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Rodrigo Flores Sartori

FUNÇÕES EXECUTIVAS, HABILIDADES MOTORAS E DESEMPENHO ESCOLAR EM CRIANÇAS COM DESORDEM COORDENATIVA DE DESENVOLVIMENTO

Porto Alegre
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Tese de doutorado apresentada ao Programa de Pós-Graduação em Ciências do Movimento Humano da Escola de Educação Física, Fisioterapia e Dança da Universidade Federal do Rio Grande do Sul, como requisito parcial para a obtenção do título de doutor em Ciências do Movimento Humano.

Orientadora: **Profª. Drª. Nadia Cristina Valentini**

Coorientadora: **Profª. Drª. Rochele Paz Fonseca**

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Porto Alegre
2019

APRESENTAÇÃO DA TESE E AGRADECIMENTOS

Vinte anos se passaram desde que ouvi do Professor Doutor Ruy Jornada Krebs, na Universidade Federal de Santa Maria, que havia a necessidade de estudar teorias e modelos que explicassem e estudassem o desenvolvimento infantil de maneira integrada. O que ele referia, é que mais de um dos domínios do desenvolvimento deveria ser investigado para podermos compreender de maneira mais ecológica o comportamento infantil. Prof. Ruy com seu caráter, sua sabedoria, sua liderança estava mais uma vez, coberto de razão. Cognição, emoção e o comportamento motor devem juntos explicar o desenvolvimento na infância.

Mais recentemente, há cerca de 7 anos tive a oportunidade de começar a trabalhar com um colega da PUCRS, Prof. Dr. Rodrigo Grassi de Oliveira, que vinha estudando sobre estresse precoce, imunologia do estresse e sua relação com psicopatologias ao longo do desenvolvimento. Nestes estudos, o Prof. Grassi buscava verificar como o ambiente interage com a estrutura genética de cada indivíduo, para compreender os mecanismos neurobiológicos associados no curso do neurodesenvolvimento. Os resultados destes estudos indicavam que havia um impacto negativo no curso do desenvolvimento das crianças, sobretudo, nos aspectos emocionais e cognitivos, no entanto, foi possível perceber que pouco se mencionava sobre o papel do comportamento motor no estudo deste tema.

A busca para compreender estes aspectos do neurodesenvolvimento e suas relações com a área do comportamento motor ressaltam um dos pontos principais desta tese de doutorado que pretende dizer que, "*Crianças com Desordem Coordenativa de Desenvolvimento (DCD), um desordem caracterizada por dificuldades na execução das habilidades motoras, tem também déficits em funções cognitivas, especificamente, prejuízos das funções executivas e que estes prejuízos levam a um déficit do desempenho escolar*". Para demonstrar essa tese, há a necessidade de compreender de forma mais aprofundada os aspectos relacionados ao curso do desenvolvimento motor, compreender como ocorrem os atrasos motores em crianças e como estes atrasos estão vinculados aos mecanismos cognitivos do desenvolvimento infantil.

A entrada no Grupo de Pesquisa da Prof. Drª Nadia Cristina Valentini possibilitou aprofundar os aspectos relacionados ao estudo do desenvolvimento motor de crianças em situação de risco e/ou em situação de vulnerabilidade socioeconômica. Além disso, possibilitou a compreensão da avaliação do desenvolvimento motor e os processos de intervenção quando atrasos e riscos são detectados o que pode levar a um prejuízo de atividades funcionais na vida criança. Nesse sentido, um dos pontos mais importantes, foi compreender junto à Prof. Nadia, que o recém-nascido não entra no mundo apenas com habilidades para pensar ou com cognição; tampouco entram no mundo com memórias processuais ou declarativas. A criança entra no mundo com movimento.

Esse período de estudos no laboratório da Prof. Nádia reforça ainda mais a ideia que as habilidades motoras desenvolvidas neste início da jornada da vida serão fundamentais para o desenvolvimento de uma variedade de habilidades mais complexas em fases posteriores do ciclo vital. Desperdiçar as possibilidades de movimento da primeira infância, significa limitar o potencial individual, uma vez que nem sempre é possível recuperá-lo plenamente com investimentos posteriores. Um ambiente com oportunidades de práticas motoras irá exigir de cada criança com suas diferentes capacidades, processos de controle adaptativo que devem ser recrutados para atender às demandas de situações nos contextos de jogos e exercícios. A partir desta compreensão pode se pensar o desenvolvimento motor como "*berço das funções executivas*" conforme apontado por Koziol (2016).

As funções executivas são fundamentais para que o indivíduo, progressivamente, gerencie os diferentes aspectos de sua vida com autonomia em todos os aspetos e contextos do desenvolvimento. Neste sentido, a Prof. Drª Rochele Paz Fonseca tem um papel fundamental nesta tese no sentido de aproximar seu campo de interesse; a avaliação neuropsicológica, a neuropsicologia cognitiva e, sobretudo a avaliação de perfil neuropsicológico de populações especiais, com os aspectos do desenvolvimento motor, fazendo com que compreendêssemos o papel fundamental das interações executivas/motoras para tentar explicar alguns comportamentos das crianças nos seus contextos de aprendizagem. Especificamente, esta coorientação fornece suporte para propor como tese para este estudo que as funções executivas são preditoras do desempenho acadêmico e especificamente, das habilidades de escrita e de matemática em crianças com Desordem Coordenativa Desenvolvimental.

Um dos argumentos e justificativa para propor esta Tese é que, na medida em que as funções executivas são preditoras desempenho da escrita e da matemática, a investigação do desenvolvimento motor deve ser parte de qualquer tipo de avaliação clínica durante a infância, pois comportamentos motores, cognitivos e emocionais são interativos e indissociaveis. Nesse sentido, busca-se compreender o comportamento das funções executivas em crianças típicas e com DCD, assim como investigar como estas variáveis podem agir como preditoras do desempenho escolar em um grupo de crianças com DCD e com rsico para esta desordem.

Finalmente, deixo este último parágrafo para agradecer profundamente a oportunidade dada pela Prof. Nadia. Tive a experiencia de conviver em um ambiente de busca de conhecimento, onde os processos de aprendizagem foram colaborativos e sobretudo, aprendi que a dedicação é algo essencial na busca do conhecimento. Da mesma forma, agradeço a Prof. Rochele pela oportunidade de aprendizagem em seu grupo de pesquisa e mais do que isso, oportunidade de viver plenamente uma prática interdisciplinar. Deixo registrado aqui minha gratidão, aos Professores Fernando Copetti, Maria Helena Ramalho pelos anos de orientação e amizade, ao Prof. Flávio Castro, à Prof. Natalia Dias pela oportunidade e desafio de escrever sobre este tema em seu livro. Aos meus colegas do Grupo GAIM, a todos os professores e alunos das escolas. Agradeço ao meu colega e amigo Glauber Nobre, aos estudantes de graduação e pós-graduação da PUCRS que auxiliaram neste processo de aprender. À minha família, minha Mãe e meus colegas de trabalho, Professores da PUCRS e FSG pela compreensão que tiveram comigo em todos os momentos.

ORGANIZAÇÃO DA TESE

Esta tese é apresentada conforme o modelo Escandinavo para estudos acadêmicos. Portanto, os resultados obtidos por meio dos métodos propostos para responder as finalidades e objetivos dessa pesquisa, estão organizados em forma de uma sequência de artigos escritos desmembrados do problema de pesquisa. Os artigos, de acordo com as normas do regimento do PPGCMH, foram escritos na língua inglesa a partir da proposta de internacionalização da Universidade. Todos os 4 artigos já estão no formato das respectivas revistas que foram selecionadas para posterior publicação.

Com relação a organização da tese O **primeiro capítulo** apresentará a problematização da tese com os argumentos teóricos que sustentam a pesquisa, além dos objetivos, gerais e específicos e as respectivas hipóteses de pesquisa. O **segundo capítulo** apresenta uma revisão de literatura sobre os temas mais importantes relacionados a tese. No **terceiro capítulo**, será apresentado um artigo de revisão sistemática na literatura para mapear as tarefas de exame de cada componente das funções executivas (controle inibitório, memória de trabalho e flexibilidade cognitiva) em estudos com crianças com Desordem Coordenativa Desenvolvimental (DCD) e com dificuldades motoras e seus respectivos desfechos. Este artigo está apresentado no formato para a revista ***Journal of Science and Medicine in Sport***. O **quarto capítulo** apresenta um artigo de validação de um instrumento de pesquisa (*Go/No-goApp*) que busca apresentar as evidências de validade de conteúdo, construto e critério de 4 tarefas de controle inibitório baseados no paradigma *Go/No-go* para crianças típicas e com DCD. Este artigo está apresentado no formato para a revista ***Measurement in Physical Education and Exercise Science.*** Com o estudo de validação realizado, é apresentado o **quinto capítulo** através de um estudo descritivo comparativo sobre o desempenho das funções executivas nos grupos de crianças com DCD, em crianças com Risco Desordem Coordenativa Desenvolvimental (r/DCD) e com crianças com desenvolvimento típico (DT)**.** Este artigo está formatado para ser submetido no ***Journal Child Health Care and Devepolpment.*** O **sexto capítulo** desta tese, busca avaliar as habilidades motoras fundamentais e as funções executivas como preditoras do desempenho da escrita e matemática em crianças com DCD, r/DCD e DT**.** Este artigo está organizado para ser submetido na revista ***Developmental Disabilities.*** Por fim, o **sétimo capítulo** expõem as considerações finais sobre a tese buscando responder as questões problema que foram estabelecidas.

SARTORI, Rodrigo Flores. Funções executivas, Habilidades Motoras e Desempenho Escola em Crianças com Desordem Coordenativa de Desenvolvimento. Porto Alegre: UFRGS, 2019, p.188

RESUMO

Esta tese é apresentada conforme o modelo Escandinavo para estudos acadêmicos. Portanto, os resultados obtidos por meio dos métodos propostos para responder e atender as finalidades e objetivos dessa pesquisa, estão organizados em forma de uma sequência de artigos escritos que são desmembrados do problema de pesquisa. A tese está dividida em duas partes. Na primeira etapa pretende-se dizer que crianças com Desordem Coordenativa Desenvolvimental (DCD) tem também déficits em funções cognitivas, especificamente, prejuízos das funções executivas (FE). Na sequencia é apontada a Tese de que há uma estreita relação entre comportamento motor e cognitivo e mais especificamente que crianças com DCD apresentam deficits nas funções executivas que predizem deficits do desempenho da escrita e da matemática no contexto escolar. Essa tese aponta para a necessidade de se pensar o funcionamento executivo/motor como parte dos processos de intervenção. Dessa forma, o objetivo desta tese é investigar as relações entre habilidades motoras e componentes das funções executivas em crianças com DCD, com risco para DCD e com desenvolvimento motor típico, assim como desenvolver tarefas para controle inibitório nesta população e averiguar o impacto das interações motoras-executivas como preditoras do desempenho da escrita e da matemática.

Para iniciar esta investigação o primeiro artigo propôs mapear as tarefas e testes de exame de cada componente da função executiva (memória operacional, inibição e flexibilidade cognitiva) em estudos com crianças com DCD, risco de DCD e crianças com dificuldades motoras, bem como caracterizar os desfechos apresentados. Para isso foi realizado um estudo de revisão sistemática conduzido de acordo com o método *Preferred Reporting Items for SystematicReviews and Meta-Analyzes* (PRISMA). Após o processo de seleção, dos 1475 artigos encontrados inicialmente e identificados por triagem de título e resumo, 29 artigos foram elegidos para a análise. Os resultados apontaram 31 diferentes tipos de testes e tarefas para a avaliação das FE em crianças com DCD. Os resultados apontam ainda que parte dos testes e tarefas encontrados nos estudos requerem processamento verbal, não verbal ou complexo viso espacial, com ou sem demanda motora envolvida. Em algumas tarefas cognitivas, essas diferentes demandas ou diferentes tipos de estímulos envolvidos nos testes podem causar perda secundária na execução, camuflando os deficits executivos primários que devem ser predominantemente examinados (viés de desempenho motor ou de percepção visual), limitando assim a avaliação mais específica as funções executivas reais neste grupo de crianças com atraso motor.

Estas conclusões do artigo 1 levaram a proposta de apresentar o processo de desenvolvimento e busca de evidências de validade de conteúdo, construto e critério de um conjunto de 4 tarefas verbais e não verbais baseadas no paradigma Go/No-go, desenvolvidas em *smartphone*, denominado *Go/No-go App Test.* Levando em consideração a exposição de crianças a dispositivos eletrônicos em diferentes países, um App para avaliar a funções executivas parece uma solução prática que poderia ser utilizada em pesquisas e clínicas, possibilitando a medição de variáveis verbais e motoras relacionadas ao controle inibitório de crianças. Além disso, pode minimizar o papel dos aspectos secundários na avaliação do controle inibitório. Para validar este teste participaram do presente estudo três profissionais com doutorado em Neuropsicologia e com mais de 10 anos de experiência em pesquisa e ensino em funções executivas. 252 crianças foram incluídas para investigar a validade do paradigma em crianças, sendo constituído um grupo de 53 crianças com DCD para verificar a validade do modelo em crianças com esse tipo de desordem de desenvolvimento. Os resultados do presente estudo sugerem que o teste *Go/No-Go App* minimiza o viés motor para investigação do controle inibitório. Os presentes resultados demonstram que o *Go/No-Go App* é um teste com evidência adequada de validade para a avaliação do controle inibitório em crianças típicas entre 8 a 10 anos de idade e em crianças com DCD.

Com o desenvolvimento e validação deste instrumento foi realizado o terceiro artigo desta tese que aponta como hipótese que crianças com DCD, além do comprometimento motor também apresentam prejuízo no desempenho em alguns componentes das funções executivas. No entanto, não há consenso sobre qual subdomínio executivo específico é mais afetado. Dessa forma, o objetivo deste estudo foi comparar as funções executivas - memória de trabalho, controle inibitório e flexibilidade cognitiva, em crianças com DCD, em risco de DCD (r-DCD) e em crianças com Desenvolvimento Típico (TD). Uma amostra de 397 crianças foi avaliada, distribuída posteriormente nos grupos, com DCD (n = 63), em r-DCD (n = 31) e com TD (n = 63) com base nos tesets de triagem; MABC-2, *MABCChecklist* e teste WASI para avaliação do QI. Todas as medidas de função executiva incluíram tarefas verbais e não verbais para memória de trabalho (*Odd-One-Out e Span auditivo de palavras*), controle inibitório (testes Go / *No-Go e Hayling*) e flexibilidade cognitiva (Teste de Cinco Dígitos e *Trail Making Teste*). A análise de variância multivariada foi utilizada para verificar os efeitos do grupo nas funções executivas. Os resultados deste estudo apontam que o grupo DCD apresentou diferenças significativas com menores escores em relação ao grupo TD na memória de trabalho viso espacial e verbal; no controle inibitório (tarefas G*o/No-Go e Hayling* Parte B / erros) e tarefas verbais e não verbais de flexibilidade cognitiva; O grupo r-DCD apresentou escores mais baixos em comparação ao grupo TD para memória de trabalho visoespacial e para flexibilidade cognitiva. Na medida em que as crianças com DCD e rDCD também apresentavam síndrome descendente, as funções executivas preventivas deveriam ser estimuladas especialmente para esse grupo subclínico.

Ao verificar a tese que existe um déficit das funções executivas em crianças com DCD e com risco para DCD o quarto artigo desta tese buscou examinar se as funções executivas (memória de trabalho, inibição e flexibilidade cognitiva), habilidades locomotoras e habilidades motoras de controle de objetos são fatores preditivos significativos para o desempenho da escrita e matemática em crianças com DCD e em risco de DCD. A mesma estrutura metodológica do terceiro estudo foi realizada. Além disso, foram avaliadas as habilidades motoras fundamentias através do teste TGMD-3 e testes de desempenho da escita e matemática, através do teste TDE II. Uma análise de regressão linear múltipla multivariada e modelo de equação foram utilizados para verificar a capacidade preditiva das variáveis investigadas. Os resultados deste estudo sugerem que o baixo desempenho em medidas de inibição e nos testes de memória de trabalho visuoespacial predizem performances de escrita e matemática nas crianças com DCD e r-DCD.

Palavras-chave: função executiva, habilidades motoras, desempenho acadêmico, atraso motor, desordem coordenativa de desenvolvimento.

SARTORI, Rodrigo Flores. Funções executivas, Habilidades Motoras e Desempenho Escola em Crianças com Desordem Coordenativa de Desenvolvimento. Porto Alegre: UFRGS, 2019, p.188

ABSTRACT

This thesis is presented according to the Scandinavian model for academic studies. Therefore, the results obtained through the methods proposed to answer and to meet the aims and objectives of this research, are organized in the form of a sequence of written articles that are dismembered of the research problem. The thesis is divided into two parts. In the first stage it is intended to say that children with Developmental Coordination Disorder (DCD) also have deficits in cognitive functions, specifically, impairments of executive functions (EF). In the sequence it is pointed out the Thesis that there is a close relationship between motor and cognitive behavior and more specifically that children with motor delay present deficits in executive functions that predict deficits in the performance of writing and mathematics in the school context. This thesis points to the need to think of the executive / motor functioning as part of the intervention processes. Thus, the objective of this thesis is to investigate the relationships between motor skills and components of executive functions in children with DCD, with risk for DCD and with typical motor development, as well as to develop tasks for inhibitory control in this population and to investigate the impact of motor-executive interactions as predictors of writing and math performance.

To begin this investigation, the first article proposed to map the tasks and examination tests of each component of the executive functions (operational memory, inhibition and cognitive flexibility) in studies with children with DCD, risk of DCD and children with motor difficulties, as well as characterize the outcomes presented. For this, a systematic review study was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyzes (PRISMA) method. After the selection process, of the 1475 articles initially found and identified by title and abstract screening, 29 articles were selected for analysis. The results showed 31 different types of tests and tasks for the evaluation of EF in children with DHD. The results also show that part of the tests and tasks found in the studies require verbal processing, non-verbal or complex spatial vision, with or without motor demand involved. In some cognitive tasks, these different demands or different types of stimuli involved in the tests can cause secondary loss in the execution, camouflaging the primary executive deficits that must be predominantly examined (motor performance bias or visual perception bias), thus limiting the more specific evaluation of the real executive functions in this group of children with motor delay.

These conclusions of article 1 led to the proposal to present the process of development and search for evidence of content validity, construct and criterion of a set of 4 verbal and non-verbal tasks based on the Go/No-go paradigm, developed on smartphone, called Go/No-go App Test. Taking into account the exposure of children to electronic devices in different countries, an App to evaluate the executive function seems a practical solution that could be easily used in researches and clinics, enabling the measurement of verbal and motor variables related to the inhibitory control of children, in addition it could minimize the role of secondary aspects in the evaluation of inhibitory control. To validate this test participated in the present study three professionals with doctorate in Neuropsychology and with more than 10 years of experience in research and teaching in executive functions. 252 children were included to investigate the validity of the paradigm in children, constituting a group of 53 children with DCD to verify the validity of the model in children with this type of disorder. The results of the present study suggest that the Go / No-Go App test minimizes the motor bias for investigation of inhibitory control.

With the development and validation of this instrument, the third article of this thesis was carried out, which hypothesizes that children with DCD, in addition to motor impairment, also present performance impairment in some components of executive functions. However, there is no consensus on which specific executive subdomain is most affected. Thus, the objective of this study was to compare executive functions - working memory, inhibitory control and cognitive flexibility in children with DCD, at risk of DCD (r-DCD) and in children with typical development (TD). A sample of 397 children was evaluated, distributed later in the groups, with DCD (n = 63), r-DCD (n = 31) and TD (n = 63) based on MABC-2, MABC-2. Checklist and WASI tests. All executive function measures included verbal and non-verbal tasks for working memory (Odd-One-Out and auditory word span), inhibitory control (Go / No-Go and Hayling tests) and cognitive flexibility (Five Digits Test and Trail Making Test). The multivariate analysis of variance was used to verify the effects of the group on the executive functions. The results of this study show that the DCD group presented lower scores in relation to the TD group in the spatial and verbal vision working memory; in the inhibitory control (Go/No-Go and Hayling Part B tasks / errors) and verbal and non-verbal tasks of cognitive flexibility; The r-DCD group presented lower scores in comparison to the TD group for visuospatial working memory and for cognitive flexibility. To the extent that children with DCD and r-DCD also had descending syndrome, preventive executive functions should be stimulated especially for this subclinical group.

When checking the thesis that there is a deficit of executive functions in children with DCD and at risk for DCD, the fourth article of this thesis sought to examine whether the executive functions (working memory, inhibition and cognitive flexibility), locomotive abilities and motor control skills objects are significant predictive factors for the performance of writing and mathematics in children with DCD and at risk of DCD. The same methodological structure of the third study was performed. n addition, the foundational motor skills were evaluated through the TGMD-3 test and the scales and mathematics performance tests through the TDE II test. A multivariate multiple linear regression analysis and equation model were used to verify the predictive capacity of the variables investigated. The results of this study suggest that poor performance in inhibition measures and visuospatial working memory tests predict writing and mathematical performances in children with DCD and r-DCD.

Keywords: executive function; motor abilities; academic achievement; motor delay; Developmental Coordination Disorder.

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LISTA DE ABREVIATURAS E SIGLAS

CFI	Comparative Fit Index
CVC	Coeficiente de Validade de Conteúdo
DCD	Desordem Coordenativa Desenvolvimental
DCD	Development Coordination Disorder
DP	Desvio Padrão
DT	Desenvolvimento Típico
EIDP	Early Intervention Developmental Profile
EF	Executive Function
FE	Funções Executivas
GFI	Goodness-of-Fit
ICC	Coeficiente de Correlação Intraclasse
ITC	International Test Commission
M	Média
MABC	Movement Assessment Battery for Children
MABC-2	Movement Assessment Battery for Children – Second Edition
r	Correlação de Pearson
RMSEA	Root Mean Square Error of Approximation
RVC	Razão de Validade de Conteúdo
TDE	Teste de Desempenho Escolar
TGMD-2	Test of Gross Motor Development – Second Edition
TGMD-3	Test of Gross Motor Development – Third Edition

SUMÁRIO

CAPÍTULO 1

1.1 INTRODUÇÃO

1.1.1 Problematização

Crianças com atrasos nos marcos motores e com dificuldades na execução de tarefas motoras, especialmente aquelas que envolvem atividades diárias e que repercutem nas questões escolares relacionadas à aprendizagem, são diagnosticadas com o termo Desordem Coordenativa desenvolvimental (DCD) (AMERICAN PSYCHIATRIC ASSOCIATION, 2013). Dificuldades na coordenação e no controle de movimentos e atrasos nos marcos motores são reportados em crianças que possivelmente tem esta desordem de movimento (VALENTINI et al., 2012; WILSON et al., 2012; ZWICKER et al., 2012a).

A manifestação e o diagnóstico de crianças com DCD estão relacionados a quatro critérios apontados pelo Manual Diagnóstico de Transtornos Mentais 5ª edição considera primeiramente que estas crianças apresentam atraso em habilidades motoras para a idade cronológica (Critério A) e podem quando menores apresentar atraso para atingir marcos motores (i.e., sentar, engatinhar, andar), embora muitas alcancem os marcos motores em idades adequadas. Ainda mais, o atraso nas habilidades motoras interfere significativamente no desempenho ou na participação nas atividades diárias da vida social, escolar ou comunitária (Critério B). Considerando o critério C, ressalta-se que o início dos sintomas do transtorno do desenvolvimento da coordenação deve se dar precocemente no período do desenvolvimento. A desordem, entretanto, não costuma ser diagnosticada antes dos 5 anos. O Critério D especifica que o diagnóstico de DCD é feito quando as dificuldades de coordenação não são mais bem explicadas por deficiência visual ou não são atribuíveis a alguma condição neurológica, ou ainda se a deficiência intelectual estiver presente, as dificuldades motoras excedem as esperadas para a idade mental (AMERICAN PSYCHIATRIC ASSOCIATION, 2013).

