carried out, also produce results that are not consistent and generalizable.

Regarding the use of neurofeedback in DCD, there is a vast research gap that has not yet been filled. The use of neurofeedback has been shown to be effective in populations that share many characteristics with DCD (with ADHD being predominant), showing improvement in features and characteristics that are a significant problem in children with DCD. The need for recent researchers to produce the same protocols applied to different populations is raised more and more for discussion.

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