Esta desordem afeta drasticamente uma grande amplitude de habilidades motoras de locomoção, as quais envolvem mover o corpo através do espaço de um lugar para outro (por exemplo, correr, pular, correr e saltar) e habilidades de controle de objeto que consistem em manipular a projeção e interceptação de objetos principalmente com as mãos e pés (por exemplo, arremessar, receber, rebater e chutar) (ULRICH, 2000; VALENTINI et al., 2012). As habilidades motoras fundamentais são consideradas como a base para o desenvolvimento de tarefas mais complexas e específicas do esporte, para atividades diárias, e para a saúde (HAYWOOD; GETCHELL, 2009). O prejuízo do desenvolvimento das habilidades motoras fundamentais pode privar uma criança de se engajar em atividades, e, dessa forma, tem relação direta com a aquisição de competências cognitivas, sociais e habilidades emocionais (VALENTINI; RUDISILL, 2004a) (STODDEN et al., 2008)(CAIRNEY; RIGOLI; PIEK, 2013).

A desordem coordenativa desenvolvimental pode apresentar-se de forma isolada, com a criança evidenciando dificuldades na realização de habilidades motoras fundamentais (VALENTINI; CLARK; WHITALL, 2014), ou ainda associada a dificuldades cognitivas de escrita e matemática (ALLOWAY, 2007), bem como perceptivas na organização e planejamento do movimento (BROWN-LUM; ZWICKER, 2015; ZWICKER et al., 2012a). Consequentemente, dimensões sociais e emocionais do desenvolvimento são afetadas (CAIRNEY; RIGOLI; PIEK, 2013), assim como o funcionamento motor (VALENTINI et al., 2012), o desempenho acadêmico (ASONITOU et al., 2012; GOMEZ; PIAZZA; JOBERT, 2015) e/ou cognitivos (LEONARD et al., 2015a).

A compreensão da interação sobre as diferentes dimensões do desenvolvimento infantil necessita uma visão dos múltiplos elementos comportamentais presentes nas habilidades motoras que são realizadas pelas crianças, além das restrições ambientais na organização das diferentes tarefas. Uma vez que as habilidades motoras agem como restrições sobre nossas ações, o que afeta nossas interações com o ambiente é a maneira pela qual aprendemos e percebemos os diferentes sentidos (THELEN, 1995). Entender as restrições decorrentes da desordem pode auxiliar o entendimento das limitações e potencial destas crianças. Quando o controle motor é afetado, tal como ocorre em crianças com DCD, podemos esperar diferenças na forma em que o ambiente é percebido e como estas informações são processadas (LEONARD, 2016). Dessa forma, a percepção, cognição, e o controle motor devem ser vistos como sistemas funcionalmente integrados (LEONARD; HILL, 2015).

Considerando que o controle destas habilidades motoras apoia-se em uma rede complexa e interativa de estruturas neurais, atrasos no desenvolvimento destas habilidades são suscetíveis e relacionam-se não apenas á areas do córtex motor, mas também estão associados com áreas do processamento cognitivo (RAHIMI-GOLKHANDAN et al., 2015). Há pouco conhecimento sobre as bases neurais das relações entre o desempenho das habilidades motoras e cognitivas em crianças (GRISSMER et al., 2010). De uma perspectiva neuropsicológica, a estreita associação entre variáveis motoras e cognitivas pode ser explicada quando as áreas cerebrais que se especializam no controle motor mostram ativação durante a execução de certas tarefas cognitivas (DIAMOND, 2000). Por sua vez, as áreas associadas ao controle cognitivo mostram ativação durante a execução de habilidades motoras complexas (DIAMOND, 2013). Como exemplo, percebe-se uma co ativação do cerebelo durante determinadas tarefas motoras, sobretudo nos aspectos de controle postural e ao mesmo tempo para os atividades complexas do ponto de vista do funcionamento cognitivo (DIAMOND, 2000).

Evidências ainda sugerem que há relações entre atrasos motores e cognitivos do desenvolvimento, especificamente, relacionando atrasos nos aspectos motores com deficts em algumas das funções executivas (LEONARD et al., 2015a; MICHEL; MOLITOR; SCHNEIDER, 2016; PIEK et al., 2004; WILSON et al., 2012). As funções executivas são processos cognitivos que caracterizam-se por um conjunto de habilidades que, de forma integrada, permitem ao indivíduo direcionar comportamentos à metas, avaliar a eficiência e adequação desses comportamentos, abandonar estratégias ineficientes em prol de outras mais eficientes e deste modo, resolver problemas imediatos de médio e longo prazo (MIYAKE; FRIEDMAN, 2012). As funções executivas são formas de cognição, que tem como função a percepção e atuação do sistema nervoso central na regulação do comportamento humano (DIAMOND, 2012a) e neste caso inclui-se o comportamento motor (LEONARD, 2016). Essas habilidades atuam em ações como a resolução de problemas, a inibição seletiva do comportamento, a seleção, a verificação e o controle de uma dada ação, a flexibilidade cognitiva e a memória de trabalho (MIYAKE et al., 2000).

As habilidades motoras e o funcionamento executivo são subordinados por conexões estruturais e funcionais subjacentes entre córtex parietal, córtex pré-frontal e cerebelo (DIAMOND, 2013). Em crianças com DCD, essas estruturas apresentam uma reduzida conectividade funcional no âmbito destas redes (ZWICKER et al., 2011), ou, então, um imaturo acoplamento entre áreas de controle frontal e posterior (RUDDOCK et al., 2015). Estes processos poderiam explicar as dificuldades motoras observadas em crianças com desordem coordenativa desenvolvimental (DCD) (LEONARD, 2016).

Estudos com crianças com DCD apresentam associações positivas com os três principais componentes das funções executivas; na memória de trabalho, resultados apontam que crianças com DCD apresentam dificuldades em tarefas que exigem a manutenção e manipulação de informações no sistema nervosos central, (LEONARD et al., 2015b; MICHEL et al., 2011; PIEK et al., 2004; TSAI et al., 2012; WILLIAMS et al., 2013); Crianças com DCD também apresentam dificuldades em tarefas de controle inibitório (CHEN; WILSON; WU, 2012; LEONARD et al., 2015b; QUERNE et al., 2008; RAHIMI-GOLKHANDAN et al., 2014; TSAI, 2009); e na flexibilidade cognitiva (LEONARD et al., 2015b; MICHEL et al., 2011; PIEK et al., 2007; WUANG; SU; SU, 2011).

Estudos com crianças com DCD também ressaltam problemas significativos em atividades acadêmicas (GOMEZ; PIAZZA; JOBERT, 2015; LEONARD et al., 2015a; PRUNTY et al., 2016; ZWICKER et al., 2012a). Por outro lado, as funções executivas estão associadas positivamente com o desempenho acadêmico (BEST; MILLER; NAGLIERI, 2011; JACOB; PARTKINSON, 2015). As funções executivas são melhores preditores do que o QI na detecção de prontidão para a aprendizagem em crianças da educação infantil (BLAIR; RAZZA, 2007). Além disso, as funções executivas também foram identificadas como fortes preditores dos resultados acadêmicos de crianças no contexto escolar (BEST; MILLER; NAGLIERI, 2011; YENIAD et al., 2013). No ambiente escolar, as funções executivas são requisitadas, pois as situações apresentadas na escola demandam da criança soluções para os problemas propostos, planejamento e adaptação a situações variadas na busca de novos objetivos.

Estudos que avaliaram, se há déficits das funções executivas em crianças com DCD ainda são escassos na literatura, sobretudo no Brasil. Da mesma forma, não tem sido apresentado se as funções executivas e as habilidades motoras fundamentais são preditoras do desempenho acadêmico (escrita e matemática) em crianças com DCD e com risco para DCD (r-DCD). Embora as habilidades motoras finas e funções executivas tenham sido consideradas como poderosos preditores do sucesso acadêmico subsequente (GRISSMER et al., 2010) é importante avaliar se as relações entre funções executivas e habilidades motoras fundamentais (grossas) também podem predizer o desempenho nas atividades escolares. As respostas sobre como se estabelecem as associações entre habilidades motoras fundamentais e as funções executivas justificam-se na possibilidade de fornecer informações úteis para potencializar o desenvolvimento infantil através de programas de intervenção com abordagem motora/cognitiva, mais específica para as demandas necessárias aos processos de aprendizagem das crianças. Além disso, podem indicar de forma mais clara o papel das habilidades motoras fundamentais nos contextos educacionais e nas políticas públicas para o desenvolvimento infantil, a partir da valorização de programas de Educação Física na Educação Básica. A compreensão das relações entre os domínios percepto-cognitivo (funções executivas), e físico-motor (habilidades motoras) é um passo vital para ajudar no planejamento de uma intervenção precoce em crianças com dificuldades coordenativas de desenvolvimento (DCD) ou com dificuldades de aprendizagem (LEONARD; HILL, 2015). A partir destes apontamentos, esta Tese está dividida em seis capítulos com seus respectivos objetivos, descritos a seguir;

1.2 OBJETIVOS

1.2.1 Objetivo Geral

Comparar o desempenho dos componentes das funções executivas em crianças com Desordem Coordenativa Desenvolvimental (DCD), com risco para DCD (r-DCD) e com desenvolvimento motor típico (DT), assim como desenvolver e validar tarefas para controle inibitório nesta população e averiguar o impacto das habilidades motoras-executivas como preditoras do desempenho da escrita e da matemática.

1.2.2 Objetivos Específicos

- Mapear os testes e tarefas de avaliação dos componentes das funções executivas (controle inibitório, memória de trabalho e flexibilidade cognitiva) em estudos com crianças com DCD e com crianças com dificuldades motoras.

- Investigar os resultados dos estudos que utilizaram testes e tarefas para avaliar os componentes das funções executivas (controle inibitório, memória de trabalho e flexibilidade cognitiva) em estudos crianças com DCD e com dificuldades motoras

- Apresentar o processo de desenvolvimento e busca de evidências de validade de conteúdo, construto e critério de um conjunto de tarefas verbais e não verbais em forma de App (Go/No-goApp) baseadas no paradigma Go/No-go para crianças com típico desenvolvimento e crianças com DCD;
- Comparar o desempenho das funções executivas em crianças com Desordem Coordenativa de Desenvolvimento (Grupo DCD), em crianças em risco DCD (Grupo r-DCD) e crianças com desenvolvimento típico (Grupo DT)**;**
- Analisar o papel preditor das habilidades motoras fundamentais e das funções executivas no desempenho da escrita e matemática em crianças com Desordem Coordenativa Desenvolvimental (DCD) e em crianças em risco para DCD (r/DCD)**.**

1.3. HIPÓTESES

1.3.1 Hipóteses - artigo 3

- Crianças com DCD e crianças com risco para DCD demonstram menor desempenho das funções executivas quando comparadas ao grupo de crianças com desenvolvimento típico

1.3.2 Hipóteses - artigo 4

- O desempenho das habilidades motoras fundamentais é preditor do desempenho das habilidades de escrita e matemática em crianças com DCD e crianças com Risco para DCD.
- O desempenho das funções executivas é preditor do desempenho das habilidades de escrita e da matemática para crianças com DCD e crianças com Risco para DCD.

1.4 JUSTIFICATIVA E RELEVÂNCIA DA PESQUISA

O diagnóstico do desempenho motor permite aos profissionais da saúde e educação identificarem os fatores que levam ao atraso motor, possibilitando a tomada de decisão sobre que habilidades e/ou critérios motores devem ser enfatizados nos programas. Da mesma forma é possível planejar o tempo de prática para cada habilidade e as metas de desempenho para cada criança (VALENTINI; RUDISILL, 2004b). Assim como é verificada a importância da avaliação motora, os resultados da avaliação neuropsicológica possibilitam recursos para a elaboração de intervenções para estimular as funções executivas em crianças, acompanhando a manutenção dos seus efeitos, principalmente no que se refere aos aspectos do desenvolvimento cognitivo e social associado ao rendimento escolar (CARDOSO et al., 2016). No entanto, observa-se a carência de investigações sobre as funções executivas e habilidades motoras fundamentais, no sentido de compreender como estas variáveis atuam como preditoras do desempenho acadêmico tanto em crianças típicas, quanto em crianças com DCD. Observa-se ainda a falta de estudos que avaliem e discutam a associação das habilidades motoras fundamentais com o desempenho das funções executivas (AADLAND et al., 2017) e sobretudo verificar a capacidade destas funções executivas em crianças com DCD e em risco para DCD.

Em atividades de intervenção motora, os processos de aprendizagem devem exigir que as funções executivas, conjunto de processos cognitivos, ajudem as crianças a conseguir focalizar e deslocar a sua atenção nas diferentes atividades, além de poder manipular a informação na memória de trabalho e desenvolver a capacidade de inibir as respostas inadaptadas para cumprir as metas propostas (CAMERON et al., 2016). As abordagens que utilizam programas de intervenção motora com demandas cognitivas em suas atividades é uma maneira efetiva de preparar as crianças para os desafios presentes e futuros em diferentes contextos (LUZ; RODRIGUES; CORDOVIL, 2014), o que justifica a necessidade de avaliar e discutir as interações entre as habilidades motoras fundamentais e o desempenho das funções executivas em crianças, sobretudo em crianças com DCD. Recentes estudos vêm discutindo as interações entre Desordem Coordenativa de Desenvolvimental e Funções Executivas em diferentes países, como por exemplo, na Inglaterra (ALLOWAY, 2011; LEONARD et al., 2015a; PRATT et al., 2014), Alemanha (MICHEL et al., 2011; MICHEL; MOLITOR; SCHNEIDER, 2016), na Austrália, Itália e Canadá (CAIRNEY; RIGOLI; PIEK, 2013; PIEK et al., 2004; RIGOLI et al., 2012a), França (BIOTTEAU et al., 2016; TOUSSAINT-THORIN et al., 2013) e Taiwan (TSAI, 2009, 2009; TSAI et al., 2012). Entretanto, este fenômeno não tem sido investigado em crianças brasileiras.

O primeiro estudo desta tese se justifica na medida em que é necessário identificar os testes/tarefas e baterias de avaliação das funções executivas (memória de trabalho, controle inibitório e flexibilidade cognitiva) já utilizados em estudos com crianças com DCD e com dificuldades motoras para identificação de quais são os instrumento de pesquisa mais utilizados, além de estabelecer melhor os critérios para as escolhas de testes/tarefas de avaliação das FE em futuros estudos.

Com relação à segunda etapa da tese de doutorado, que se refere a validação de tarefas de investigação do controle inibitório, é possível que muitos instrumentos de pesquisa utilizados para avaliação das funções executivas exigam respostas motoras ou de processamento viso-espacial complexos, os quais podem causar prejuizos na execução devido a deficiências de aspectos prímários dos intrumentos (por exemplo, viés motor de performance) e não pelo desempenho das funções executivas. Nesse sentido, este segundo estudo da tese é voltado à validação de 4 tarefas cognitivas de avaliação do controle inibitório em situações verbais e não verbais com e sem demanda motora em crianças com Desordem Coordenativa Desenvolvimental (DCD) e em crianças com desenvolvimento típico (DT)**.**

A etapa seguinte, que busca descrever e comparar o desempenho das funções executivas dos grupos (DCD, rDCD e DT) se justifica pela importancia de compreendermos de que forma as funções executivas estão associadas aos diferentes níveis de desempenho motor em crianças. Essas comparações podem auxiliar profissionais da educação e saúde a estabelecer critérios mais adequados para a avaliação e intervenção motora em crianças com diferentes níveis de desempenho das capacidades motoras. Com relação aos aspectos relacionados ao imapcto das habilidades motoras e das funções executivas no desempenho academico, esta últiam etapa do estudo se justifica pela necessidade de a capacidade preditora de cada parâmetro investigado sobre o desemneho academico de crinças nos diferentes grupos.

Várias dificuldades metodológicas e de interpretação decorrentes de estudos anteriores com funções executivas em crianças com DCD ou com dificuldades motoras foram encontradas. Para minimizar as dificuldades metodológicas e de interpretação observadas, foram adotadas algumas estratégias que envolvem aspectos metodológicos da estrutura do estudo, justificando a pesquisa.

1 - Referente à amostragem, a desordem DCD, por ser uma condição heterogênea, muitas vezes leva a identificação de grupos com uma sobreposição de diagnósticos clínicos

(LEONARD et al., 2015a). O diagnóstico DCD é feito por meio de uma síntese clínica da história (de desenvolvimento e médica), do exame físico, de relatórios escolares ou profissionais e da avaliação individual utilizando-se testes padronizados, psicometricamente adequados e culturalmente apropriados. (AMERICAN PSYCHIATRIC ASSOCIATION, 2013). A identificação de grupos de crianças denominadas grupo DCD podem apresentar sintomas subclínicos de outras condições coocorrentes tais como TDAH, Autismo ou transtornos de linguagem o que pode interferir nas associações entre varáveis motoras e cognitivas que serão investigadas. Para minimizar este possível viés da amostra, neste estudo foram utilizados na triagem instrumentos que apontem todos os 4 critérios ressaltados pelo DSM V para a identificação de crianças com DCD. Ressalta-se que deixar claro os critérios que foram utilizados para formação dos grupos neste estudo, uma vez que estes indivíduos podem demonstrar deficiências funcionais semelhantes em habilidades tais como as funções executivas ou no prórpiro desempenho academico, mas, no entanto, podem não ter sido identificados para encaminhamento clínico como crianças com DCD.

Foi utilizado, através da bateria MABC2, a identificação de grupos denominados; Grupo DCD, um segundo grupo denominado Grupo com Risco para DCD (r-DCD) e um Grupo de crianças com Desenvolvimento Típico (DT). Para o grupo DCD foram identificadas crianças que apresentem escores no teste MABC2 menor que o percentil 5, referente ao critério A que se refere à aquisição e a execução de habilidades motoras coordenadas que estão substancialmente abaixo do esperado considerando-se a idade cronológica do indivíduo. Além disso, o déficit nas habilidades motoras do critério (A) foram investigadas na medida em que estes atrasos interfiram, significativa e persistentemente, nas atividades cotidianas, causando impacto na produtividade acadêmica (critério B), e finalmente, foi investigado, a situação em que os déficits nas habilidades motoras não podem ser explicados por deficiência intelectual (por meio da aplicação do teste WASI) ou por deficiência visual, não sendo atribuíveis a alguma condição neurológica que afete os movimentos (critério D) (p. ex., paralisia cerebral, distrofia muscular, doença degenerativa). Para o Grupo de crianças r-DCD, foram identificadas crianças que apresentem escores no teste MABC2 entre o percentil 5 e 15.

2 – Percebe-se que os usos de tarefas para avaliação das funções executivas (testes/baterias) são altamente complexas e podem depender de uma série de outras habilidades cognitivas para realizá-las com sucesso (WILSON et al., 2012). A complexidade da tarefa se

refere a possibilidade de, em um mesmo teste haver outras várias funções executivas envolvidas nas tarefas, e esta falta de pureza da tarefa poderia afetar os resultados (MIYAKE et al., 2000; PIEK et al., 2007). Além disso, percebe-se que não há a replicação de baterias de avaliação entre os estudos, o que impede uma análise mais contextualizada das funções executivas em crianças com DCD. No que se refere aos aspectos instrumentais da avaliação das funções executivas, foi utilizado nesta pesquisa, uma série de testes de avaliação que já foram utilizados em outros estudos e que buscam a pureza do dado investigado, além de poder comparar dados de crianças brasileiras com crianças de outros estudos em outros contextos no mundo.

3 – Outra questão chave é que muitas tarefas para avaliação das funções executivas exigem respostas verbais, não verbais ou processamento visuo-espacial complexos com demandas motoras envolvidas, as quais podem causar prejuizos na execução (viés motor de performance ou de percepçãpo visual) e não pelas próprias funções executivas. Esta interpretação é evidenciada por (ALLOWAY, 2007, 2011; ALLOWAY; ARCHIBALD, 2008) e mais recentemente por (LEONARD et al., 2015a). Nesse sentido, foi utilizado uma bateria de tarefas de funções executivas adotando paradigmas que minimizem o viés motor da ação com relação a memória de trabalho, controle inibitório e flexibilidade cognitiva a partir de instrumentos para avaliação dos três componente, em situações verbais e não verbais com *output* motor e verbal.

4 – Uma última justificativa para abordagem metodológica utilizada nesta Tese se refere às condições de avaliação motora das crianças envolvidas no estudo. Considerando que grande parte dos estudos utiliza a bateria de avaliação MABC2 (HENDERSON; SUGDEN; BARNETT, 2007), que é uma bateria voltada, sobretudo, a identificação de grupos com desordens motoras (DCD), foi estabelecido também o uso do teste de avaliação das habilidades motoras fundamentais, *Test of Gross Motor Development* (TGMD) (ULRICH, 2000). Este teste possibilita uma inferência mais concreta das relações dos níveis de habilidades motoras fundamentais com as funções executivas das crianças envolvidas no estudo. Associações positivas foram encontradas entre as habilidades com bola no teste TGMD e as funções executivas, sobretudo a inibição de comportamento (WESTENDORP et al., 2014b). O desenvolvimento de habilidades motoras fundamentais (correr, saltar, arremssar etc.) é parte importante dos programas de intervenção (VALENTINI et al., 2016), e dessa forma justifica-se como um componente importante para avaliação das possíveis associações com as funções executiva.

2. REVISÃO DE LITERATURA

A revisão de literatura do presente projeto de tese está estruturada em seis tópicos: 1 – Funções Executivas; 2- Neuroanatomia das Funções executivas; 3 - Relação entre Desenvolvimento Motor e Funções Executivas; 4- Desordem Coordenativa Desenvolvimental e Funções Executivas; 5 – Relação entre aspectos motores/cognitivos e o Desempenho Acadêmico e 6- Desordem Coordenativa Desenvolvimental e Desempenho acadêmico. Cada tópico será apresentado a seguir.

2.1 Funções Executivas

Na perspectiva de estudos interdisciplinares cabe ressaltar que novos estudos na área da Neuropsicologia creditam importante papel às estruturas neurais para compreender como estas se organizam para auto ajustar-se nas dinâmicas situações do cotidiano das pessoas. É necessário compreender que a relação entre aspectos biológicos ontogenéticos e ambientais irão definir os processos cognitivos do comportamento humano e dentre estes processos encontram-se as funções executivas.

As funções executivas são habilidades essenciais para a saúde física e mental, capazes de influenciar o sucesso na escola e na vida, além de afetar aspectos cognitivos, sociais e o desenvolvimento psicológico (DIAMOND, 2012b). Alguns processos relacionam-se com as funções executivas, como por exemplo; a resolução de problemas, a inibição seletiva do comportamento, a seleção, a verificação e o controle de uma dada ação, a flexibilidade cognitiva e a memória de trabalho (MIYAKE et al., 2000). Estes processos cognitivos denominados de funções executivas caracterizam-se por um conjunto de habilidades que, de forma integrada, permitem ao indivíduo direcionar comportamentos a metas, avaliar a eficiência e adequação desses comportamentos, abandonar estratégias ineficientes em prol de outras mais eficientes e deste modo, resolver problemas imediatos, de médio e longo prazo (MIYAKE; FRIEDMAN, 2012). As funções executivas são formas de cognição, que tem como função a percepção e atuação do sistema nervoso central na regulação do comportamento humano (DIAMOND, 2013) e neste caso inclui-se o comportamento motor (LEONARD, 2016). Embora habilidades motoras e cognitivas sejam frequentemente estudadas separadamente, é crescente a compreensão da estreita relação entre esses domínios do desenvolvimento (LEONARD; HILL, 2015).

Em termos filogenéticos, as funções executivas parecem se desenvolver em uma relação direta com o processo de evolução humana (MALLOY-DINIZ et al., 2008) e ontogeneticamente se caracterizam por permitir ao indivíduo, ao longo de sua vida, interagir com o mundo de maneira intencional, baseando-se nas experiências prévias (MIYAKE et al., 2000). Do ponto de vista terminológico, percebem-se na literatura nomenclaturas como "funções de supervisão", "funções frontais" ou "funções de controle" (ANDRADE; SANTOS; BUENO, 2004). As funções executivas, tal como têm sido estudadas nas publicações sobre o desenvolvimento cognitivo, têm sido vinculadas às habilidades específicas de processamento de informações divididas em 3 funções principais de acordo com MIYAKE et al., (2000); (1) memória de trabalho, definida como o armazenamento e a atualização das informações enquanto o indivíduo desempenha alguma atividade relacionada com elas; (2) controle inibitório, definido como a inibição da resposta prepotente ou automatizada quando o indivíduo está empenhado na execução de uma tarefa; e (3) flexibilidade mental, definida como a capacidade de mudar a postura de atenção e cognição entre dimensões ou aspectos distintos, mas relacionados, de uma determinada tarefa (DIAMOND, 2013; MIYAKE et al., 2000), conforme percebe-se na Figura 1.

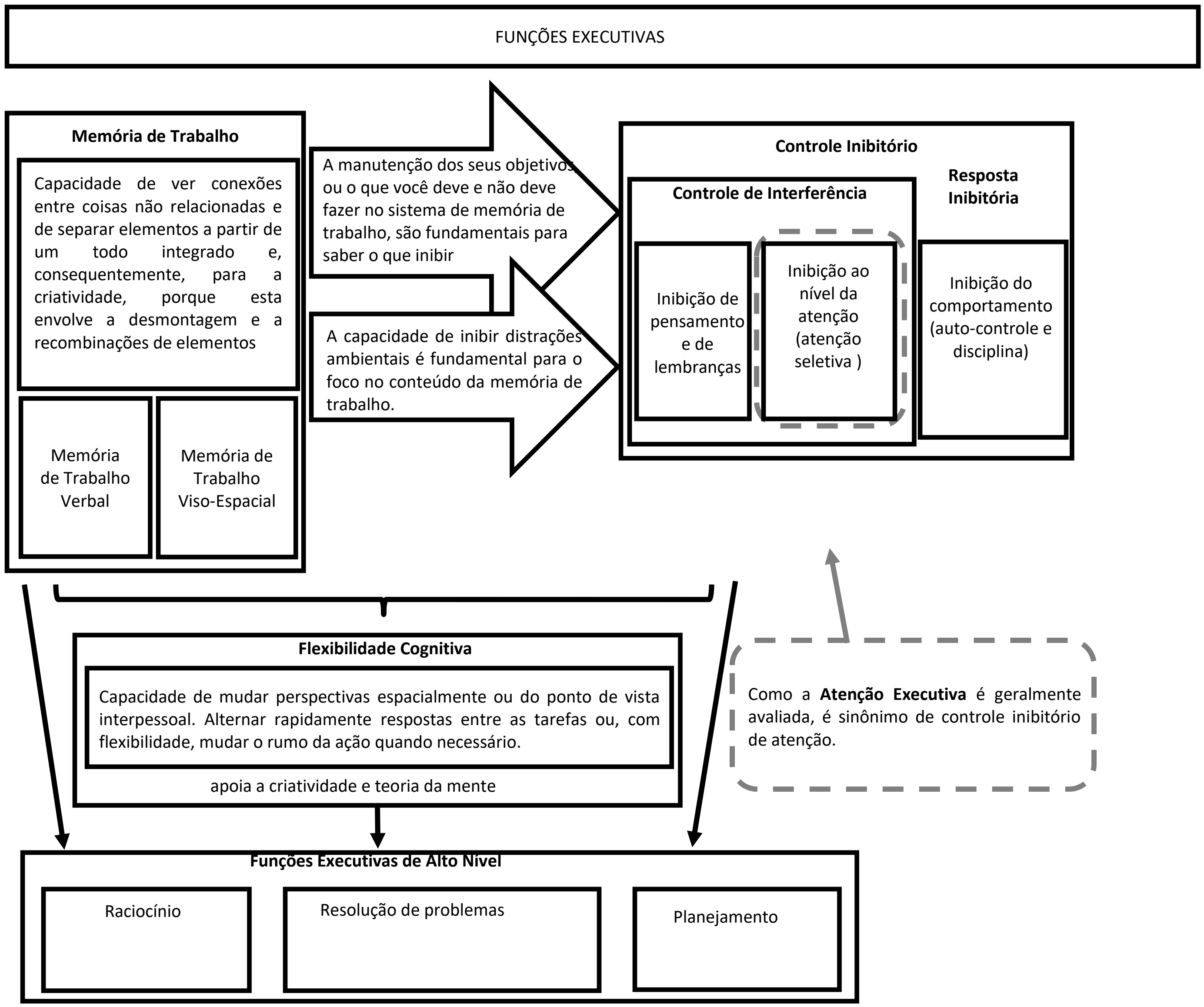

Figura 1- *Componente das funções executivas (Adaptado de Diamond, 2013).*

A memória de trabalho é um sistema temporário de armazenamento de informações ultrarrápido que permite o monitoramento e o manejo dessas informações (BADDELEY, 2003) e relaciona-se à retenção da informação em mente e à possibilidade de trabalhar mentalmente com esta informação, relacionando uma coisa a outra, ou usando pistas desta informação para resolver um problema (DIAMOND, 2013). Com relação à memória de trabalho, pelo menos dois tipos (ou subsistemas) podem ser percebidos: um para informações não verbais (também denominado visual-espacial) e outro para informações verbais (BADDELEY, 2003). Esta capacidade de retenção nos torna capazes de conectar elementos não relacionados, bem como separar elementos integrados (ALLOWAY, 2011; DIAMOND, 2012b). Estes processos de desmontagem e recombinação dos elementos mostram-se fundamentais para a criatividade, além disso, nos permitem levar o conhecimento conceitual para a tomada de decisões (DIAMOND, 2012a).

O controle inibitório refere-se à capacidade de inibir respostas tendenciosas, bem como aquelas que interrompem o curso eficaz de uma ação, especialmente as que já estão em curso (BARKLEY, 2001). Este controle está relacionado, por exemplo, à capacidade de suprimir uma resposta, mesmo quando existem estímulos internos e externos gratificantes e que, dessa forma, envolvem a capacidade de resistir às tentações e não agir de maneira impulsiva ou prematura (DIAMOND, 2000). Quando um estímulo saliente, como um movimento visual ou de um barulho alto, atrai a nossa atenção, chamamos de estímulo exógeno, no qual, de forma automática ou involuntária, a atenção orienta-se pelas propriedades destas informações ambientais em si mesmas. Por outro lado, também podemos optar por voluntariamente ignorar, ou inibir a atenção em relação a determinados estímulos e atender a outras informações, com base em nossa meta ou intenção. Esta ação, que tem sido denominada inibição de atenção endógena, ocorre de forma voluntaria. (DIAMOND, 2013).

Já a flexibilidade cognitiva, diz respeito à capacidade do indivíduo modular seus comportamentos e assim, adaptar-se a diferentes regras ou exigências de determinada tarefa (LEONARD et al., 2015b). Também pode ser referida à capacidade de mudar o curso de ações e/ou pensamentos de acordo com a exigência do ambiente (DOS SANTOS ASSEF; SEABRA; CAPOVILLA, 2007). Este capacidade sugere perspectivas de mudança ou abordagens diferenciadas para um problema, de forma flexível, ajustando-se às exigências, regras ou prioridades de cada tarefa fornecendo a base para funções de ordem superior, tais como planejamento e raciocínio (DIAMOND, 2013). A flexibilidade cognitiva aparece mais tarde em termos de desenvolvimento (DIAMOND, 2012b) quando comparada a memória de trabalho e controle inibitório. Um de seus aspectos é a capacidade de mudar perspectivas espacialmente ou do ponto de vista interpessoal (MIYAKE et al., 2000). Para mudar perspectivas, é necessário inibir (ou desativar) a nossa intenção anterior e ativar a memória de trabalho em um roteiro diferente (DIAMOND, 2013). Outro aspecto da flexibilidade cognitiva envolve a mudança sobre a forma como pensamos sobre algo. Por exemplo, se uma maneira de resolver um problema não está funcionando, podemos chegar a uma nova forma não considerada anteriormente (DIAMOND et al., 2007).

Na medida em que as funções executivas são complexas, apresentando subdomínios e relações entre suas funções, a avaliação neuropsicológica envolve tipos de procedimentos específicos para cada destas funções (PUREZA et al., 2013). A avaliação neuropsicológica das funções executivas tem despertado interesse dos pesquisadores por ser um procedimento de investigação das relações entre cérebro e comportamento, especialmente das disfunções cognitivas associadas aos distúrbios do sistema nervoso central (HAMDAN; PEREIRA, 2009). Porém, apesar dos avanços na área de investigação neuropsicológica, não se conseguiu ainda decifrar o funcionamento de nosso cérebro e todos os processos cognitivos que envolvem as inúmeras operações e funções que se desempenha para a realização de um simples gesto motor de forma assertiva.

A avaliação neuropsicológica das funções executivas (FE) tem despertado interesse dos pesquisadores por ser um procedimento de investigação das relações entre cérebro e comportamento, especialmente das disfunções cognitivas associadas aos distúrbios do Sistema Nervoso Central (HAMDAN; PEREIRA, 2009). Na avaliação neuropsicológica, a denominação FE é utilizada para designar uma ampla variedade de funções cognitivas que implicam em: atenção, concentração, seletividade de estímulos, capacidade de abstração, planejamento, flexibilidade de controle mental, autocontrole e memória operacional. Os instrumentos utilizados na avaliação neuropsicológica auxiliam no conhecimento acerca do perfil cognitivo dos sujeitos assim como na estimativa da evolução, prognóstico e o delineamento de programas de reabilitação cognitiva (FONSECA; JACOBSEN; PUREZA, 2016).

2.2 Neuroanatomia das Funções executivas

As funções cognitivas são mediadas por áreas especializadas no neocórtex, distribuídas nos hemisférios cerebrais em um arranjo ordenado. Isso já estava bem estabelecido em 1962, quando Alexander Luria publicou *Higher Cortical Functions in Man*, um livro que foi um marco na área (KANDEL et al., 2013). Do ponto de vista anatômico a localização da função executiva é no lobo frontal, mais especificamente no córtex pré-frontal (LURIA, 1966). Neurologistas da geração de Luria sabiam que lesões em determinadas áreas na superfície cortical tendem a produzir sintomas relacionados, como por exemplo, lesões no setor posterior do lobo frontal originam deficiências motoras de baixa ordem (fraqueza e paralisia) e, por outro lado, as lesões mais anteriores originam deficiências de alta ordem do controle executivo (KANDEL et al., 2013).

Anatomicamente, regiões do lobo frontal, mais especificamente no córtex pré-frontal, mostram-se extremamente importantes para o controle executivo (DIAMOND, 2013). No entanto, as funções executivas não estão restritas aos lobos frontais, os lobos parietais participam do controle atencional e o armazenamento de informações (FINN et al., 2016). O córtex pré-frontal (CPF) divide-se em 3 partes: CPF dorso lateral, córtex orbito-frontal e cingulado anterior. O CPF dorso lateral é um sistema operacional dinâmico e flexível, capaz de representar informações (KANDEL et al., 2013). Lesões desta região em humanos resultam em comportamento desorganizado e distração (KANDEL et al., 2013). As funções do córtex pré-frontal dorsolateral incluem seleção de representação necessária a uma tarefa e habilidade para ignorar distrações potenciais, além de flexibilidade cognitiva e da capacidade de registrar a memória operacional (FUENTES et al., 2014). Uma importante consequência do comprometimento desse circuito é a dificuldade em recuperar algum conhecimento aprendido, além de prejuízo no planejamento e categorização (MALLOY-DINIZ et al., 2008).

Com relação ao circuito orbito-frontal, há projeções do córtex orbito frontal para o núcleo caudado ventromedial, que recebe sinais do giro temporal superior e inferior, além do tronco encefálico (MALLOY-DINIZ et al., 2008). O córtex pré-frontal orbito-ventromedial contribui para estados motivacionais por meio da representação dos valores emocionais dos objetos que podem se tornar alvos da ação. Lesões neste córtex em humanos resultam no fracasso da avaliação das consequências esperadas de uma ação (KANDEL et al., 2013). O circuito orbito-frontal parece estar envolvido em alguns aspectos do comportamento social e emocional, além do controle inibitório e auto monitoramento (ANDRADE; SANTOS; BUENO, 2004), bem como de uma influência na memória, na atenção, na execução e nos seus subprocessos relacionados, como a inibição de comportamento (LICARI et al., 2015). O comprometimento do circuito orbito frontal gera dificuldades nos processos de tomada de decisão pela não antecipação de futuras consequências (MALLOY-DINIZ et al., 2008). As áreas pré-frontais orbital e ventromedial pertencem ao lobo límbico, são fortemente conectadas com a amígdala e com o hipotálamo e contribuem para os processos emocionais, porém outras regiões do lobo límbico não estão envolvidas primariamente com as emoções (KANDEL et al., 2013).

Outra área envolvida com o CPF é o circuito cingulado anterior que se projeta para o estriado ventral e, na sequência, para o globo pálido ventral e a substância negra rostro dorsal (MALLOY-DINIZ et al., 2008). Esta área apresenta duas funções importantes, um sistema de monitoramento da atenção para detecção de erros e a capacidade de ativar em resposta a situações de conflito, como no desempenho no teste de *Stroop* (ANDRADE; SANTOS; BUENO, 2004). Quando comparadas com crianças com desenvolvimento típico, há uma ativação mais forte do cingulado anterior nas crianças com DCD (ZWICKER; MISSIUNA; BOYD, 2009). O cingulado anterior é bem conhecido por seu papel na detecção de erros e, presumivelmente, a atividade é maior nesta região como uma compensação direta para a reduzida ativação do córtex pré-frontal (KANDEL et al., 2013).

2.3 Desenvolvimento Motor e Cognitivo na Infância: possíveis associações

As experiências de movimento desempenham um papel integral na cognição humana; a cognição depende crucialmente de possuir um corpo com uma percepção e habilidades motoras únicas e dos tipos de experiências que esse corpo proporciona (CLARK, 1997). A cognição é um produto do corpo e das maneiras pela qual ele se move e interage com o mundo (IVERSON; THELEN, 2005). Das tarefas diárias aos programas esportivos, e nas diferentes manifestações da dança, as habilidades motoras formam o mosaico da experiência humana (CLARK; METCALFE, 2002). Parece existir uma relação de ajuste entre o indivíduo e o contexto, o qual é necessário para realizar atividades funcionais (GIBSON, 1979). Dessa forma, a percepção, a cognição e o desenvolvimento motor são vistos como sistemas funcionalmente integrados (LEONARD, 2016).

A cognição é, portanto, emergente dos mesmos processos dinâmicos que regem os primeiros ciclos de percepção e ação. Atividades mentais complexas (exemplo: funções executivas, atenção, linguagem) emergem de maneira auto-organizada a partir das atividades que a criança repete em tempo real (THELEN, 1995). Consequentemente, assim como o movimento, o pensamento surge dentro da atividade contextual, histórica e especifica de um momento no tempo (THELEN, E. & SMITH, 1994; THELEN, 1995), por meio da interação do indivíduo com o mundo que o rodeia e se mantém assim ao longo do ciclo da vida (IVERSON; THELEN, 2005). Uma possível explicação para essas relações entre desenvolvimento das habilidades motoras e cognitivas reside na existência de conexões neuronais entre o cerebelo, responsável pelo controle e coordenação temporal dos movimentos, e o córtex pré-frontal, responsável, principalmente, pelas funções executivas (DIAMOND, 2000)**.** O cerebelo, o córtex pré-frontal dorso-lateral e as estruturas de conexão (incluindo os gânglios basais) são coativados durante tarefas motoras e cognitivas (HOUWEN et al., 2017). Como exemplo, percebe-se uma coativação do cerebelo durante o controle postural e, de forma análoga, para as atividades cognitivas complexas (DIAMOND, 2000).

Ainda mais, considerando que o processo de desenvolvimento motor apoia-se em uma rede complexa e interativa de estruturas neurais, o desenvolvimento das habilidades motoras é suscetível às diferentes demandas e experiencias dos contextos e relaciona-se não apenas a áreas do córtex motor, mas também está associado com áreas do processamento cognitivo (RAHIMI-GOLKHANDAN et al., 2015). As funções executivas podem ter uma sequência de desenvolvimento semelhante em relação ao curso do desenvolvimento motor em alguns períodos, além de apresentarem processos neuronais implícitos que também são comuns (VAN DER FELS et al., 2015). Não surpreendentemente, portanto, que problemas motores e cognitivos associados, muitas vezes, ocorrem em crianças com transtornos do neurodesenvolvimento (AMERICAN PSYCHIATRIC ASSOCIATION, 2013); entretanto, o conhecimento ainda é restrito sobre as bases neurais das relações entre o desempenho cognitivo e motor em crianças (GRISSMER et al., 2010).

A primeira infância é marcada por um período que possibilita muitas experiências de movimento, e compreender os processos subjacentes nas relações do desenvolvimento motor e cognitivo neste período do desenvolvimento traz implicações para os processos educacionais e também para a saúde pública. Especificamente, durante o primeiro ano de vida, no período de aquisição dos movimentos voluntários (exemplo: sentar, arrastar, engatinhar, caminhar), as funções executivas das crianças progridem rapidamente (RIGGS et al., 2006). Poucos anos depois, entre 3 e 7 anos de idade, outro impulso de desenvolvimento das funções executivas ocorre, com ênfase no controle inibitório (DIAMOND; TAYLOR, 1996; RIGGS et al., 2006), na capacidade da criança de atenção seletiva (HUMPHREY, 1982), no planejamento de ações (HUDSON; SHAPIRO; SOSA, 1995), e na memória de trabalho (ESPY et al., 1999).

Coincidentemente, este também é um período de dramáticas mudanças motoras em componentes amplos e finos do movimento. Com relação à motricidade fina, um padrão sistemático diferenciado na forma de usar instrumentos, associadas à demanda da tarefa, passa a ser observado nas crianças. Nesse sentido, observa-se uma transição de movimentos bruscos para movimentos mais suaves e com melhor monitoramento visual; gradativamente o movimento vai se tornando mais eficiente em decorrência das tentativas e erros e da prática constante (HAYWOOD; GETCHELL, 2016). Similar tendência é observada na motricidade ampla (correr, saltar, galopar, arremessar, chutar, dentre outras), com um período acelerado de aquisição de componentes motores que tornam o movimento, inicialmente mais grosseiro, em movimento coordenados e mecanicamente adaptados para otimizar a força e a velocidade (HAYWOOD; GETCHELL, 2016).

Portanto, a infância é caracterizada por extensas mudanças na estrutura, função e conectividade do cérebro. Por exemplo, entre 3 a 7 anos, o surto no desenvolvimento neural (estrutura e conectividade) incide no amadurecimento dos lobos frontais, e na melhoria das habilidades executivas associadas (GOGTAY; GIEDD; RAPOPORT, 2002). Paralelamente observa-se o período de aquisição motora diversificada mediada pelas oportunidades de práticas apropriadas. As experiências motoras das crianças neste período possivelmente estimulam os processos de aprendizagem nos diferentes contextos. Consequentemente, um estilo de vida ativo durante a infância, com oportunidades variadas de movimento, pode ter efeitos protetores no desenvolvimento cerebral. Por outro lado, a falta de movimento pode restringir alguns aspectos do desenvolvimento.

Assumindo que os lobos frontais são componentes fundamentais na rede que que sustenta as funções executivas (DIAMOND, 2012a) e que os componentes destas habilidades, como por exemplo a capacidade de inibir impulsos, desviar a atenção de uma tarefa para outra, planejar uma ação frente a um objetivo, iniciar tarefas e/ou utilizar a memória de trabalho (LURIA, 1966; PENNINGTON; OZONOFF, 1996) são, até certa extensão, inerentemente associados aos movimentos, o interesse por essa relação se expande de forma intensiva na área, principalmente na última década. Sob o ponto de vista fisiológico, o aumento do fluxo sanguíneo cerebral (aumentando a disponibilidade de nutrientes no cérebro), mudanças na distribuição de neurotransmissores (liberados depois de exercícios agudos) e aumento nos níveis de norepinefrina, epinefrina, e serotonina são exemplos de mecanismos que explicam a relação entre a atividade física e a cognição (GLIGOROSKA; MANCHEVSKA, 2012). Mudanças nas estruturas do sistema nervoso central (como aumento na vascularização cerebral e encurtamento da distância da difusão vascular) são outra possível explicação para os efeitos da atividades física nas funções cerebrais, o que tem recebido suporte de pesquisas com animais (MEDINA; RATEY; SPARK, 2008).

Embora muito se tenha avançado nas pesquisas sobre mecanismos específicos, os efeitos da atividade física e motora sobre os principais processos cognitivos e suas bases neurais ainda carecem de evidências. Por exemplo, ainda resta verificar os mecanismos subjacentes às relações e a causalidade das relações entre a prática de atividade física e das práticas motoras sistemáticas com as melhorias da função cognitiva de indivíduos em desenvolvimento (crianças e jovens). Evidências sugerem que o aumento da prática de atividades físicas (CHANG et al., 2012; DE GREEFF et al., 2018; DONNELLY et al., 2016) e motoras (KOUTSANDRÉOU et al., 2016; LUZ; RODRIGUES; CORDOVIL, 2014; WESTENDORP et al., 2011) e/ou o aumento da complexidade dos programas de atividade física em termos de criatividade e processos de tomada de decisão envolvidos na tarefa (MARCHETTI et al., 2015) poderiam estar associados a um melhor funcionamento executivo ao longo da infância.

Entretanto, tradicionalmente, pesquisadores interessados na promoção da competência motora não consideravam as funções executivas ou outros possíveis benefícios cognitivos em seus estudos, quer sejam de natureza associativa e/ou interventiva. A investigação desses fatores por muito tempo ocorreu de maneira independente (DIAMOND, 2013). O potencial clínico e educacional do entendimento da relação desses fatores na intervenção de crianças de desenvolvimento típico, com atrasos desenvolvimentistas e com deficiências é ainda pouco reconhecido.

De uma forma sequencial, as fases do desenvolvimento motor seguem um padrão relacionado à idade da criança, no entanto essas fases podem apresentar variações relacionadas ao nível maturacional e aos aspectos ambientais ocasionando uma variação de uma habilidade para outra no desempenho motor. Uma criança típica passará, com 2 e 3 anos de idade, pelo estágio inicial, no qual terá como objetivo desempenhar habilidades fundamentais. A partir deste estágio a criança desenvolverá um aprimoramento destas habilidades fundamentais adquiridas tendo um maior controle rítmico destes movimentos, nesta fase uma criança tem entre 4 e 5 anos de idade e está no estágio elementar. Com 6 e 7 anos de idade a criança entra no estágio maduro no qual desenvolve movimentos mecanicamente eficientes e com um bom nível de coordenação e controle, entretanto esse desenvolvimento é propiciado por condições ambientais e pelo nível de maturação da criança (HAYWOOD; GETCHELL, 2016). A variação que crianças apresentam no nível de maturação e no desempenho de habilidade motora se explica pelo ambiente onde ela vive (CLARK, 2007)

Por volta do primeiro ano de vida a criança já é capaz de planejar e realizar atividades mentais para alcançar uma meta ou resolver problemas. A partir desta idade o desenvolvimento destas funções evolui rapidamente. Já nos anos escolares, o progresso se destaque na capacidade de atenção, processar e reter informações monitorando assim seu comportamento. Nesta fase a criança é capaz de compreender o funcionamento da sua memória, sabendo como usá-la de maneira a facilitar seu planejamento e estratégia de lembrança (HAYWOOD; GETCHELL, 2009).

Na execução de uma tarefa temos que manter determinadas informações ativas, em contrapartida é necessário inibir outras informações irrelevantes para o sucesso da tarefa. Esta seleção de tarefas é um trabalho associado às funções executivas, filtrando informações desnecessárias (DOS SANTOS ASSEF; SEABRA; CAPOVILLA, 2007). Podendo ser considerado como um sistema de gerenciamento dos recursos cognitivo-emocionais, objetivando a solução de problemas, as funções executivas correspondem a um amplo espectro de "processos cognitivos, destacando-se o estado de alerta, a atenção sustentada e seletiva, o tempo de reação, a fluência e a flexibilidade de pensamento", assim como a memória de trabalho e o controle inibitório.

Nesse sentido, o papel das funções executivas é de extrema importância, sendo fundamental ao desenvolvimento adequado do controle motor, da fluência das etapas do planejamento, da regulação do *self* (impulsividade), e do funcionamento adaptativo em busca de determinado objetivo. Déficits nesta habilidade cognitiva podem significar falhas na capacidade de obedecer a instruções, regras e limites, comprometendo a socialização, além do comprometimento do funcionamento executivo, compreendendo a habilidade para manter um esquema para a solução de um determinado problema e a sequência planejada para realizá-lo, criando a representação mental da tarefa, sua execução e o monitoramento dos procedimentos. (DIAMOND et al., 2012)

2.4 Desordem Coordenativa Desenvolvimental e Funções Executivas

As ações motoras e funcionamento executivo são subordinados por conexões estruturais e funcionais subjacentes entre cortex parietal, córtex pré-frontal e o cerebelo (DIAMOND, 2013).

Em crianças com desordem cordenativa de desenvolvimento, essas estruturas apresentam uma reduzida conectividade funcional no âmbito destas redes (ZWICKER et al., 2011), ou então, um imaturo acoplamento entre áreas de controle frontal e posterior (RUDDOCK et al., 2015). Estes processos poderiam explicar as dificuldades motoras observadas em crianças com DCD (LEONARD, 2016).

Indivíduos com dificuldade de movimento apresentam associações com os três principais componentes das funções executivas; na memória de trabalho (ALLOWAY; ARCHIBALD, 2008; ALLOWAY; TEMPLE, 2007; BIOTTEAU et al., 2016; DYCK; PIEK, 2010a; GIOFRÈ; CORNOLDI; SCHOEMAKER, 2014; LEONARD et al., 2015b; MICHEL et al., 2011; PIEK et al., 2004; TSAI et al., 2012; WILLIAMS et al., 2013) os estudos de maneira geral apontam associação da memória de trabalho com o desempenho motor em crianças com DCD e também em crianças com dificuldades motoras; O controle inibitório (CHEN; WILSON; WU, 2012a; LEONARD et al., 2015b; LIVESEY et al., 2006; MANDICH; BUCKOLZ; POLATAJKO, 2002, 2003; PRATT et al., 2014; QUERNE et al., 2008; RAHIMI-GOLKHANDAN et al., 2014a; TSAI, 2009) também apresenta associações positivas deste domínio das funções executivas com os aspectos motores tanto em crianças com DCD quanto em crianças com dificuldades motoras; e na flexibilidade cognitiva (LEONARD et al., 2015b; MICHEL et al., 2011; PIEK et al., 2007; WUANG; SU; SU, 2011) sugerem também associações positivas, no entanto, ainda existem poucos estudos que investigam este domínio da função executiva em crianças com dificuldades de movimento ou crianças com DCD.

Em uma meta análise elaborada por (WILSON et al., 2012) investigando funções executivas em crianças com DCD, percebe-se o prejuízo destas funções cognitivas. Ao comparar os resultados da FE percebe-se que o grau de disfunção nas funções executivas tem sido maior em crianças com DCD do que em crianças com Transtorno de Deficit de Atenção e Hiperatividade (TDAH) e também maior com relação às crianças com desenvolvimento típico (ALLOWAY, 2011).

A variabilidade de deficits das funções executivas em crianças com DCD leva a reconsiderar problemas na maturação cortical geral (WILSON et al., 2012). Neste caso, existem duas possibilidades inter-relacionadas sobre mecanismos que explicam as desordens associadas a Desordem Coordenativa de Desenvolvimento; em primeiro lugar, os sistemas cognitivos e neuromotores tiveram prejuízos no seu processo de maturação do processo biológico e, em segundo lugar, os sistemas neurais emergentes não foram estimulados o suficiente (via experiências de aprendizagem adequadas), de forma que promovam o acoplamento entre sub-sistemas especializados (RAHIMI-GOLKHANDAN et al., 2015). Nesse sentido, não são oferecidas experiências de aprendizagem (ou seja, estimulação) que possam permitir conexões neurais eficientes para formar os subsistemas cada vez mais especializados (WILSON et al., 2012).

Enquanto essas habilidades cognitivas complexas (memória de trabalho, controle inibitório e flexibilidade), tradicionalmente, têm sido relacionadas com o funcionamento do córtex pré-frontal, há cada vez mais evidências de conexões estruturais e funcionais entre o córtex pré-frontal e o cerebelo (LEONARD et al., 2015a). Em um estudo com crianças com DCD, os resultados indicaram menor ativação no córtex pré-frontal dorsolateral em comparação com o grupo de crianças típicas. Estes achados sugerem que hipoativação na rede de atenção pode impactar os mecanismos subjacentes envolvidos com planejamento motor observado em crianças com DCD (BROWN-LUM; ZWICKER, 2015). Há relativamente pouco conhecimento sobre as bases neurais da disfunção motora em crianças com DCD, embora se saiba que a baixa ativação do circuito relacionado ao córtex pré-frontal dorso lateral durante a prática de uma tarefa motora (ZWICKER et al., 2011) pode estar relacionada com a dificuldade que indivíduos com DCD têm em adquirir novas habilidades motoras (GEUZE, 2005).

Já em relação ao cerebelo, é importante ressaltar que este orgão não está apenas envolvido aos aspectos relacionados com o movimento, mas também para as funções executivas (MARIËN; VAN DUN; VERHOEVEN, 2015; PICAZIO; KOCH, 2015; STOODLEY, 2012; STOODLEY; LIMPEROPOULOS, 2016). Achados clínicos anatômicos em pacientes com DCD revelam perturbações na rede cerebelo-cerebral como uma possível explicação para o distúrbio (ZWICKER et al., 2012b). Dificuldades na realização de habilidades motoras de forma automática estariam associadas a alterações cerebelares (KASHIWAGI; TAMAI, 2013). Esta hipótese conduz à especulação que alterações nas redes que envolvem o cerebelo podem explicar os problemas de coordenação motora em crianças com DCD (BROWN-LUM; ZWICKER, 2015). O cerebelo recebe uma cópia eferente do comando motor e compara o movimento previsto com o movimento real. Se houver incompatibilidade, o cerebelo envia um sinal de erro como retroalimentação para criar um movimento mais preciso (ZWICKER et al., 2012b). A capacidade de adaptação envolve a modificação de ações motoras aprendidas em resposta a alterações do ambiente. Estas adaptações ocorrem por meio da atualização dos modelos internos (representações neurais) de movimento, localizados dentro do cerebelo e baseados em sinais de erro que são identificados (MARIËN; VAN DUN; VERHOEVEN, 2015).

O cerebelo desempenha um papel único na adaptação, especialmente para o armazenamento de representações sensório-motores de longo prazo (BO; LEE, 2013). Uma explicação para a hipótese cerebelar ser uma das causas dos sintomas em crianças com DCD é que este órgão parece se desenvolver relativamente mais tarde e de forma mais lenta do que a maioria das outras regiões do cérebro (BO; LEE, 2013; BROWN-LUM; ZWICKER, 2015), por exemplo, os volumes de matéria cinzenta no córtex premotor, córtex pré-frontal e cerebelo correlacionam-se positivamente com funções executivas em adultos (KANDEL et al., 2013). Consequentemente, pode-se supor que as crianças com desenvolvimento motor tardio devem ter funções executivas relativamente pobres quando adultos (RIDLER et al., 2006). Uma possível explicação pode ser que as crianças cujas habilidades de locomoção se desenvolvem precocemente têm mais oportunidades de treinar atividades auto-reguladas, o que por sua vez ajuda a promover o desenvolvimento de funções executivas (MICHEL; MOLITOR; SCHNEIDER, 2016).

O lobo parietal e suas conexões também desempenham um papel crítico em numerosas funções cognitivas, particularmente no controle sensorial de ação motora (ISHII-TAKAHASHI et al., 2014). Evidências sugerem que o lobo parietal pode estar implicado em crianças com DCD devido a seu papel primordial no processamento de informações viso-espaciais (KASHIWAGI; TAMAI, 2013). Crianças com DCD demonstraram menor ativação nas redes cerebelar-pré-frontal e parietal-cerebelar, bem como em regiões do cérebro associadas com aprendizagem visuoespacial (ZWICKER et al., 2011). Um estudo realizado por meio de ressonância magnética funcional com crianças com DCD indicou redução da conectividade entre estriado e lobo parietal inferior durante uma tarefa de controle inibitório *Go/no-go* (ZWICKER; MISSIUNA; BOYD, 2009). Crianças com DCD mostraram também, em um estudo com ressonância magnética funcional, que houve menor ativação no lobo parietal superior esquerdo (SPL), no lobo parietal inferior esquerdo (IPL) e no giro pós-central esquerdo durante tarefas viso-motoras (KASHIWAGI; TAMAI, 2013). Já um estudo sobre a aprendizagem processual em crianças com DCD apontou que as bases neurocognitivas da desordem de movimento podem ser localizadas no lobo parietal (WILSON et al., 2012). Um estudo com crianças com DCD, através de ressonância magnética funcional, apontou uma diminuição da ativação no giro frontal superior esquerdo (SFG) em tarefas de sequencia motora em crianças com DCD (ZWICKER et al., 2011), indicando que as crianças com DCD potencialmente tem um deficit nesta região.

Tanto o cerebelo quanto o córtex posterior parietal estão envolvidos em funções motoras e executivas, mediando uma variedade de processos neurocognitivos, como memória de trabalho, atenção, percepção e aprendizagem verbal (FERNANDES et al., 2016). Esta rede é especialmente ativada, ao executar uma tarefa motora complexa, uma nova tarefa ou uma condição de mudança de tarefa (Fernandes et al. 2016), o que caracteriza de forma clara as relações entre o funcionamento cognitivo e motor. Esta relação entre o comportamento motor e os aspectos do funcionamento cognitivo, através das funções executivas como base para compreensão dos processos de aprendizagem no contexto educacional e esportivo é o foco do presente estudo.

2.5 Relação entre aspectos motores/cognitivos e o desempenho acadêmico

Dificuldades em atingir as expectativas da idade para o desempenho acadêmico em sala de aula e dificuldades em executar as habilidades de movimento fundamental com o mesmo nível de proficiência que seus pares aponta para como aspectos que mostram a interdependencia entre os aspectos motores e cognitivos do desenvolvimento. As habilidades motoras fundamentais estão associadas a uma variedade de habilidades acadêmicas e comportamentais, incluindo decodificação de letras e palavras, resolução de problemas quantitativos, escrita e interação efetiva com colegas e adultos (WESTENDORP et al., 2011). As habilidades motoras não são apenas os movimentos em si, mas incluem os processos cognitivos que dão origem aos movimentos. As habilidades motoras, incluindo as habilidades perceptivo-motora e sensório-motora, implicam a interação dos sistemas de movimento com o sistema cognitivo (DIAMOND, 2012b, 2013).

O comportamento bem-sucedido na sala de aula é complexo e requer processos perceptuais e funções executivas, que se inter-relacionam e desenvolvem um sobre o outro (CAMERON et al., 2016). Aspectos específicos das funções executivas, como memória de trabalho viso espacial e controle inibitório são indiretamente ativados para recuperar imagens e suprimir respostas impulsivas durante tarefas que envolvem estas funções (BADDELEY, 2003).

Essas habilidades são essenciais para a escrita em particular e para a aprendizagem em geral, e estão diretamente relacionadas ao desempenho acadêmico (GRISSMER et al., 2010).

Em um estudo que envolveu variáveis motoras e cognitivas em crianças, o melhor preditor relacionado ao desempenho acadêmico foi a coordenação motora (FERNANDES et al., 2016). A correlação entre coordenação motora e desempenho escolar, verificada neste estudo, parece estar relacionada à própria capacidade de execução da habilidade motora por seus aspectos cognitivos inerentes à tarefa executada e também à percepção visual necessária para a identificação e localização de objetos. Nesse sentido ressalta-se que a coordenação viso motora e a atenção seletiva visual, podem influenciar o desempenho acadêmico (FERNANDES et al., 2016). Ao examinar se a relação entre coordenação motora e realização acadêmica é mediada pela memória de trabalho em uma amostra de adolescentes RIGOLI et al., (2012b) sugerem que a associação entre desempenho motor e desempenho acadêmico (especificamente, Leitura de Palavra e Operações Numéricas) pode ser melhor compreendido quando intermediado pela memória de trabalho. Consequentemente argumenta-se que o desempenho motor pode ser crucial na identificação de crianças em risco de insucesso acadêmico (RIGOLI et al., 2012b). Tanto as habilidades motoras finas quanto as grossas também foram positivamente associadas com o desempenho de matemática e leitura (GEERTSEN et al., 2016). Pode se perceber que menor tempo para completar o teste de habilidade motora grossa e maior precisão no teste de habilidade motora fina apresentaram correlações com o desempenho acadêmico (GEERTSEN et al., 2016).

O desempenho acadêmico é um fator complexo de medida (PRUNTY et al., 2016) e por esse motivo parece existir uma lacuna na análise da relação entre habilidades de movimentos fundamentais (HMF) e desempenho acadêmico. As habilidades motoras fundamentais representam uma série organizada de movimentos básicos que envolvem a combinação de padrões de movimento de duas ou mais partes do corpo (JAAKKOLA et al., 2015). Ao analisar pesquisas relacionadas ao desempenho acadêmico, permanece incerto se o domínio das habilidades motoras fundamentais tem uma relação positiva com o desempenho escolar em crianças com DCD. No entanto, quando investigadas estas associações entre habilidades motoras fundamentais e desempenho escolar em crianças com desenvolvimento típico encontrou-se associação positiva entre as variáveis (JAAKKOLA et al., 2015; WESTENDORP et al., 2011). Ao analisar as associações longitudinais entre as habilidades motoras fundamentais e desempenho acadêmico, os resultados indicaram que as habilidades motoras fundamentais na 8ª série previam o desempenho acadêmico na 9ª série (JAAKKOLA et al., 2015). Estes resultados também foram encontrados em um estudo na Holanda (WESTENDORP et al., 2014a). A proficiência das habilidades motoras fundamentais facilitam o funcionamento cognitivo das crianças no que se refere ao desempenho escolar (MURRAY et al., 2006) e, mais especificamente, apontam que as correlações verificadas entre as habilidades motoras grossas e finas com os níveis de matemática eram significativamente maiores do que com a leitura (SON; MEISELS, 2006).

Com relação às associações entre o desempenho escolar e a utilização do teste TGMD que investigas as variáveis de controle de objetos e locomoção, pode se perceber que crianças de 7 a 11 anos com dificuldades de aprendizagem, submetidos a um programa de intervenção de habilidades com bola, apontou uma relação positiva entre a alteração no desempenho do domínio controle de objetos e mudanças positivas na resolução de problemas escolares (WESTENDORP et al., 2014a). Crianças com dificuldades de aprendizagem, com idades entre 6 e 8 anos, obtiveram escores mais baixos em ambos os domínios; controle de objetos e locomoção (WOODARD; SURBURG, 2001). Além disso, ZHANG (2001) encontrou crianças entre 6 e 10 anos com dificuldades de aprendizagem que também apresentaram menor pontuação nos testes de locomoção e controle-objeto em relação aos dados normativos de TGMD-2. Ao comparar as habilidades motoras fundamentais de crianças de 7 a 12 anos com dificuldades de aprendizagem com um grupo controle utilizando o TGMD2, os tamanhos de efeito obtidos indicam que a diferença entre o desempenho do grupo com dificuldades de aprendizagem e o grupo controle era maior para os itens relacionados ao controle de objeto TGMD-2 do que para os itens locomotores. Pode se perceber que quanto maior o atraso de aprendizagem na leitura, menor o desempenho locomotor (WESTENDORP et al., 2011).

2.6 Desordem Coordenativa Desenvolvimental e Desempenho acadêmico

Relações entre os aspectos motores e o desempenho acadêmico em crianças com Desordem Coordenativa Desenvolvimental também são importantes como elementos de suportes à programa de intervenção e identificação de desordens motoras e de aprendizagem. As crianças com DCD parecem ter problemas motores e cognitivos que são propensos a ser associados com problemas de aprendizagem em diferentes áreas acadêmicas e com risco significativo de ter fracasso escolar (ASONITOU et al., 2012). Os déficits cognitivos de planejamento e atenção no grupo de crianças com DCD podem indicar uma relação com um desempenho acadêmico deficiente (por exemplo, problemas em matemática ou compreensão de leitura) (SUMNER; PRATT; HILL, 2016). Esses déficits demonstram a necessidade de uma intervenção sistemática para melhorar a maneira como essas crianças processam a informação em contextos de aprendizagem. A identificação precoce das dificuldades cognitivo-motoras pode ser essencial para a intervenção nas áreas motoras e acadêmicas (ASONITOU et al., 2012).

Dificuldades em tarefas escolares podem afetar negativamente a realização acadêmica em crianças com DCD, por exemplo, copiar, desenhar, pintar, imprimir, manusear, usar tesouras, organizar e terminar o trabalho no tempo. A participação nas aulas de educação física também pode ser afetada, pois as crianças com DCD têm dificuldade em jogar, pegar ou chutar uma bola, correr, pular e praticar esportes. Apesar de apresentarem escores na média ou até acima da média no que se refere à inteligência, as crianças com DCD têm resultados escolares mais pobres do que os seus pares (ZWICKER et al., 2012a; ZWICKER; MISSIUNA; BOYD, 2009). Evidências indicam que a memória de trabalho visuoespacial está intimamente relacionada ao desempenho acadêmico em crianças com DCD (ALLOWAY, 2007, 2011; ALLOWAY; ARCHIBALD, 2008) o que pode ser uma hipótese para explicar o baixo desempenho acadêmico em crianças com DCD.

Dados de um estudo mostram que cerca de metade do grupo de crianças com DCD apresentou déficits de memória diária, principalmente em tarefas de memória verbal e visual (CHEN; WILSON; WU, 2012b). Os resultados têm algumas implicações importantes, pois embora a complexidade das atividades diárias envolva vários domínios de memória, crianças com DCD precisam de assistência em atividades que exigem mais habilidades verbais (CHEN et al., 2013; CHEN; WILSON; WU, 2012b) o que justificaria a dificuldades em determinadas tarefas escolares.

Crianças com DCD apresentaram baixas habilidades de memória visuoespacial e resultados significativamente piores em subtests de operações numéricas (adição, subtração, divisão, multiplicação, frações e álgebra) e no raciocínio matemático (de Wechsler Objective Numerical Dimensions) quando comparadas com crianças que tiveram melhores resultados em habilidades de memória visuoespacial (VAIVRE-DOURET, 2014; VAIVRE-DOURET et al., 2011). Com relação à capacidade de leitura e escrita as crianças com DCD apresentaram uma porcentagem mais elevada de erros de soletração durante a tarefa da escrita (PRUNTY et al., 2016). As dificuldades na transcrição têm implicações reais na qualidade do texto produzido pelas crianças (PRUNTY et al., 2016) o que levaria as dificuldades de aprendizagem no contexto escolar.

2.7 Definição Operacional das Variáveis

2.7.1 *Habilidades motoras fundamentais*.

Neste estudo será avaliado como as crianças coordenam partes do corpo, por exemplo, como o tronco e membros se organizam durante o desempenho de uma habilidade motora. Nesse sentido a avaliação dos padrões de movimento permitem verificar a presença ou não dos componentes de diferentes habilidades (ex.: se a aproximação da bola é rápida e contínua no chute) ao invés de avaliar prioritariamente o produto final do desempenho (ex.: distância saltada, número de acertos na recepção de uma bola). Para esta avaliação será utilizado O teste *TGMD-2* desenvolvido por ULRICH, (2000).

2.7.2 *Funções executivas*.

Caracterizam-se por um conjunto de habilidades que, de forma integrada, permitem ao indivíduo direcionar comportamentos a metas, avaliar a eficiência e adequação desses comportamentos, abandonar estratégias ineficientes em prol de outras mais eficientes e deste modo, resolver problemas imediatos de médio e longo prazo (MIYAKE; FRIEDMAN, 2012). Neste estudo será considerado como função executiva seus três principais componentes; a memória de trabalho, o controle inibitório e a flexibilidade cognitiva (MIYAKE et al., 2000).

2.7.3 *Desempenho escolar*

É uma medida das capacidades do estudante, que expressa a aprendizagem ao longo do processo formativo no contexto escolar. Também abarca a capacidade do aluno em responder aos estímulos educativos. Nesse estudo será utilizado o teste de desempenho escolar II (TDE II) que é composto por três subtestes que avaliam as capacidades básicas para o desempenho escolar:

leitura, escrita e aritmética. A proposta desse instrumento é que os subtestes apresentem uma escala de itens em ordem crescente de dificuldade, os quais devem ser apresentados para as crianças independente de seu ano escolar.

2.7.4 *Desordem coordenativa Desenvolvimental.*

É uma desordem de habilidades motoras que afeta cinco a seis por cento de todas as crianças em idade escolar. A relação entre meninos e meninas varia de 2: 1 a 5: 1, dependendo do grupo estudado. Ocorre quando um atraso no desenvolvimento de habilidades motoras, ou dificuldades na coordenação dos movimentos, resultando em uma incapacidade de executar tarefas diárias. Por definição, as crianças com DCD não têm uma condição médica ou neurológica identificável que explique os seus problemas de coordenação. Os seguintes critérios são necessários para um diagnóstico de DCD: A) a aprendizagem e a execução de habilidades motoras estão abaixo do nível esperado para a idade, dada a oportunidade para a aprendizagem de habilidade; B) as dificuldades de habilidade motora interferem significativamente nas atividades da vida diária e afetam o desempenho acadêmico e as atividades de lazer; C) o início é no período precoce de desenvolvimento; D) as dificuldades de habilidade motora não são melhor explicadas por atraso intelectual, deficiência visual ou outras condições neurológicas que afetam o movimento (AMERICAN PSYCHIATRIC ASSOCIATION, 2013).

CAPÍTULO 3

Artigo 1: Assessment of executive functioning in children and adolescents with Developmental Coordination Disorder and poor motor skills: a systematic review.

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Abstract

Objective: The aim of this study was to describe the tests/tasks used to assess working memory, inhibition and cognitive flexibility, and to identify the main results of studies investigating the executive functions in children and adolescents with Developmental Coordination Disorder (DCD) or who are at risk of DCD and/or with poor motor skills. This review was registered with the international prospective register of systematic reviews PROSPERO network. Data sources: MEDLINE (accessed by PubMed), *Web of Science*, APA PsycNET, *EMBASE* and Google Scholar since the start of base until the 14th of September 2017. Setting: Observational studies (cross-sectional, cohort and case-control studies) with exposed and unexposed groups. Participants: children and adolescents, from 5 to 16 years old, with DCD, risk of DCD, or poor motor skills. Quality appraisal was conducted using the Newcastle Ottawa Scale. Results: After the selection process, of the 1475 papers found, 29 matched the review criteria. 31 different Executive Function tests/tasks used for children with DCD or poor motor skills were found. Sample sizes with DCD or poor motor skills ranged from 11 to 71 participants with samples from England, Germany, Australia, Italy, Canada, France, Finland, Taiwan, and the USA. Across the 29 studies included in this systematic review: 11 studies examined only the working memory; 10 studies measured only inhibition; a single study measured only cognitive flexibility; 2 studies examined the working memory and inhibition; 1 study examined inhibition and cognitive flexibility; 1 study examined working memory and cognitive flexibility; and 3 studies that examined the three constructs of EF, such as working memory, inhibition and cognitive flexibility. In conclusion, many tasks were used to evaluate the executive functions presented in

studies with DCD. In those tests or tasks children require verbal, nonverbal or complex visuo-spatial processing, with or without motor demand involved. In some cognitive tasks, these different demands or different types of stimulus involved in tests may cause secondary loss in execution. The executive functions in children with DCD or poor motor skills shows that EF deficits are wide ranging, extending across basic functions measured (working memory, inhibition, and cognitive flexibility). The pervasive and persistent nature of the executive function deficits suggests a heightened focus on this issue in future research.
Keyword: working memory, inhibition, cognitive flexibility, DCD and poor motor skill.

Rationale

Children with delays in the motor milestones and with difficulty in the execution of motor tasks, especially those involved in daily activities and that rebound in school matters related to learning, are diagnosed with the term Developmental Coordination Disorder (American Psychiatric Association, 2013). Difficulties in the coordination and the control of movements, and delays in the motor behavior are reported in children who possibly have this disorder related to movement (Valentini et al., 2012; Wilson, Ruddock, Smits-Engelsman, Polatajko, & Blank, 2012; Zwicker, Missiuna, Harris, & Boyd, 2012).

The Developmental Coordination Disorder (DCD) can present itself in a more isolated manner, with the child showing difficulties in executing basic motor abilities (Valentini, Clark, & Whitall, 2014), or even being associated to cognitive difficulties in reading or mathematics (Alloway, 2007), as well as perceived in the organization and planning of the movement (Brown-Lum & Zwicker, 2015; Zwicker et al., 2012). Consequently, the social and emotional dimensions in the development are affected (Cairney, Rigoli, & Piek, 2013), as well as the motor function (Valentini et al., 2012) and the academic (Asonitou, Koutsouki, Kourtessis, & Charitou, 2012; Gomez, Piazza, & Jobert, 2015) and/or cognitive development (Leonard, Bernardi, Hill, & Henry, 2015a).

From a neuropsychological perspective, the narrow relation between motor and cognitive variables can be explained when the cerebral areas which specialize themselves in the motor control show neural activation during the execution of certain cognitive tasks (Diamond, 2000). Moreover, evidences suggest that there is a relation between the delay in motor and cognitive development, specifically relating delays in motor aspects with deficits in some executive functions (Leonard et al., 2015a; Michel, Molitor, & Schneider, 2016; Piek et al., 2004; Wilson et al., 2012).The executive functions are cognitive processes which are characterized by a group of abilities that, in an integrated manner, allow the individual to direct behaviors to goals, evaluate the efficiency and adequacy of these behaviors, abandon inefficient strategies in favor of some other that is more efficient, and thus solve immediate problems of medium and long term (Miyake & Friedman, 2012). These executive functions are types of cognition which have as an attribute the perception and execution in the nervous system in regulating human behavior (Diamond, 2013) and in this case motor behavior is included (Leonard, 2016). These abilities execute actions such as the solution of problems, the selective inhibition of behavior, the verification and control of a given action, the cognitive flexibility, and working memory (Miyake et al., 2000). The executive functions, as they have been studied in publications about cognitive development, have been linked to specific abilities of processing information and are divided in three main functions (Miyake et al., 2000): (1) working memory, defined as the storing and updating information while the individual does some activity related to them; (2) inhibitory control, defined as the inhibition of automatized response when the individual is engaged in the execution of a task; (3) cognitive flexibility, defined as the ability of changing the focus of attention and cognition between dimensions or distinct aspects, but related to a given task (Diamond, 2013; Miyake et al., 2000).These functions rely on other cognitive components such as attention, planning, the initiation and inhibition of processes and the monitoring of multiple tasks and actions (Pureza, Jacobsen, Grassi-Oliveira & Fonseca, 2011).

The identification of motor and executive function deficits in children is essential to the development of interventive programs that have the goal of potentializing the development of new abilities, minimizing difficulties already established and/or developing new learning strategies in different contexts. Recent studies have been arguing the interaction between Developmental Coordination Disorder with executive functions in different countries such as England (Alloway, 2011; Leonard & Hill, 2015; Pratt, Leonard, Adeyinka, & Hill, 2014), Germany (Michel et al., 2016; Roebers et al., 2014), Australia, Italy and Canada (Cairney et al., 2013; Rigoli et al., 2013; Rigoli, Piek, Kane, & Oosterlaan, 2012a), France (Biotteau, Albaret, Lelong, & Chaix, 2016; Toussaint-Thorin et al., 2013), and Taiwan (I. Chen, Tsai, Hsu, Ma, & Lai, 2013; Tsai, Chang, Hung, Tseng, & Chen, 2012; Tsai, Pan, Chang, Wang, & Tseng, 2010). This study justifies itself by searching to identify the different tasks or tests of these executive functions used in studies with children with DCD or poor motor skill.

The literature has been highlighting the use of tests/tasks that are highly complex or that cover more than one components of the executive functions which can depend on a series of other cognitive abilities to be performed successfully (Leonard & Hill, 2015; Wilson et al., 2012). Another aspect is that, depending on the complexity of test/task, the research instruments can evaluate various executive functions, and this lack of purity in the task can affect the results (Leonard et al., 2015a; Piek, Dyck, Francis, & Conwell, 2007). Besides that, a verification is yet to be done to see if there is a replicability of each test/task applied in children with DCD or with motor difficulties. Another aspect that should be mentioned as the justification for this study is that many evaluation tasks of executive functions demand motor responses or complex visuospatial processing, which can worsen the execution due to deficiencies of motor behavior, presenting a motor performance bias instead of the actual executive functions. This interpretation is evidenced in a series of studies related by Tracy Alloway (Alloway, 2011, 2013; Alloway, Gnanathusharan, & Archibald, 2009) and more recently by Hayley Leonard (Leonard et al., 2015a). The necessity is highlighted to verify the characteristics of these neuropsychological tests and tasks used to evaluate executive functions and the results of evaluations which have already been investigated in studies with children with DCD or with children with motor difficulties. Thus, there is more clarity of which instruments should be used to study executive functions in children with DCD.

Review question(s)

The aim of this study was to was to describe the tests/tasks used to assess working memory, inhibition and cognitive flexibility, and to identify the main results of studies investigating the executive functions in children and adolescents with Developmental Coordination Disorder (DCD) or who are at risk of DCD and/or with poor motor skills.

Methods

This review is registered with the international prospective register of systematic reviews PROSPERO network (http://www.crd.york.ac.uk/prospero/): Registration CRD42016047299. This is a systematic review study conducted according to the methods *Preferred Reporting Items for Systematic Reviews and Meta-Analyses* (PRISMA)(Moher, Liberati, Tetzlaff, & Altman, 2009).

All the original studies that investigated using tests/tasks of the executive function phenomena in children and adolescents with Developmental Coordination Disorder (DCD) or poor motor skills were eligible for this systematic review. We used the acronyms PECOT

(Population, Exposure, Comparing, Outcome and Type of study) in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Protocols **(**PRISMA-P) as an auxiliary in the inclusion of studies. We included studies if they were: **(P) Population:** children and adolescents, from 5 to 16 years old, with Developmental Coordination Disorder or poor motor skills. We also adopted, as the population for this systematic review, children with "probable" DCD (Bo et al., 2014; Jelsma, Ferguson, Smits-Engelsman, & Geuze, 2015; Joshi et al., 2015). These children have shown poor motor performance, but other criteria for DCD from the Diagnostic and Statistical Manual of Mental Disorder V (DSM V) was not evaluated or reported by these studies; **(E) Exposure:** instruments or procedures of clinical evaluation that were described to evaluate the three main components of the executive functions (working memory, inhibition or cognitive flexibility) (Miyake et al., 2000) in children and adolescents with DCD or poor motor skills; **(O) Outcome:** measurements of the executive function capacity that were found in working memory, inhibition control and cognitive flexibility assessments in children and adolescents with DCD or poor motor skills; **(T) Type of study:** For the effect of this analysis, we included observational (i.e. cohort, case-control or cross sectional) or interventions.

We excluded articles if they; (1) do not show assessment of clinical instruments (tests or tasks) or procedures to evaluate the working memory, inhibition, or cognitive flexibility; (2) executive function studies, but with other developmental disorder (i.e. cerebral paralysis, muscular dystrophy); (3) case studies, comments, case series, editorial and replies; (4) duplicate studies.

We conducted a systematic review regarding the measurements (tests/tasks) of working memory, inhibition and cognitive flexibility in children with DCD or poor motor skills. We researched the following electronic databases: MEDLINE (accessed by PubMed), *Web of*

Science, APA PsycNET, *EMBASE* and Google Scholar until the 14th of April 2017. For the research strategy**,** we used the logic based in specific descriptors, vinculated to Boolean operators (AND & OR) and the help of parenthesis to delimitate intercalations within the same logic. Using the Boolean operators and quotation marks for the words or compound terms, the following keywords were used for the searches made separately for each of the components of the executive functions. For **Working Memory and DCD or Poor Motor skills** ("Developmental Coordination Disorder"[All Fields] OR "Motor Disorder"[All Fields] OR "DCD"[All Fields] OR "Dyspraxia"[All Fields] OR "Motor Skill disorder" OR "poor motor skill" [All Fields]) AND "working memory"[All Fields] OR "visuospatial working memory"[All Fields] OR "verbal working memory"[All Fields]); For **Inhibition and DCD or Poor Motor skills** ("Developmental Coordination Disorder"[All Fields] OR "Motor Disorder"[All Fields] OR "DCD"[All Fields] OR "Dyspraxia"[All Fields] OR "Motor Skill disorder" OR "poor motor skill" [All Fields]) AND ("Inhibitory control"[All Fields] OR "inhibitory function"[All Fields] OR "Response inhibition"[All Fields] OR "Inhibitory controls"[All Fields] OR "inhibition"[All Fields]); For **Cognitive Flexibility and DCD or Poor Motor skills** ("Developmental Coordination Disorder"[All Fields] OR "Motor Disorder"[All Fields] OR "DCD"[All Fields] OR "Dyspraxia"[All Fields] OR "Motor Skill disorder" OR "poor motor skill" [All Fields]) AND ("cognitive flexibility"[All Fields] OR "Flexible cognition"[All Fields] OR "Shifting"[All Fields] OR "Set-shifting"[All Fields] OR "mental flexibility"[All Fields]). We did not add any filter, for example: language, date of publication, or target audience.

The exportations of the papers were made in the Medline, Ris and Bibtex extensions. The data was imported by specific software for the systematic review *StArt* (*State of the Art through*

Systematic Review) to help identify duplicates, excluded and included papers. This procedure was made by two authors, Rodrigo Flores Sartori e Glauber Carvalho Nobre (RFS and GCN).

The titles and/or abstracts of studies were retrieved using the research strategy, and those from additional sources were screened independently by two review authors (RFS and GCN) to identify studies that potentially meet the inclusion criteria outlined above. The full text of these potentially eligible studies was retrieved and independently assessed for eligibility by two review authors (RFS and GCN). Any disagreement between them over the eligibility of the studies were resolved through a discussion with a third reviewer, Rochele Paz Fonseca (RPF). The duplicates and articles failing to meet the inclusion criteria were removed.

Two raters (RFS and GCN) independently extracted data from all the articles included using custom data extraction development by RFS and GCN (attachment 1). We extracted the following categories: (A) *background:* (1) aim of the studies; (2) construct or domain of the executive function (i.e. working memory, inhibition and cognitive flexibility); **(B)methods:** (3) the executive function by neuropsychology tests/tasks (i.e. instruments or procedures for assessing the executive function); (4) age samples; (5) sex and the number of children or adolescents with and without DCD; (6) motor function tests and cut off used; (7) confounding factor evaluated; (C) main findings and other relevant information reported by studies.

Assessment of study quality

The quality of the studies was appraised using a scale adapted from the Newcastle/Ottawa Scale (NOS) (Takahashi & Hashizume, 2014). Based on the NOS, each study was evaluated using the point system. Two authors (RFS and GCN) did a critical appraisal of the included studies for potential sources of bias including selection bias, detection bias, reporting bias, performance bias, and attrition bias, with consideration given to methods of participant allocation and allocation concealment, and assessment of blinding. Study design were assessed by the following categories: **(1) Selection**: **r**epresentativeness of the sample, sample size, description of groups, ascertainment of exposure; **(2) Confound Comparability**: based on design and analysis; **(3) Outcome**: assessment of outcome and statistical test. The assessment considered the follow cut offs: a maximum score of five for cross-sectional studies and eight points for cohort studies. Cross-sectional studies assigned 5, 4, 3 or 0-2 points were evaluated as very good, good, satisfactory, or unsatisfactory studies, respectively. Similarly, cohort/case-control studies with 7-8, 5-6, 4 and 0-3 points were identified as very good, good, satisfactory, or unsatisfactory, respectively. The two raters (RFS and GCN) achieved consensus through discussion (K=0.90). The discrepancies were settled by a third author (RPF).

Results

After the selection process, of the 1475 found papers initially identified by title and abstract screening, 29 matched review criteria. Approximately 86.6 % (*n* = 26 studies) occurred within the last 10 years, showing a recent surge of literature aimed toward creating and understanding the measures of EF in children with Developmental Coordination Disorder or motor difficulties. In addition, 31 different tests/tasks for measurements of the executive function in children with DCD or poor motor skills were found within the 29 studies. Sample sizes with DCD or poor motor skills ranged from 11 to 71 participants with samples from England, Germany, Australia, Italy, Canada, France, Finland, Taiwan, and the USA. Figure 1 includes a flowchart of the synthesis of the process of selecting articles. Tables 1 and 2contain a description of the studies analyzed in this systematic review.

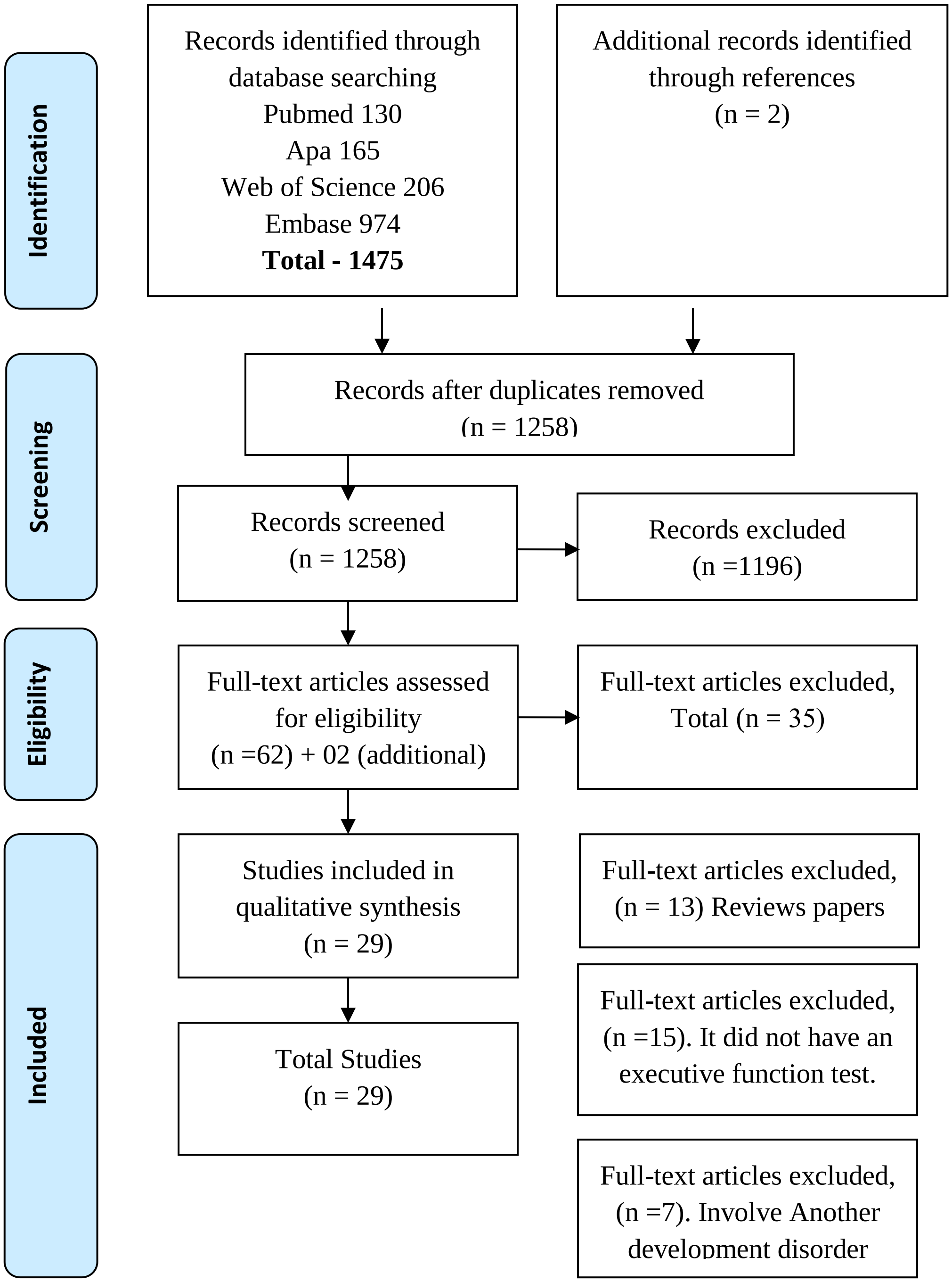

Figure 1. Flow chart of study selection.

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The investigations about inhibition in children with DCD (or poor motor skill) which show tasks/tests to evaluate this component of the executive function began in 2002 (Mandich, Buckolz, & Polatajko, 2002; Mandich, Buckolz, & Polatajko, 2003). The instrument used in these two studies to verify the inhibitory control in children with DCD was the Simon Task. To evaluate the relations between the motor development and inhibitory control in children with DCD, the Go/no-Go paradigm was used (Dyck & Piek, 2010a; Piek et al., 2004). Using the technique of neuroimaging to investigate the neural processes of inhibitory control in children with DCD, the Go/no-Go paradigm was also used (Querne et al., 2008). The relation between two versions of the paradigm of inhibitory control *Go/no-Go* (hot and cold) with children with DCD was also investigated (Shahin Rahimi-Golkhandan, Steenbergen, Piek, & Wilson, 2015)(S. Rahimi-Golkhandan, Steenbergen, Piek, Caeyenberghs, & Wilson, 2016).

Another study investigated the association between tests such as *The stop-signal task* (SST) and *Day/Night Stroop* with the motor performance in children with DCD (Livesey, Keen, Rouse, & White, 2006). In two intervention studies in children with DCD, the Posner Paradigm (selective attention) was used to study the inhibitory control of children with a motor disorder (Tsai, 2009; Tsai, Wang, & Tseng, 2012).In this paradigm, the ability of visuospatial selective attention provides a measurement of conflict resolution and also can be treated as a valid and trustworthy index of the ability of inhibitory control of an individual (Tsai, 2009; Tsai et al., 2010).

A follow up study of one (Michel, Roethlisberger, Neuenschwander, & Roebers, 2011) and two years (Michel et al., 2016) evaluated the measurements of inhibitory control in children with and without motor difficulties where the *Fruit Stroop Task* test was used. In a partnership between researchers from Taiwan and Australia, the behavior patterns were used related to inhibitory control in children with DCD by means of the *Covert orienting of visuospatial attention task* (COVAT)(W. Y. Chen, Wilson, & Wu, 2012a). The COVAT is a paradigm of spatial attention in which the nature of the attention can be evaluated by means of varying the social cue, its probability and its asynchrony in a stimulus given and what can characterize the concept of inhibition (Chen, Wilson, & Wu, 2012b).In a study done in the United Kingdom, the different associations were investigated between measurements of inhibitory control with the motor behavior of children using *The Stroop task* and the *Knock-Tap task* (Pratt et al., 2014).While evaluating the inhibitory control of children with motor difficulties and children with CDD, another studied done in the United Kingdom used the V*erbal Inhibition, Motor Inhibition* task (VIMI) with instruments to evaluate the cognitive task of verbal and nonverbal inhibitory control (Leonard & Hill, 2015).

Working Memory Measures

The investigations found about working memory in children with DCD have its beginning in a study which had the objective to explore the relation between this component of the executive function and the proficiency in motor abilities in children with DCD (Piek et al., 2004)(Dyck & Piek, 2010b). Regarding the task used to verify the ability of working memory, both studies showed the *Trail Making Test* (TMT) adapted to evaluate working memory. The TMT was conceived to evaluate behavioral inhibition and cognitive flexibility, but in this study it was adapted to investigate working memory (Piek et al., 2004, 2007). The working memory of children with DCD has been explored in a series of studies by Alloway et al. (Alloway & Temple 2007; Alloway 2007; Alloway & Archibald, 2008; Alloway et al., 2009; Alloway 2011). The studies have as their main instrument of evaluation working memory the battery *Automated Working Memory Assessment* (AWMA). The AWMA is a computerized test which covers the evaluation of both the storing ability and the information processing in the verbal and visuospatial modality (Alloway & Temple, 2007).

In a follow up study of one (Michel et al., 2011) and two years (Michel et al., 2016) to measure the component of working memory of children with motor retardation, the *Backwards Color Recall task* and the *Corsi-Blocks Backwards* tests were used to evaluate the visuospatial working memory. To verify the relation between the motor coordination deficits and the academic performance measured by working memory, the *N-Back* task was used to evaluate the working memory both in its verbal and visuospatial forms (Rigoli et al., 2012a). A study with children with DCD which investigated the visuospatial working memory mechanisms compared the brain activity (electroencephalography) with typical children during the performance of tasks of *Visuospatial Working Memory Paradigm* (VSWM)(Tsai, Chang, et al., 2012). While investigating the relation between motor coordination and visual working memory in children with DCD, the *CogState One-Back* task was used to evaluate the visual working memory (Rigoli et al., 2013). To verify the measurements of attention and working memory, extending the analysis with *The Hand Rotation Task* with children with motor retardation, the *Cambridge Neuropsychological Test Automated Battery* (CANTAB) was used (Williams, Omizzolo, Galea, & Vance, 2013).

A studied done in Italy tested the validity of the MOQ-T questionnaire as an instrument of tracking the detection of symptoms related to Developmental Coordination Disorder (DCD), with the goal of studying the relation of the motor deficit to the visuospatial working memory done in the *Corsi blocks test* (Giofrè, Cornoldi, & Schoemaker, 2014). In England, an investigation (Leonard & Hill, 2015) compared the performance of a complete range of executive functions in children with DCD and with motor difficulties, with the working memory test Working Memory Battery for Children (WMBT-C)(Gathercole, Pickering, Ambridge, & Wearing, 2004) being used as a verbal working memory task and the *Odd-One-Out* test (Henry, 2001) as a nonverbal working memory test (Leonard & Hill, 2015).

Cognitive Flexibility Measurements

When evaluating if the children with DCD and attention deficit hyperactivity disorder (ADHD) showed deficits in tasks of cognitive flexibility, an Australian study used the *Inspection time task* (Piek et al., 2007). This task involves the ability to shift attention between one task and another, allowing quick and efficient adaptation in different situations (Miyake et al., 2000).

In a follow up study of one year which evaluated the development of cognitive competence in children with motor difficulty, a cognitive flexibility measurement was used called the *Cognitive Flexibility Test* (Michel et al., 2011).. This test is used to measure the executive component which allows changes in the paths of decision making (Diamond et al., 2012). In the same manner, to evaluate the cognitive flexibility ability in a follow up period of two years, the *Flanker Task* was used (Michel et al., 2016). While investigating and comparing the cognitive flexibility between children with dyspraxia and typical children, the *Wisconsin Card Sorting Test* (WCST) was used. The *Wisconsin Card Sorting Test* (WCST-64) was developed to evaluate the abstract reasoning and the ability of changing cognitive strategies in response to environmental changes (Nelson, 1976).To evaluate the cognitive flexibility of children with dyspraxia, a French study used the *Trail Making Test A and B* (TMT)(Toussaint-Thorin et al., 2013). This test was also applied in an investigation which compared the development of cognitive flexibility in children with DCD and children with motor difficulties (Leonard, Bernardi, Hill, & Henry, 2015b). In the same investigation (Leonard et al., 2015b), an evaluation task of nonverbal cognitive flexibility was used named *Intra-Extra Dimensional test Set Shift*, which is part of the battery of Cambridge Neuropsychological Test (2006).

Table 01. Description of tools (tests/tasks) and outcome variables administered to assess executive functions (Inhibition, working memory and cognitive flexibility) in children with DCD and/or poor motor skills.

Code	**Autor/Year**	**Executive function measured**	**Tests/task**	**Description of the test/task**	**Outcome Variables**
1 / 2	(MANDICH; BUCKOLZ; POLATAJKO, 2002, 2003)	Inhibition	Simon task	The participant is told that they should press the button on the right when they see something red appear on the screen, and the button on the left when they see something green. Participants are usually told to ignore the location of the stimulus and base their response on the task-relevant color.	Reaction times and errors
3	(PIEK et al., 2004)	Working memory; Inhibition	Trail Making Test Go/No-Go Task (GNG)	This task consists of the presentation of a target set (i.e. the letters A, B, C, and D), with the actual target presented being an ordered rotation of these four letters. Participants must differentiate if: (1) the letter presented on the computer screen is a member of the target set (i.e. A, B, C, or D) and (2) if it is the current target. Some letters are designated as 'Go' or 'No-go' and are displayed in 1s intervals. When a Go stimulus is presented it is necessary to press a button and inhibit when a new stimulus is presented.	Mean time/ number correct answers Total errors
4	(LIVESEY et al., 2006)	Inhibition	The stop-signal task (SST) Day–night Stroop task	The participant must respond to a stimulus (represented by arrows) by touching either of the two options depending on the direction in which the arrow points point Four pairs of stimuli presented to children (day / night, boy / girl, large / small and up / down). The children were directed to say the opposite of the presented stimulus.	Reaction times and response accuracy Total errors
5/6/7/ 8 e 9	(Alloway, Gnanathusharan, & Archibald, 2009; Alloway & Archibald, 2008; Alloway & Temple, 2007; Alloway, 2007, 2011)	Working memory	Automated Working Memory Assessment - AWMA	Verbal and visuo-spatial working memory were measured using tasks involving simultaneous storage and processing of information. One example of a verbal working memory task is counting recall, in which the participant counts the number of target items in each of a series of successive arrays and then recalls the totals for each array in the original sequence. Visuo-spatial working memory tasks include rotating images and recalling their locations.	Total correct trials.

10	(PIEK et al., 2007)	Working memory Cognitive Flexibility	Trail making test for updating; Inspection time task	This task consists of the presentation of a target set (i.e. the letters A, B, C, and D), with the actual target presented being an ordered rotation of these four letters. Participants must differentiate if: (1) the letter presented on the computer screen is a member of the target set (i.e. A, B, C, or D) and (2) if it is the current target. This is a task where the length of a line is discriminated, and the time of visual inspection is checked to correctly discriminate a type of stimulus.	Mean time/ number correct answers Mean time/ number correct answers
11	(QUERNE et al., 2008)	Inhibition	Go/No-Go Task	The task requested of participants was to press a reply key to any letter presented sequentially (Go), except X (No-go). According to Casey et al. (1997), its design allows to isolate the brain regions involved in the suppression of the motor response (Go-No-go)	Total errors
12	(TSAI, 2009)	Inhibition	Posner-paradigm protocols	Children are seated in front of a computer screen situated at eye level. They are instructed to fixate at a central point on the screen, marked by a dot or cross. To the left and the right of the point are two boxes. For a brief period, a cue is presented on the screen. Following a brief interval after the cue is removed, a target stimulus, usually a shape, appears in either the left or right box. The observer must respond to the target immediately after detecting it.	Reaction times and response accuracy
13	(DYCK; PIEK, 2010b)	Working memory; Inhibition	Trail Making Test Go/no go task.	This task consists of the presentation of a target set (i.e. the letters A, B, C, and D), with the actual target presented being an ordered rotation of these four letters. Participants must differentiate if: (1) the letter presented on the computer screen is a member of the target set (i.e. A, B, C, or D) and (2) if it is the current target. Some letters are designated as 'Go' or 'No-go and are displayed in 1s intervals. When a Go stimulus is presented it is necessary to press a button and inhibit when a new stimulus is presented.	Times and response accuracy Total errors and omissions
14	(MICHEL et al., 2011)	Cognitive Flexibility Working memory Inhibition	*Cognitive Flexibility Test* *Backwards Color Recall* task *Fruit Stroop task*	Children are informed that their task is to feed two families of fish consecutively. They must feed one member of one family and one member of the other family in sequence. Each time one of the two fish appeared the child must decide who it was to feed instead of the previous action. A sequence of colored disks was presented to the children on a computer screen and the children were asked to recall the sequence in reverse order. It is a task with images of four different types of fruit and vegetables presented so that colors are named as quickly as possible in congruent or incongruent assays.	Reaction times and response accuracy Total correct trials Time and total errors
15	(WUANG; SU; SU, 2011)	Cognitive Flexibility	Wisconsin Card Sorting Test	Several stimulus cards are presented to the participant. The participant is told to match the cards, but not how to match; however, he or she is told whether a match is right or wrong.	Total errors

16	(RIGOLI et al., 2012c)	Working memory	N-Back Task	The task is done from the presentation of the examinee to a stimulus that must be stored, at the same time as it should evoke the stimulus presented to him either a (1-back), two (2-back) or three (3-back) positions.	Total correct trials
17	(TSAI et al., 2012)	Working memory	VSWM - Visuospatial Working Memory Paradigm.	The children were asked to compare the positions and directions of the ladybirds in the rectangles. In two spatial memory tasks, the rectangles and ladybirds appeared following a 3-second or a 6-second delay.	Total correct trials
18	(TSAI; WANG; TSENG, 2012)	Inhibition	The visuospatial attention paradigm	The pupils were black-filled circles inside the eyes and were centered vertically to the eyes. When cuing, the pupils were just touching the right or left side of the eye (valid, invalid, and catch trials) or were centered (neutral and catch trials) in the eyes	Reaction times and response accuracy
19	(CHEN; WILSON; WU, 2012a)	Inhibition	COVAT - Covert orienting of visuospatial attention task	The cueing task has been used to measure manual and eye-movement reaction times to target stimuli to investigate the effects of covert orienting of attention in response to different cue conditions.	Reaction times and response accuracy
20	(WILLIAMS et al., 2013)	Working memory	CANTAB Spatial Working Memory task	It is a self-ordered searching task measuring working memory for spatial stimulus. It requires participants to use mnemonic information to work towards a goal	Times and response accuracy
21	(TOUSSAINT-THORIN et al., 2013)	Cognitive Flexibility Inhibition	Trail Making Test Auditory Attention/ Response NEPSY task	Participants must draw a line between numbers and letters in sequence, switching between the two (e.g. 1–A–2–B, etc.) In the first part, the child learns to produce a response to the « red » stimulus (place a red chip when the child hears the word « red »). In the second part, the child must change the response pattern and respond to contradicting stimuli (place a red chip when hearing the word « yellow »).	Time and Total errors Response accuracy
22	(RIGOLI et al., 2013)	Working memory	One-Back task CogState Brief Battery	Determine whether the current playing card shown is the same or different from the previous one or the second-previous one	Response accuracy
23	(TSAI et al., 2014)	Working memory	VSWM - Visuospatial Working Memory Paradigm.	The children had to compare the positions and directions of the ladybugs in the rectangles; (ii) two spatial memory tasks with a 3s-delay or (iii) with a 6s-delay, where the rectangles and ladybugs appeared with the respective delays.	Total correct trials
24	(GIOFRÈ; CORNOLDI; SCHOEMAKER, 2014)	Working memory	Corsi blocks test	Participants were asked to recall a sequence of blocks just indicated by the experimenter in the same (forward) or in reverse (backward) order.	Total correct trials

25	(PRATT et al., 2014)	Inhibition	The Stroop task NEPSY Knock-Tap task	The participants should state the color of the ink in which a word was printed (for example, the word "blue" printed in red ink; "red" response). The task requires participants to place the non-dominant hand on the table and use the dominant hand to complete certain actions that the researcher explained at the beginning of each set of trials.	Total correct trials Total correct trials
26	(RAHIMI-GOLKHANDAN et al., 2015)	Inhibition	Go/no-Go (“cool and hot”).	Neutral facial expressions were used for the cool task, while the stimuli for the hot task were happy and fearful faces of the same individuals. The task included pictures of neutral/calm, happy, and sad facial expressions of a group of men and women. Children were asked to respond (by pressing the spacebar) as quickly as possible to only that expression, and not the other.	Omission/ Errors and Reaction Time
27	(LEONARD et al., 2015b)	Working memory Working memory Inhibition Inhibition Cognitive Flexibility Cognitive Flexibility	Listening recall Odd-one-out “Verbal Inhibition, Motor Inhibition” task Trail Making Test/ Intra-/extra-dimensional shift(CANTAB)	Participants recall the last word of a sentence after making a judgement as to whether the sentence was true or false, with the number of sentences increasing as the task continues. Participants recall the spatial location of a nonsense shape after making a judgement as to which of the shapes was the ‘odd-one-out’ Participants copy a word said by the experimenter, or provide another word (i.e. inhibit the copying response), depending on instructions Participants copy an action demonstrated by the experimenter, or provide another action (i.e. inhibit the copying response), depending on instructions Participants have to draw a line between numbers and letters in sequence, switching between the two (e.g. 1–A–2–B, etc.) Participants learn a rule through initial trial and error in relation to a shape and then must switch to a different rule to continue achieving ‘correct’ answers	Total correct trials Total correct trials Total errors Total errors Completion time switching cost Total errors
28	(RAHIMI-GOLKHANDAN et al., 2016)	Inhibitory control	Go/no-Go (‘cool’ and ‘hot’).	The task included pictures of neutral/calm, happy, and sad facial expressions of a group of men and women. Children were asked to respond (by pressing the spacebar) as quickly as possible to only that expression, and not the other.	Omission Errors and Reaction Time

29	(MICHEL; MOLITOR; SCHNEIDER, 2016)	Working memory	Color Span Backwards Task and	A series of colored discs is presented for 2 seconds per disc. After the trial, a circle with all the colored discs is presented and the child must tap the correct sequence of colors (on a touchscreen) in reverse order	Mean of sequences correctly recalled
		Working memory	Corsi-Blocks Backwards Task	There are numbers on the Corsi-blocks that only the administrator can see. The administrator touches some blocks and the child must touch the blocks in the inverted order immediately after presentation.	The longest sequence correctly recalled.
		Inhibitory control	Go/no-Go Task	The test requires a participant to perform an action given certain stimuli (press a button - Go) and inhibit that action under a different set of stimuli (not press that same button - No-Go).	Total errors
		Cognitive Flexibility	Flanker Task	In the first part (the standard Flanker task), children have to react to a red fish that appears on-screen and are told to press the right or left button, according to the direction in which the fish is facing. An additional task set was added to the second part of this task: when appears yellow fish the child has to react according to the direction of the four-flanking fish (rule switching)	Accuracy and mean reaction time

In table 2 the main results of the executive functions in children with Developmental Coordination Disorder and poor motor skill were presented. The studies used three different types of motor batteries to measure the Developmental Coordination Disorder and/or to verify the poor motor skills condition as also described in table 2. 21 studies used the *Movement Assessment Battery for Children*-MABC-2, 05 studies used a *McCarron Assessment of Neuromuscular Development*-MAND and 01 used the *Bruininks–Oseretsky Test of Motor Proficiency* – 2nd edition. A single study used the diagnosis of developmental dyspraxia based on a multidisciplinary assessment on the diagnostic criteria proposed by Gerard and Dugas. In addition, to discriminate children with DCD, two studies used questionnaires, one with interviews with parents and another study used the *MOQ-T + Ideomotor test* questionnaire. Finally, one study applied the KTK test.

Regarding the main results of the executive functions in children with DCD or poor motor skills a major portion of the studies did not report the effect size of the comparisons between children with DCD or motor delay and groups of children with typical development. Most of the studies indicate that there is a deficit of inhibition in children with DCD. Fifteen studies whose main objective was to compare children with DCD with a control group in tasks of inhibition control were found. From those studies, three studies (code 13, 25, 26) found no difference between groups of children with DCD with typical development. Among these studies, there was one result (code 26) that showed that children with DCD and typical children showed comparable accuracy in Go/No-go Tasks and had similar errors during the task, except when the *No-go* stimulus is associated with hot executive functions. Regarding working memory, fifteen studies whose main objective was to compare children with DCD with control group in tasks of working memory were found. Only one study found no difference between groups of DCD and children with typical development (code 14). In this study, for the *Backwards Color Recall* task, there were no differences between children with and without motor coordination delay. Regarding the cognitive flexibility tests in children with DCD or with motor difficulty, 6 studies were found. The studies point to a smaller ability of cognitive flexibility in children with DCD or with motor difficulty, independently of tests or batteries that were applied when compared to a group of typical children.

Table 2. Motor Function tests and main results of the executive functions in children with Developmental Coordination Disorder and poor motor skill.

Code	Autor	Age (year-old)	Motor function tests/cut off ***	Groups	Main results
1 / 2	(MANDICH; BUCKOLZ; POLATAJKO, 2002, 2003)	7–12	Parents questionnaire (from authors) + MABC ≤15th	DCD = 20; Control group = 20	Reaction time and errors produced with the Simon task indicate that children with DCD exhibit an inhibitory response dysfunction relative to the control group.
3	(PIEK et al., 2004)	6 - 14	MAND ≥ 80 score (NDI*)	DCD risk =28 (m=20; f=8); Control = 100 (m=33; f=43)	There was an association between the motor capacity and the task of executive function that investigates working memory; Motor performance does not appear to be linked to inhibitory control deficits but may involve temporal deficits related to the cerebellum.
4	(LIVESEY et al., 2006)	5 - 6	MABC	DCD (15 boys, 21 girls).	The relationship between motor performance and stop-signal task performance was in the expected direction but did not reach significance.
5	(ALLOWAY ; ARCHIBALD, 2008)	6 - 11	MABC, Check list MABC teacher	DCD with typical language= 11 (m=8; f=3); DCD = 12 (m=8 f=4); Specific language impairment (SLI)= 11 (m=7; f=4)	Children with DCD had general deficits in short-term verbal and visuospatial memory and working memory. Children with DCD with typical language skills were impaired in all four areas of memory function for their age level, and this pattern was also found to be characteristic of a larger DCD group with varied language abilities.
6	(ALLOWAY ; TEMPLE, 2007)	6 - 11	MABC ≤5th	DCD = 20 (m=14; f=6); Moderate Learning difficulties = 20 (m=15; f=5)	Children with DCD had significantly lower levels than children with learning difficulties in measures of short-term verbal, short-term visuo-spatial memory, and working memory. Children with DCD appear to be impaired in all four areas of memory function; in particular they performed at significantly lower levels than children with MLD in measures of verbal short-term memory, visuo-spatial short-term and working memory
7	(ALLOWAY , 2011)	6- 10	Check list MABC/ MABC/ NI	DCD = 55 (m=44; f=11); Control = 50 (m=30; f=20); TDAH = 50 (m=43; f=7)	Children with DCD performed poorly on all memory tests, with particularly low scores on visuospatial memory tasks. The children with DCD had a depressed performance in all working memory tests, with particularly low scores in visuospatial memory tasks; children with ADHD performed within age-expected levels in short-term memory but had a pervasive working memory deficit that impacted both verbal and visuospatial domains.

8	(ALLOWAY , 2007)	5 - 11	MABC +Check list MABC	DCD = 55 (m=44; f=11)	Performance levels in verbal working memory measures were slightly lower in children with DCD than in the control group. Deficits observed in visuospatial short-term and working memory tasks were significantly worse than in the verbal short-term memory
9	(ALLOWAY ; GNANATH USHARAN; ARCHIBAL D, 2009)	6 - 10	Interview with the child, and his or her parentes + neurological examination	ADHD = 83 (m=71/f=12); DCD = 5 (m=44/ f=11); Specific language impairment = 15 (m=9/f=6); Aspeger 10 (m=8; f=2)	Children with DCD performed poorly in all areas, particularly with low scores on visuospatial memory tasks. Specifically, language impairments were associated with selective deficits in verbal short-term and working memory, whereas motor impairments (DCD) were associated with selective deficits in visuospatial short-term and working memory. Children with attention problems were impaired in working memory in both verbal and visuospatial domains, whereas the children with AS had deficits in verbal short-term memory but not in any other memory component.
10	(PIEK et al., 2007)	6 - 14	MABC +Check list MABC	DCD = 18 (m=12; f=6); Control = 138 (m=59; f=79); TDAH – PI = 20 (m=6; f=4); TDAH – C = 19 (m=15; f=4)	Children with DCD were slower in both trials and had greater variability in performance. The DCD group was significantly slower in the flexibility task.
11	(QUERNE et al., 2008)	8 – 13	MABC $\leq 5^{th}$	DCD = 9 (m=7 f= 2); Control= 10 (m=7 f= 3)	Children with DCD obtained a similar score for correct inhibitions compared to the control group, but the responses were slower and with more variability than in the control group.
12	(TSAI, 2009)	9- 10	MABC $\leq 5^{th}$ MAND < 80 score	Control group = 29 (m=13/f=16); DCD Training group = 14; DCD No Training group = 14	DCD groups had the deficit of endogenous visuospatial attention when compared to typically developing children. This finding was in line with previous research that indicated a deficit of inhibitory control in children with DCD. This study showed a significant improvement in motor and cognitive functions in such children after the intervention of the 10- week group physical activity program conducted in the school setting
13	(DYCK; PIEK, 2010b)	3- 14	MABC / NI	Language Disorder Group = 30 (m=22/f=8); DCD = 20 (m=13/f=7); Poor language ability = 22 (m=14/f=8); Poor Motor Coordination = 28 (m=17/f=11)	DCD with and without language problems differ significantly in measures of IQ, social cognition and verbal work memory compare to children with Language Disorder and children with poor motor skills No significant differences were found in the inhibition between the DCD group and the group with Language Disorder and children with poor motor skills.

14	(MICHEL et al., 2011)	5- 6	MABC-2 ≤10th	23 impaired children (n = 19 boys) and 23 control children (n = 11 boys); the group of older children included 24 impaired children (n = 15 boys) and 24 control children (n = 10 boys)	Inhibition and shifting performance were consistently lower, compared to the children without motor coordination impairments For the Backwards Color Recall task, there were no differences between children with and without motor coordination deficiency. Children with low levels of motor coordination reacted more slowly in the tasks of inhibitory control compared to the control group, but not in relation to the precision of the action.
15	(WUANG; SU; SU, 2011)	7- 11	DCDQ'07 <55th; MABC-2 ≤5th BOT-2 ≤15th	DCD = 71 (m=41; f=30) Control = 70 (m=37; f=33)	Evidence of impairment in cognitive flexibility was found in children with DCD.
16	(RIGOLI et al., 2012c)	12-16	MABC-2 DCD <5th "at risk"6th≤15th	DCD - 93 adolescents, 38 girls and 55 boys	The present study demonstrates an important relationship between throwing and receiving skills in sports games, working memory and academic performance.
17	(TSAI et al., 2012)	±11	MABC ≤5th	N= 998 DCD group - 24 (m=12/f=12) Control = 30 (m=15/f=15)	Children with DCD showed no impairment in spatial information processing but exhibited a deficit of retrieval of geographic information when performing the visuospatial working memory task.
18	(TSAI; WANG; TSENG, 2012)	9 – 10	MABC ≤5th	N=368 DCD-training (n = 16) (m=09/f=07) DCD non-training (n = 14) (m=09/f=05) TD (n = 21) (m=11/f=10)	Compared to typical children, children with DCD responded significantly more slowly under all conditions of the visuospatial care task, presenting a deficiency of inhibitory control capacity. After accounting for pre-training differences, on the strength of inhibitory control across the post-training period indicated a significant group difference in post-training behavioral performance.
19	(CHEN; WILSON; WU, 2012a)	9 – 10	MABC ≤5th	typically developing - TD (N = 36) moderate DCD MDCD (N = 46) (m=16 e f=30) severe DCD (N = 20) (m=9 e f=11)	Children with DCD took significantly more time on attention tasks, a problem that is likely to involve inhibitory control deficits.

20	(WILLIAMS et al., 2013)	7- 12	MABC-2 NI DCD – 4 criteria DSM IV	ADHD = 14; ADHD + DCD = 16; DCD = 10; control = 18	The ADHD + DCD group was slower to complete the task of spatial working memory compared to the ADHD group.
21	(TOUSSAINT-THORIN et al., 2013)	10-12	Dyspraxia-multidisciplinary Assessment proposed by Gerard and Dugas.	Dyspraxia group = 13(m=11, f=2 girls); Control group = 14 (m=8 boys, f=6)	Neuropsychological tests highlighted planning and inhibition disorders, but no impaired flexibility
22	(RIGOLI et al., 2013)	5 - 11	MAND $\geq$ 80 score (NDI*)	Motor difficult 18 children (11 boys and 7 girls)	Children with movement difficulty, fine motor skills significantly predicted later One-Back accuracy and speed. One-Back accuracy at baseline predicted better fine and gross motor skills following the 18-month period.
23	(TSAI et al., 2014)	11-12	MABC-2NI	DCD-training (n = 20) (m=13/f=07); DCD non-training (n 20)(m=12/f=08); TD (n = 20) (m=12/f=08)	Children with DCD exhibited visuospatial working memory deficits with respect to behavioral performance.
24	(GIOFRÈ; CORNOLDI; SCHOEMAKER, 2014)	5- 11	MOQ-T + Ideomotor test	DCD Group = 23 (m=11 e f=12); Control Group = 23 (m=11 e f=12)	Children with DCD symptoms also had deficits in visuospatial work memory, but the magnitude of the difference versus the control group was moderate.
25	(PRATT et al., 2014)	6 – 9	MABC $\leq 5^{th}$	DCD (N = 26) (m=22 e f=04); typically developing - TD (N = 24) (m=13 e f=11)	Children with DCD had difficulties for measures of inhibition of behavior and planning compared to a control group, although without significant correlations between motor skills and performance in tasks related to executive functions.
26	(RAHIMI-GOLKHANDAN et al., 2015)	7–12	MAND $\geq$ 80 score (NDI*)	(DCD = 12 (m=06 e f=06); Typically developing TD = 28 (m=10 e f=18)	Children with DCD and typical children showed comparable accuracy in Go tasks, and also had similar errors, except when the No-go stimulus is associated with hot executive functions.
27	(LEONARD et al., 2015b)	7- 11	Check list MABC > 15^{th} MABC-2 $\leq 15^{th}$	DCD= 23 (m=16; f=7); TD = 38 (m=17; f=21); MD = 30 (m=17; f=13)	The motor difficulties and DCD groups scored below the control group on nonverbal tests of working memory. The DCD and low motor performance groups had results below the typical group of children in non-verbal inhibitory control tests. There were no significant differences between DCD and motor difficulties groups with the group of typical children in the tasks of cognitive flexibility.

28	(RAHIMI-GOLKHANDAN et al., 2016)	7- 12	MAND $\geq$ 80 score (NDI*)	36 children, DCD = 12 (boys = 4, girls = 8; TD = 24 (boys = 10, girls = 14;	Children with DCD have difficulty modulating their approach to rewarding stimuli when the task demands inhibited behavior.
29	(MICHEL; MOLITOR; SCHNEIDER, 2016)	4- 6	MABC-2 $\leq 10^{th}$ + Körperkoordinations-Test für Kinder (KTK)	Motor impairment Group = 48; Control Group = 48	The children's executive functions dramatically improved during the one-year period. Regarding to motor coordination performance, half of the impaired children caught up to the control children's level ("remission group"), while the remaining half showed no improvement ("persisting group").

The assessment of study quality is described in table 3 and 4. Five studies used experimental design, and twenty-four studies used a cross-sectional design. Based on NOS, all 5 experimental studies were of very good quality. 10 of the 24 cross sectional studies were of very good quality, 09 were of good quality and the remaining 6 were satisfactory. In general, the methods of recruitment of subjects, controlling for the confounders, and outcome assessment were appropriate. The 06 studies that presented satisfactory results obtained this classification because there was no description of procedures adopted to guarantee that there is no influence of the researcher's knowledge about the sample in relation to the measurement of the outcome.

Table 03. Results of the critical appraisal of the included cross-sectional studies.

Study design		**Selection**			**Confound Comparability**	**Outcome**	**Total**
		Representativeness of the sample	*Description of Groups*	*Ascertainment of exposure*	*Based on design and analysis*	*Assessment of outcome*	
Mandich, Buckolz, Polatajko et al.(2002)	Cross sectional	+ (a)	+(b)	+(b)	+ (a)	-	04
Mandich, Buckolz, Polatajko et al.(2003)	Cross sectional	+ (a)	+(b)	+(b)	+ (a)	-	04
Piek et al (2004)	Cross sectional	+ (a)	+ (a)	+ (a)	+(a)	+(a)	05
Livesey et al. (2006)	Cross sectional	+ (a)	+(b)	+	+(a)	-	04
Alloway; Temple (2007)	Cross sectional	+ (a)	-	+ (a)	+(a)	-	03
Piek et al. 2007	Cross sectional	+ (a)	+ (a)	+ (b)	+(b)	-	04
Alloway, 2007	Cross sectional	+ (a)	-	+ (a)	+ (b)	-	03
Alloway; Archibald, 2008	Cross sectional	-	+ (a)	+ (a)	+(a)	-	03
Querne et al. (2008)	Cross sectional	+ (a)	+ (a)	+ (b)	+ (a)	+ (b)	05
Alloway; Rajedran; Archibald, 2009	Cross sectional	-	+ (a)	+ (a)	+ (a)	-	03
Dyck; Piek, 2010	Cross sectional	+ (a)	+ (a)	+ (a)	+ (b)	-	04
Alloway 2011	Cross sectional	+ (a)	+ (a)	+ (a)	+ (a)	+ (b)	05
Michel, et al.(2011)	Cross sectional	+ (a)	+ (a)	+ (a)	+ (a)	+ (a)	05
Wuang; Su ; Su, 2011	Cross sectional	+ (a)	+ (a)	+ (a)	+ (a)	-	04
Rigoli et al. 2012	Cross sectional	+ (a)	+ (a)	+ (a)	+ (a)	+ (a)	05
Williams et al., 2013	Cross sectional	+ (a)	+ (a)	+ (a)	+ (a)	+ (b)	05
Toussaint-Thorin et al. (2013)	Cross sectional	+ (a)	+ (a)	+ (b)	+ (a)	+ (b)	05
(RIGOLI et al., 2013)	Cross sectional	+ (a)	+ (a)	+ (a)	+ (a)	+ (a)	05
Giofrè et al., 2014	Cross sectional	+ (a)	+ (a)	+ (a)	-	-	03
Pratt et al (2014)	Cross sectional	+ (a)	+(b)	+ (a)	+ (a)	-	04
Rahimi-Golkhandanetal.(2015)	Cross sectional	+ (a)	+ (b)	+ (a)	-	-	04
Leonard et al., 2015	Cross sectional	+ (a)	+ (a)	+ (a)	+ (a)	+ (a)	05
Rahimi-Golkhandan, et al., (2016)	Cross sectional	+ (a)	+ (b)	+ (a)	+(b)	-	04
Michel, Molitor, & Schneider, 2016	Cross sectional	+ (a)	+ (a)	+ (a)	+ (a)	+ (a)	05

Table 04. Results of the critical appraisal of the included experimental studies

Study design		Selection				Comparability	Outcome			Total
		Is the case definition adequate	*Represen tativeness of the cases*	*Selection of Controls*	*Definition of Controls*	*Comparability of cases and controls*	*Ascertainment Of exposure*	*Same method of ascertainment*	*Non-Response rate*	
Tsai (2009)	Experimental	+ (a)	+ (a)	+ (a)	+ (a)	+ (a)	+ (a)	+ (a)	+ (a)	8
Tsai et al., (2012)	Experimental	+ (a)	+ (a)	+ (a)	+ (a)	+ (a)	+ (a)	+ (a)	+ (a)	8
Tsai et al., 2012	Experimental	+ (a)	+ (a)	+ (a)	+ (a)	+ (a)	+ (a)	+ (a)	+ (a)	8
Chen et al., (2012)	Experimental	+ (a)	+ (a)	+ (a)	+ (a)	+ (a)	+ (a)	+ (a)	+ (a)	8
Tsai et al., (2014)	Experimental	+ (a)	+ (a)	+ (a)	+ (a)	+ (a)	+ (a)	+ (a)	+ (a)	8

Discussion

The aim of this study was to was to describe the tests/tasks used to assess working memory, inhibition and cognitive flexibility, and to identify the main results of studies investigating the executive functions in children and adolescents with Developmental Coordination Disorder (DCD) or who are at risk of DCD and/or with poor motor skills. Executive functions play a critical role in everyday life. However, despite the obvious relevance of executive functions of children with DCD, much is still unknown about the executive function abilities in individuals with that disorder or even poor motor skill. We addressed this gap in the literature by conducting a systematic review to identify tests and tasks used to measure inhibition control, cognitive flexibility and working memory.

Many tasks were used to evaluate the executive functions presented in studies with DCD. In those tests or tasks children require verbal, nonverbal or complex visuo-spatial processing, with or without motor demand involved. In some cognitive tasks, these different demands or different types of stimulus involved in tests may cause secondary loss in execution, camouflaging the primary executive deficits that should be predominantly examined (motor performance bias or of visual perception), thus limiting the more specific evaluation of the actual executive functions in this group of children. For example, inhibition is often investigated using tasks that involve button pressing or other motor responses, and so it is important to assess the extent to which any difficulties or additional processing load associated with producing these responses affects inhibition performance in children with DCD (Pratt et al., 2014).

Regarding the components, it can be understood that there is a much greater number of tasks/tests that measure inhibitory control (19 tests) in children with DCD or with motor difficulties. A possible explanation is the fact that this component presents a greater representation about the other possible components in executive functions. One of the theories about executive function holds that the satisfactory development of inhibition is essential for the normal performance of the neuropsychological abilities like working memory, internalization of speech, self-regulation, reconstitution, and also motor control (Barkley, 1997).

Among the tasks of inhibitory control used in studies of children with DCD, it is perceived that there is a great variety of tasks and that there is no replication of any test, except for the Go/No-Go paradigm which is involved in 3 studies from different researchers. The Go/No-Go test was used to measure a participant's capacity for sustained attention and inhibition (Nosek & Banaji, 2001). Using the neuroimaging technique to investigate the neural processes of inhibitory control of children with DCD, between the ages of 8 and 13, the Go/No-Go paradigm was also used (Querne et al., 2008). Two versions (cold and hot) of the Go/No-Go tasks were also used. The stimulus used were faces with neutral facial expressions for the cool Go/No-Go task, while the stimulus for the hot Go/No-Go task were the faces of the same individuals while showing happy or fear emotions. The cool executive functions are mainly associated to the lateral prefrontal cortex (L-PFC), characterized and activated when it dealt with abstract or not contextualized stimulate (S. Rahimi-Golkhandan et al., 2016). In contrast, the hot executive functions are related to the ventromedial prefrontal cortex (VM-PFC), active in many real life situations characterized by a high emotional involvement (S. Rahimi-Golkhandan, Piek, Steenbergen, & Wilson, 2014; S. Rahimi-Golkhandan et al., 2016).

The items of executive function tested in the neuropsychological tests or batteries were inconsistent because they depended on the preferences of the investigators and because they are under different task constraints, which may lead to different interpretations of the mechanisms of executive functions in children and adolescents with DCD or motor disorder. There was a great variability among studies regarding the neuropsychological tools adopted by the cognitive construct assessed. This diversity of tools may be due to the multiple components of the EF and the lack of methodological agreement in this field (Cardoso et al., 2018). In terms of inhibition and working memory, some tasks are used to assess both functions (i.e. the trail making/updating task used by Piek et al, (Piek et al., 2004, 2007) while Michel et al.(Michel et al., 2011) used separate tasks for these two functions. The tasks also differ in the extent to which they rely on motor skills, with tasks such as the *trail making/updating task* requiring button pressing responses, while the *'Fruit Stroop'* task used by Michel et al. having no motor demands (Pratt et al., 2014).

It would be worth mentioning in relation to the types of measurements (tests and tasks) on the EF performance of children with DCD that other factors such as the executive 'purity' of the tasks, their interaction with age and the different aspects of response inhibition that may be measured could also play an important role (Pratt et al., 2014). For example, results indicate that there is no relation between the *Stop-Signal Task* (SST) with other measurements of inhibitory control in children between five and six years of age (Livesey et al., 2006). It seems that the *SST* *task* and the *Day/Night Stroop* (DNS) test present aspects that are very different regarding the inhibition of behavior. The lack of association between SST and DNS do not pose any doubt about the validity of the tasks as a measurement of response inhibition. However, these different tasks seem to present different conditions regarding inhibitory control in children with DCD.

Another important condition for this discussion refers to the tests/tasks that involve motor demands. Researchers should ensure that they account for the visuospatial and motor demands of EF tasks when interpreting data relating to EF of children with DCD (Leonard et al., 2015a). For example, a group of children with DCD presented similar results to the group of typical children in the *Stroop task* and the *Knock-Tap Test*, which involve a greater motor demand (Pratt et al., 2014). Contrary to predictions, an increase of motor demand in tasks of this study of inhibitory control seem to not have affected the development of inhibitory control.

The present study underlines deficits of executive functions in children with DCD and poor motor skills. These deficits are wide ranging, extending across basic functions measured (working memory, inhibition, and cognitive flexibility). We found evidence to support the presence of broad executive function deficits in DCD participants compared to controls. Reports suggest that individuals with DCD have difficulties in many aspects of EF (Wilson et al., 2012) (Leonard et al., 2015a), particularly in the three key components of EF identified by Miyake et al. (2000): inhibition, working memory, and cognitive flexibility.

A major portion of the studies did not report the effect size of the comparisons between children with DCD or motor delay and groups of children with typical development. Besides that, there is a great heterogeneity of the tasks used, the ages investigated and mainly the tasks/tests that evaluated more than one construct of executive functions, making a concrete analysis harder about which of the components has a bigger effect on the group of children with

DCD or motor delay. However, it is perceived that there were significant differences between the groups in most studies which points to evidences of the association between executive functions and motor development. In this sense, it is important to discuss how these functions relate to motor behavior.

Fifteen studies whose main objective was to compare children with DCD or poor motor skills with a control group in tasks of inhibition control were found. From those studies, eleven studies found differences between groups of children with DCD or poor motor skills. The inhibitory control of response contributed to an efficient performance of four executive abilities, operational memory, internal speech, self-regulation, and reconstitution (Barkley, 2001), besides being related to the ability of ignoring the entry of irrelevant behavioral responses that would be inadequate in the context that the person is inserted (Diamond, 2012b). In this sense, these proceedings allow the motor execution to be fluent and efficient, characterized by behaviors directed to goals, with the inhibition of irrelevant behaviors during certain activities (Barkley, 2001). Inhibition is a cognitive function which is important for engaging in many situations, such as operating a motor vehicle, riding a bicycle, and playing dodge ball or football, where it is often necessary to suddenly prevent one’s self from executing an inappropriately prepared action (Coxon, Stinear, & Byblow, 2007). Deficits in this control process is thought to underline motor coordination problems (Tsai, 2009). For instance, additional taps in a motor inhibition test with children with DCD could reflect a deficit in motor control resulting in involuntary repetition of the taps of the same thumb (Mandich et al., 2003). Children with DCD presented a persistent large number of additional taps during all the blocks of practice. The number of additional taps may reflect a lack of inhibition. Previous studies have reported that children with DCD were less able to inhibit incorrect manual response (Mandich et al., 2002, 2003). This assumption is also in accordance with previous studies showing a global inhibition deficit in tasks that not requiring a motor response in DCD (Leonard & Hill, 2015)(Leonard et al., 2015a). Consequently, clumsiness could partially result from executive functions deficit demonstrated by children with DCD resulting from early cerebral lesion (Mandich et al., 2003).

Regarding working memory, fifteen studies whose main objective was to compare children with DCD or poor motor skills with the control group in tasks of working memory were found. Only one study found no difference between groups. In this study, for the *Backwards Color Recall task*, there were no differences between children with and without motor coordination deficiency (Michel et al., 2011). In relation to associative studies, there was an association between the motor capacity and the tasks of executive function that investigates working memory in 3 studies. Working memory is an ultra-rapid temporary information storage system that allows the monitoring and management of this information (Diamond, 2013) and is related to the retention of the information in the brain and to the possibility of working mentally with this information, relating one thing to another, or using clues of this information to solve a problem (Diamond, 2013). This retention capacity makes us capable of connecting unrelated elements as well as separating integrated elements (Alloway, 2011; Diamond, 2012a). These processes of disassembly and recombination of the elements are fundamental for creativity. In addition, this allows us to take the conceptual knowledge to the decision making (Diamond, 2012b).

It has been suggested that the association between motor aspects and working memory may be more evident in these domains in children with atypical development (Roebers et al., 2014) as a result of abnormal dependencies between neurocognitive processes (Piek et al., 2007). In agreement, a meta-analysis including studies with individuals aged 5 to 18 years with DCD reported difficulties in executive functions through a series of performance-based measurements that assess inhibition, working memory, cognitive flexibility, and planning (Wilson et al., 2012).

Children with DCD or motor coordination impairments were significantly slower in tests/tasks and had greater variability in performance in tasks of cognitive flexibility when compared to the children without motor impairment. However, two studies did not find differences between groups of children with DCD and typical children for this component of executive functions. The broad definition of EF indicates that the essence of EF is the ability to control behavior, a concept which is also the foundation of movement and action control (Koziol & Lutz, 2013).

Cognitive flexibility refers to an individual's ability to modulate their behavior and thus adapt to different rules or requirements of a particular task (Leonard et al., 2015a). It may also be referred to the ability to change the course of actions and/or thoughts according to the requirement of the environment (Malloy-Diniz, Sedo, Fuentes, & Leite, 2008). This capability suggests a change in perspectives or differentiated approaches to a problem, flexibly, adjusting to the demands, rules, or priorities of each task by providing the basis for higher-order functions such as planning and reasoning (Diamond, 2013) , as well as different control actions. However, cognitive flexibility appears later in terms of development (Diamond et al., 2012) when compared to working memory and inhibition, which may be one of the reasons for a smaller number of studies and also in the sense of results not presenting significant differences between the groups of children with DCD and typical children in all the studies presented in this systematic review.

From the point of view of the investigation of executive functions in children with DCD or with motor retardation, we can also see the absence of studies that analyze the role of context in the behavior of EF because research is needed to understand the interplay between context and executive function in children. Nevertheless, there is still a minimal amount of investment in questionnaires and scales, as well as in ecological tools (Cardoso et al., 2016). The results suggest a heightened sensitivity to emotionally significant distractors in DCD with possible implications for adaptive function and emotional well-being (Shahin Rahimi-Golkhandan et al., 2015). Those authors argue that the interaction of cognitive control and emotion processing networks may be disrupted in children with DCD.

For future studies, it would be best to standardize the neuropsychological tasks/tests, test batteries and the methods used to measure executive function in children with Developmental Coordination Disorder (DCD) or poor motor skills, to enable precise comparisons of results and pooling of evidence from many studies for future analyses. Although, this may be difficult to achieve in practice because tests that measure executive function in children are used in differing settings around the world. We argue that there may be moderators of the associations between DCD/poor motor skills and executive functions that are unaccounted in our analyses. Some studies failed to report important information, such as clinical status of participants, education, economic status, whether participants took any medication, or if the participants had a psychiatric disorder, like ADHD, precluding moderator analyses on these variables. However, it is worth emphasizing that the multiple characteristics of this disorder is a great challenge, since the DCD is part of a very interactive system, where it is recognized the overlap of different comorbidities (Wilson et al., 2012).

To further the understanding of the link between executive function and motor skills disorders, the definitional and measurement problems that plague the study of these 3 components of executive function will need to be resolved. Without a set of clearly defined terms and a consistent set of measurements, it will be very difficult to come to any definitive conclusions about how executive function relates to children with DCD.

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CAPÍTULO 4

Artigo 2: Motor and Verbal Inhibitory Control: Development and validity of the *Go/No-Go App* test for children.

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Abstract

Based on the Go/No-Go paradigm, a set of inhibitory control tasks for the smartphone, the *Go/No-Go App* was developed for typical children and children with development coordination disorder. We examined its content, construct, and criterion validity. The inhibitory control Go/No-Go App test is comprised of four tasks: auditory and visual stimulus with motor response and auditory and visual stimulus with verbal responses. Three experts with PhDs in Neuropsychology and 252 Brazilian children (139 boys; 113 girls) participated in the study. Within this group, there was a subgroup of children with development coordination disorder (n=53). A high level of agreement for clarity and pertinence was observed among the experts (Gwet's Agreement Coefficients > .09), highlighting its content validity. Suitable Cronbach's alpha and McDonald's omega results were observed. The Confirmatory factorial analysis (CFA) accepted the results for the Auditory Motor (γ = .83), Visual Motor (γ = .73), Auditory Verbal (γ = .67) and Visual Verbal (γ = .73) tasks. The model presented adequate adjustment indexes (Chi-square = .48, *p* = 0.787), 2 / DF = .24; RMSEA = .00; GFI = .99; CFI = 1.00; AIC = 326.90. The Go/No-Go app is a test which shows the adequate validity and reliability evidence for the assessment of inhibitory control in children. The tasks may be very helpful for the assessment of the executive functions for children with motor disabilities (such as DCD) due to the variation of the stimulus (verbal and visual) and the responses (motor and verbal).

Key words: Content validity, construct validity, criterion validity, Go-No/go, inhibitory control, neuropsychological assessment in children.

Introduction

Executive functions are complex cognitive processes (Diamond, 2013) which involve selective inhibition control of behavior, cognitive flexibility, and working memory (Diamond, 2000; Miyake et al., 2000). Executive functions are essential for the performance of common tasks, influencing social and psychological development and the individual achievements (Barkley, 1997; Diamond, 2013). Specifically, inhibitory control is essential in effective goal-directed executive functions that inhibit irrelevant verbal or motor behavior (Diamond & Lee, 2011). Therefore, inhibitory control plays a critical role in the self-regulation (Tsai, 2009), internalization of speech (Barkley, 2001), and for the acquisition of proficient motor and cognitive skills (Diamond, 2013). Assessing inhibition in children with language and/or motor disabilities has been challenging considering the input and output of confounding variables.

Throughout childhood, inhibitory control develops at a constant pace, with more evident changes happening later in childhood (Best, Miller & Naglieri, 2011; Pureza, Jacobsen, Grassi-Oliveira & Fonseca, 2011). The demands of everyday experiences, such as school assignments (Bernardi, Leonard, Hill, Botting & Henry, 2017), peer interactions (Satta, Ferrari-Toniolo, Visco-Comandini, Caminiti & Battaglia-Mayer, 2017), and inhibition of behaviors that lead to inappropriate action (Tsai, 2009) requires constant inhibitory control function and are a challenge for children. Yet the demands are greater for children with a disability. For example, children with attention deficit/hyperactivity disorder (Verbruggen & Logan, 2008) or with developmental coordination disorder (DCD) (Querne et al., 2008) show inhibitory control deficits that negatively affect their capacity to suppress a response, resist temptations, and not act prematurely (Diamond, 2000), resulting in difficulties in school tasks (Best et al., 2011) and social interactions (Satta et al., 2017). Therefore, the assessment of the executive functions is critical to provide appropriate opportunities for children to learn.

Inhibitory control assessment is mainly comprised of tasks with pencil and paper that require different responses, resulting in possible interpretation biases in tests results (Alloway, 2007, 2011; Alloway & Archibald, 2008: Leonard, Bernardi, Hill & Henry, 2015). Specifically, some inhibitory control instruments include verbal responses. Other instruments include non-verbal or complex visuospatial processing with or without motor demands. The motor demands or the different types of stimuli involved in the tests may cause secondary performance losses, disguising the primary executive deficits that should have been predominantly examined (performance bias or visual perception), and thus limiting a more specific assessment of one's own executive functions.

Furthermore, considering the need to identify early deficits in cognitive development and changes in the process of acquiring new abilities (Salles, Sbicigo, Machado, Miranda & Fonseca, 2014), appropriate assessments, adapted to reality (Fonseca et al., 2011), are needed. One paradigm that has a long tradition in neuropsychological assessment is the Go/No-Go. Go/No-Go tasks demands that participants respond as quickly and as accurately as possible to a series of stimuli (go signals). This creates a strong tendency to respond and, on a random subset of trials (typically 10%), the go signal is not presented (Wright et al., 2014). The assumptions of the Go/No-Go paradigm (Hamdan & Pereira, 2009; Wegmann, Brand, Snagowski & Schiebener, 2016), were taken into consideration and we developed an app to assess the child’s ability to respond to a stimuli appropriately (Go) and to inhibit an automatic response (No-Go). In this paradigm, the indication of the inhibitory control ability relies on the probability that the child inhibits a behavior to a specific stimulus (No-Go).

Although Go/No-Go tasks have a long tradition, the majority of the tests have not been validated for children (Langenecker, Zubieta, Young, Akil & Nielson, 2007). Furthermore, although the app's tests as a possible measure of cognitive function have emerged over the last few years, researches still lack content, construct, and convergent validity for the tasks. Taking into consideration the children's exposure to electronic devices across different countries, an app to assess executive functions seems to be a practical solution that could easily be used in research and clinics. This enables the measurement of verbal and motor variables related to the inhibitory control of children and minimizes the role of these secondary aspects in the assessment of inhibitory control.

There is a gap in the use of valid executive functions test to understand inhibition behavior during child development. The evaluation of this model that include four tasks of inhibition with visual and auditory stimulus and verbal and motor responses is justified in typical children, but also in children with movement disorder (DCD) in order to see the real impact of executive functions in those children. Therefore, we designed and examined the content, construct, and criterion validity of a Go/No-Go inhibitory control test in an app for the smartphone for typical children and children with DCD.

Methods

Participants

The participants in the present study were three professionals with PhDs in Neuropsychology and more than 10 years of research and teaching experience in executive functions. There were also 252 children, 139 boys and 113 girls between 8 to 10-years old who were recruited in 4 cities and 10 schools (private: 28%; public: 72%) in Brazil. The children were selected from the schools and the families had to accept to participate in the present study.

To investigate the validity of the paradigm in children with DCD, a group of 53 children was constituted to verify the validity of the model in children with this type of disorder.

The identification of children with DCD was conducted adopting recommended criteria (American Psychiatric Association, 2013). The Movement Assessment Battery for Children – second edition (MABC-2; (Henderson, Sugden, & Barnett, 2007) was used to identify motor delays (Criterion A; APA 2013); children scores ≤ 5^{th}% were categorized as having DCD. The MABC-2-Checklist (Henderson, Sugden, & Barnett, 2007) was used to assess if the motor delays meaningfully interfere in the daily activities (Criterion B; APA 2013). Parents and teachers completed a questionnaire regarding motor milestone acquisition, to assess if the onset of symptoms occurred early in the development period (Criterion C; APA 2013); The WASI-Wechsler Abbreviated Scale of Intelligence was used to assess intellectual capabilities (Criteria D; APA 2013). The exclusion criteria included the presence of previous diagnosis of neurodevelopmental disorder or medical conditions, visual or hearing disabilities, and cognitive impairment. Informed consent was obtained from each parent or legal guardian and verbal consent was obtained from each child.

Instruments

The Go/No-Go App for smartphones was developed based on modulation and inhibition of response tasks (Nosek & Banaji, 2001). The measurement of inhibitory control was observed when the participant inhibited an automatic response that had been given to the a specific stimulus (Adele Diamond, 2013). The Go/No-Go App test developed consists of four inhibitory control tasks with 60 numbers with two forms of stimuli, auditory and visual. For each stimulus, two forms of responses were evaluated, motor and verbal. The first task in the *Go/No-Go App*, with visual stimuli and motor response (Visual-Motor), consisted of 60 numbers, from 1 to 9, which were presented randomly at every second in the smartphone display. The child then had to touch the screen after visually identifying each one of the numbers unless the number was six. On the second task, with visual stimulus and verbal response (Visual-Verbal), the numbers were also presented randomly at every second in the smartphone display, and the child had to respond verbally (yes) after visually identifying each of the numbers unless the number was six. On the third task, with auditory stimulus and motor response (Auditory-Motor), the child had to hear a sequence of 60 numbers, presented one at a time in a random order, and had to touch the screen after identifying each of the numbers heard unless the number was six. On the fourth task, auditory stimulus and verbal response (Auditory-Verbal), the child had to hear a sequence of 60 numbers, presented one at a time in a random order and had to respond verbally (yes) after listening to each one unless the number was six.

To summarize, the stimuli were 60 numbers, from 1 to 9, presented randomly (visually or verbally) at every second for all the four tasks. For each form of stimulus (auditory and visual) there were two possibilities of response, motor and verbal. In motor responses, the child had to touch the display every time after the presentation of all auditory and visual stimuli other than the predetermined number (six) to be inhibited. As for verbal responses, the child had to say *yes* after each auditory and visual stimulus except when the inhibitor number six was presented. The scores, which were errors when the child touched the screen. Figure 1 refers to the *Go/No-Go App* home page (a) and the display for the *Visual-Motor (b), Visual-Verbal (c), Auditory-Motor (d), and Auditory-Verbal.*

a. Home Page b. Visual-Motor c. Visual-Verbal d. Auditory-Motor e. Auditory-Verbal

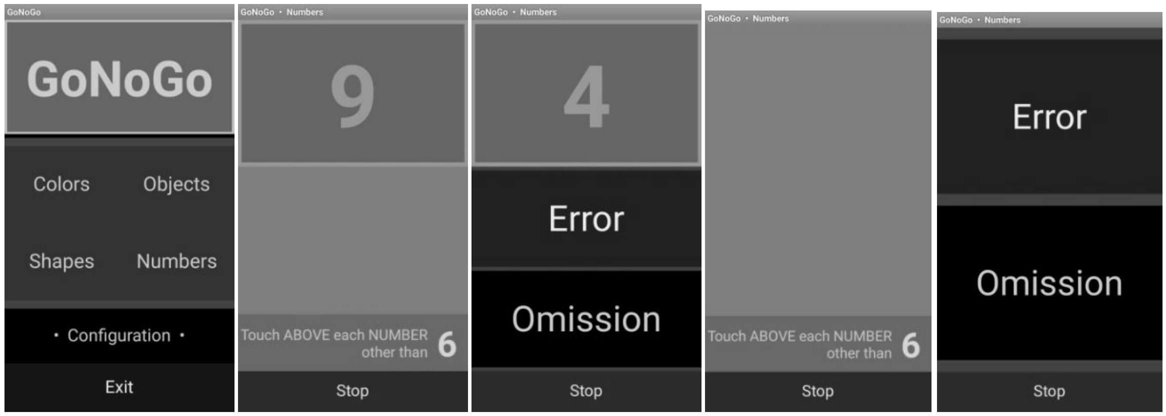

Figure 1. Homepage of *Go/No-Go App* (a) and first page of the tasks (b, c, d, e)

The Brazilian version (Fonseca et al., 2010, Siqueira, Gonçalves, Hübner & Fonseca, 2016) of the Hayling Test for Children (HTC) (Burgess & Shallice, 1996) was used in the present study to assess children's verbal behavior inhibition and investigate its convergent validity with the *Go/No-Go App*. In the HTC, the child has to complete 20 sentences as soon as possible. In section A, 10 sentences must be completed with a word that fits the requirements by the syntactic-semantic context while in section B the child has to complete the sentence with a word that is incompatible with the general meaning of the sentence. The HTC assesses reaction time and the error score for section A and B.

The Wechsler Abbreviated Scale of Intelligence (*Wechsler Abbreviated Scale of Intelligence Manual.*, 1999) was translated and adapted for Brazilian children (Trentini, Yates, & Heck, 2014) in order to assess cognitive impairment. The WASI is a brief measure of intelligence that is used from the age range of 6 to 89, measuring general intelligence. (Wagner, Camey, & Trentini, 2014).

Procedures

The ethics committee of the University approved the study. Initially, the main researchers in the present study, two experts with PhDs in Neuropsychology and one professional in software development, designed the *Go/No-Go App's* inhibitory tasks. The app was tested, and the final version was approved. Three experts, with PhDs in Neuropsychology, were invited to participate in the present study and were enrolled in the content validity investigation. Each expert received the test version, a Likert scale (5 points) with the test version, a tutorial video, and a description of the four Go/No-Go inhibitory control tasks for typical children and children with DCD. The experts judged the clarity and relevance of each task to assess inhibitory control in children (unclear/irrelevant = 1; more or less clear/relevant = 2; clear/relevant = 3; very clear/relevant = 4; optimally clear/very relevant = 5).

The board of education and school administrators were contacted. For all schools that responded positively to participate (n = 10), a meeting was held explaining the purpose and procedures of the study. The school staff contacted the parents and teachers who explained the research to all children. Initially, two procedures were adopted for sample estimation. Research information and consent forms were sent to the homes of 330 children. Of these, 286 children returned the informed consent signed by their parents or legal guardians (86% of parents' consent rate) and initially participated in the present study.

Children were assessed at schools by trained professionals. The assessments occurred during two sessions of approximately 60 minutes total. In the first session, inhibitory control tasks and HTC were conducted. In the second section, the WASI was conducted. Children with borderline (70-79) or deficient (69 and below) scores that showed intellectual level measured using the WASI scale (n = 12) and children that missed any assessment (n = 22) were excluded in the present study. Consequently, 252 children, between 8 to 10 years old, participated in the present study.

Each child completed the 3 assessments during individual testing sessions in a quiet room of the school. A random order for the assessment of the four Go/No-Go inhibitory tasks was adopted. For the Go/No-Go tasks, children first received verbal instruction and a demonstration. If the child did not understand the task, a new explanation was provided. For the motor response tasks, the examiner provided instructions demonstrating the task and after allowed children to manipulate the smartphone for about 30 seconds. After this period of adaptation, a training trial was provided before and after that the test started. For the tasks with verbal responses, the researcher provided task instructions by demonstrating the activity in a sequence of 10 numbers. After that, the child also had a training trial before the test started.

For the HTC, children were also assessed individually, in a quiet room, seated in front of a trained professional. Firstly, section A was presented orally by the researcher with the last word missing. Then the child promptly completed the sentences according to the sentence context (10 questions). In section B, the researcher also presented orally a sentence and the child had to complete it using a word with no semantic relation. For section B, the errors were computed. The assessment took approximately 15 minutes and the child then returned to the classroom.

The WASI test was individually administered (for about 15 minutes), also in a quiet room free of interruptions, to each child by a trained professional. The assessment was conducted with the child seated at a table in front of the examiner with a silence chronometer used outside of the vision range of the child. In the present study, two subtests were used, vocabulary and matrix reasoning, since these subtests estimate the general cognitive ability (Trentini et al., 2014). In the

WASI test, the vocabulary subtest has four items presented in the form of figures and 38 items represented by words. In the Matrix Reasoning subtest, the figures are missing, and the child must complete it by choosing among five possible answers. Both tests, HTC and WASI, were administered and scored following the procedures recommended in the manuals by trained professionals, psychologists familiar with children assessment.

Data analysis

Descriptive analysis was provided using mean, standard deviation, and percentages. To examine the evidence of content validity, the Content Validity Coefficient (CVC) was estimated (Hernandez-Nieto, 2002) for language clarity and relevance of each item and total items to assess inhibitory control of the children. The agreement among experts was calculated by Gwet's Agreement Coefficients (AC_1) weighted and, when recommended, unweighted by ordinal scale categories (Gwet, 2008b, 2008a). This test has been used as an alternative to measure the inter-rater (Banerjee, Capozzoli, McSweeney, & Sinha, 1999; Cicchetti & Feinstein, 1990; Feinstein & Cicchetti, 1990). Values above .80 were considered as high agreement (Landis & Koch, 1977).

The internal consistency and reliability were conducted to investigate the construct validity. Cronbach's alpha (α) and McDonald's (ω) omega tests were used. Values $\geq .70$ were considered acceptable for internal consistency of the instrument (Farsen, Fiorini, & Bardagi, 2017; Nunnally, 1978).

The investigation of construct validity was also conducted using Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA). Within EFA, initially, we verified the measure adequacy of the correlation matrix by Kaiser-Meyer-Olkin (KMO) with Bootstrap 95% confidence interval (CI95%) index and Bartlett's Sphericity Test. Values higher than .8 for KMO

(Kaiser, 1974) and significant statistics for Bartlett's test ($p <.005$) were considered as adequate. Principal Components extraction method and Varimax rotation were enrolled on EFA analysis. We examined the adequacy of the Go/No-Go app model by loading 4 skills onto the one factor. We considered the communality values (h) higher than .50. The CFA, using the covariance matrix and the estimation method Mean and Variance Adjusted Weighted Least Squares (WLSMV) were employed. Several indexes for the model were reported. The χ^2 test was used to measure the likelihood of the model to fit the data considering significant values as an indication of model discrepancies. The GFI (Goodness-of -Fit Index) and the CFI (Comparative Fit Index) with values $\geq .90$, as well as the AIC (Akaike's Information Criterion) were reported as additional indexes of the adjustment of the model (Hu & Bentler, 1999). The χ^2/degrees of freedom (χ^2/df) was used as a subjective measure of the adjustment quality, with values ≤ 5.00 accepted as an indicator of the adequacy of the theoretical model (Maroco, 2014). The RMSEA (Root Mean Square Error of Approximation Square Root of the Error) with values between .06 and .08 and 90% Confidence Interval (90% CI) were considered as appropriate adjustment of the model (Hu & Bentler, 1999). To verify if the model showed invariant adjustment among the TD and the DCD group, and an invariance factorial analysis was loaded using Multigroup analysis. We assessed: (1) configurational invariance, to analyze if the number of factors and items in each factor were acceptable for boys and girls as well as age groups. The CFI, GFI and RMSEA (90% CI) goodness fit index were used; (2) metric invariance, to analyze if loadings do not vary by groups and allow relationships to be compared between it (Babin, Borges, & James, 2016; Hair, Babin, & Krey, 2017; Kline, 2011; Maroco, 2014); (3) Scalar invariance, to analyze if the intercept terms for each variable and construct do not vary by group (Babin et al., 2016; Hair et al., 2017; Kline, 2011; Maroco, 2014). The comparisons of the models were conducted using delta RMSEA (Δ RMSEA) which means the differences between constrained and unconstrained models. Recommended cut-offs were adopted (< .015) to support the invariance assumption (Nagengast & March, 2014).

Criterion validity was investigated with two procedures, convergent and developmental item-criteria. Convergent validity was conducted to investigate the relationship of the four tasks of the Go/No-Go test with the scores of the HTC (Burgess & Shallice, 1996; Siqueira, Gonçalves, Hübner, & Fonseca, 2016). The Pearson correlation test and the analysis of the dispersion between the *Go/No-Go App* scores and the HTC errors, part B of the test, were used. Furthermore, developmental item-validity was investigated as a validity criterion using the correlation between scores in the four tasks and age. According to Cohen (1988) an absolute value of r .10 is classified as small, an absolute value of .30 is classified as medium and of .50 is classified as large (Cohen, 1988). The Psych package of R-free software (Revelle, 2011) and the Mplus version 8 program (Muthén & Muthén, 2017) were used. The significance level was set at $p \leq .05$.

Results

Error means and standard deviation are provided in Table 1 by sex and age for the *Go/No-Go App* inhibitory control tasks.

Table 1. Error Mean (M) and standard deviation (SD): Inhibitory control tasks by sex and age

Errors on Go/no-Go App	Total (n =252)	Girls (n = 113)	Boys (n = 139)	8 years (n = 84)	9 years (n =98)	10 years (n =70)
Visual-Motor	4.17(2.86)	3.92(2.65)	4.37(3.02)	4.33(2.70)	4.71(3.11)	3.98(3.71)
Auditory-Motor	5.38(2.82)	5.33(3.05)	5.41(2.63)	5.85(3.32)	5.83(3.20)	4.62(4.78)
Visual-Verbal	1.88(1.59)	1.68(1.57)	2.04(1.86)	1.94(1.43)	2.23(1.91)	1.93(2.00)
Auditory-Verbal	2.60(1.78)	2.48(1.65)	2.68(1.89)	2.90(1.82)	2.87(2.18)	2.10(2.23)

Content Validity

Most of the items were scored by three experts as total clarity (95.3% to 98.8%) and total pertinent (98.40 to 100.00%) in the 4 tasks of inhibitory control for typical children and children with DCD. We observed high content validity coefficient (CVC) regarding the totality of items among experts for linguistic clarity (from 96.60 to 97.30%) and for pertinence (100.00%). Yet the high CVC for each item also was observed (values ranged from .92 to 1.00 for linguistic clarity and .97 to 1.00 for pertinence among expert responses). The Gwet's AC_1 results ranged from .96 to .92 for clarity, and, for relevance, all coefficient values were equal to 1.00. These results show high concordance among experts. Table 2 shows the CVC and Gwet's AC_1 for language clarity and tasks relevance.

Table 2. Content validity coefficient (CVC) and Gwet'sAgreement Coefficient (AC_1) for language clarity and relevance for each item of Go/No-Go App.

Experts	**Clarity**			**Pertinence**		
	CVC (%)	AC_1 **(IC 95%)**	***p***	**CVC (%)**	AC_1 **(IC 95%)**	***P***
E-1 × E-2 × E-3	96.60	.92 (.90 to .97)	< .001	100	1.00 (1.00 to 1.00)	-
E-1 × E-2	97.31	.96 (.94 to .97)	< .001	100	1.00 (1.00 to 1.00)	-
E-1 × E-3	96.92	.92 (.93 to .90)	< .001	100	1.00(1.00 to 1.00)	-
E-2 × E-3	96.80	.94 (.91 to .95)	< .001	100	1.00 (1.00 to 1.00)	-

Abbreviation: E1, Expert 1; E2, Expert 2; E3, Expert 3; IC, Interval of Confidence, *unweighted Gwet'sAgreement Coefficients; # weighted Gwet'sAgreement Coefficients; CVC_t– content validity coefficient for total items

Construct Validity: Internal Consistency

Table 3 presents the internal consistency values of the Go/No-Go App (tasks and total test) measured by Cronbach's alpha and McDonald's omega tests. The values for total scale were suitable (α = .82; ω = .82). The exclusion of any task did not substantially alter the results. Yet, individual item results reinforce the evidence of the test construct validity

Table 3. Item and total scale reliability statistics for the internal consistency

	Cronbach's α	**McDonald's ω**
Auditory motor*	.70	.74
Visual motor*	.73	.78
Auditory verbal*	.77	.80
Visual verbal*	.76	.78
Total scale	.80	.82

*****If item was deleted

Construct Validity: Exploratory and Confirmatory Factorial Analysis

The Kaiser-Meyer-Olkin index (KMO = .81) and the Bartlett Sphericity test ((χ^2 (6) = 308.71, $p \leq .001$) indicated the adequacy of the data. The EFA showed a one-dimensional model (eigenvalue > 1.00; total variance explained 65.42 %). Consequently, for the CFA, only one factor model was tested. All factor loads were appropriate: Auditory-Motor (γ = .83); Visual-Motor (γ = .73); Auditory-Verbal (γ = .67) and Visual-Verbal (γ = .73). The model showed adequate adjustment indexes (χ^2 = .48, p = .787), χ^2/df =.24, RMSEA = .00; GFI = .99; CFI = 1.00; AIC = 326.90. We observed, by multigroup analysis, that the model without constriction demonstrated configurational invariance among children's groups with DCD and TD (CFI = .99, RMSEA = .02). The analysis also showed that the loadings do not vary by groups (Δ RMSEA = .003) to confirm the metric invariance. In addition, the scalar invariance of the model adjustment indicated that the intercept terms for each variable and construct do not vary by group (Δ RMSEA = .004). Figure 2 shows variables of the model and the factor loads of the items (λ).

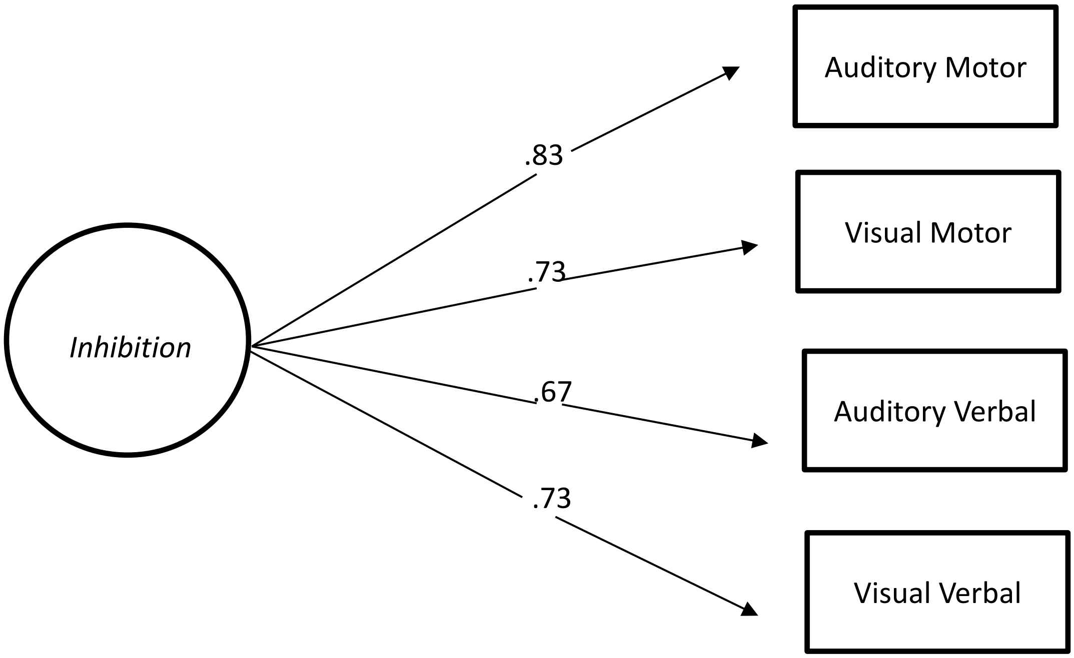

Figure 2**.** Factorial analysis diagram of the Inhibition control item in *Go/no-Go App*.

Criterion Validity: Convergent Validity

Regarding the convergent validity of the *Go/No-Go App* tasks, the Pearson correlation test indicated positive, moderate to small and significant correlation between HTC (part B) *and Auditory-Motor* score errors on typically (r = .39; p = .004) and DCD children groups (r =.15; p = .042). Positive, small and significant correlations were observed between HTC and *Auditory-Verbal* for both children groups (typically, r = .27; p = .049; and DCD, r = .17; p = .026). Small and nonsignificant correlations were found between the HTC and *Go/No-Go App* scores *Visual-Verbal* (r =.14, p = .095) and Visual-Motor (r =.12; $p < .118$). Figure 3 shows the dispersion of score errors of the *Go/No-Go App* tasks and the HTC (part B) by children groups.

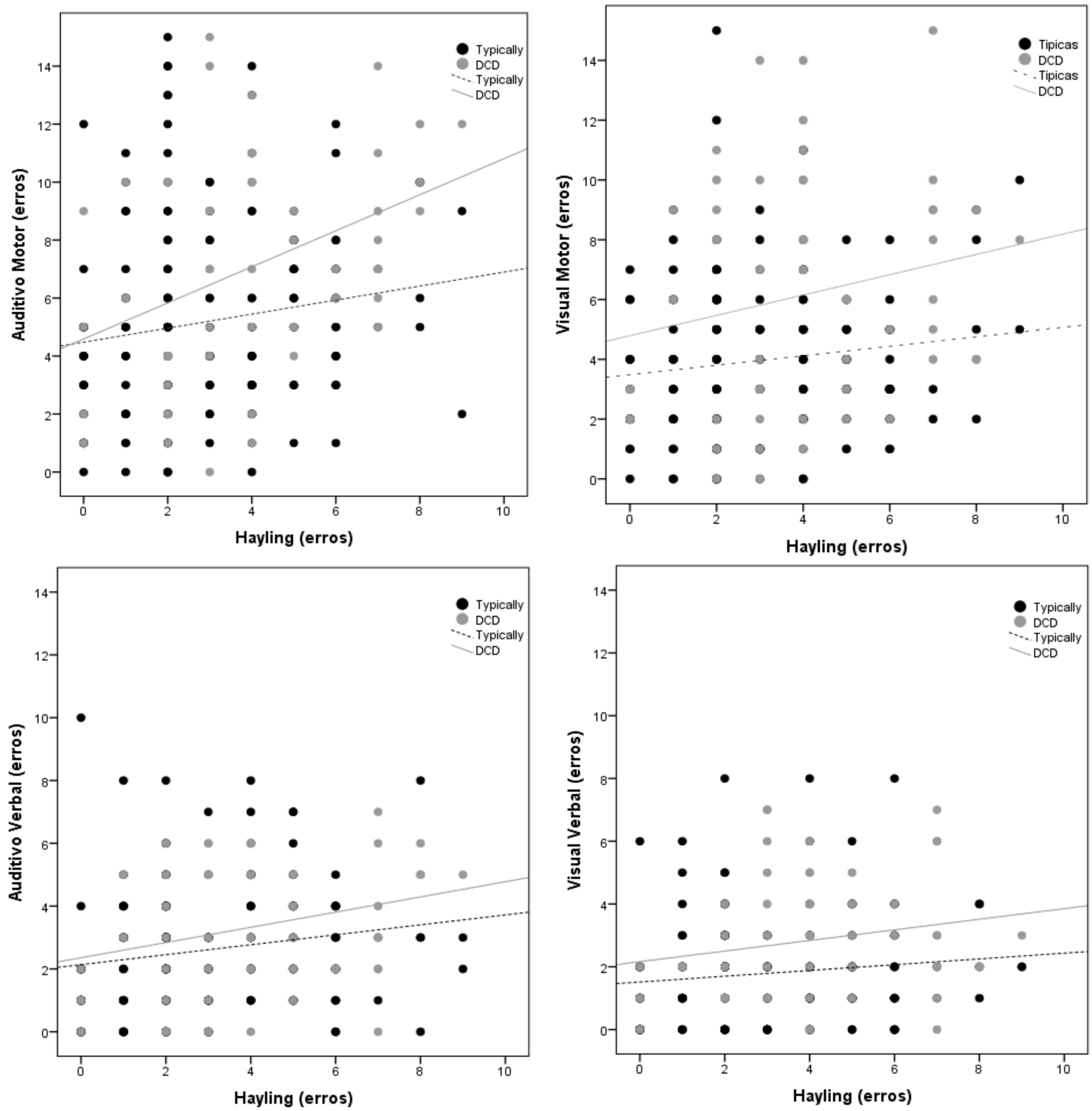

Figure 3. Scores dispersion of Go/No-Go errors in 4 tasks and Hayling Test by children groups

Criterion Validity: Item-Developmental Validity

The criterion validity of the tasks, concerning age differentiation, the item-developmental criteria validity, showed a developmental trend of decreases in the mean errors in the four tasks across age for the total of children. The figure 4 showed the mean errors in the four *Go/No-Go App* tasks by age for the children with DCD and children with typical development.

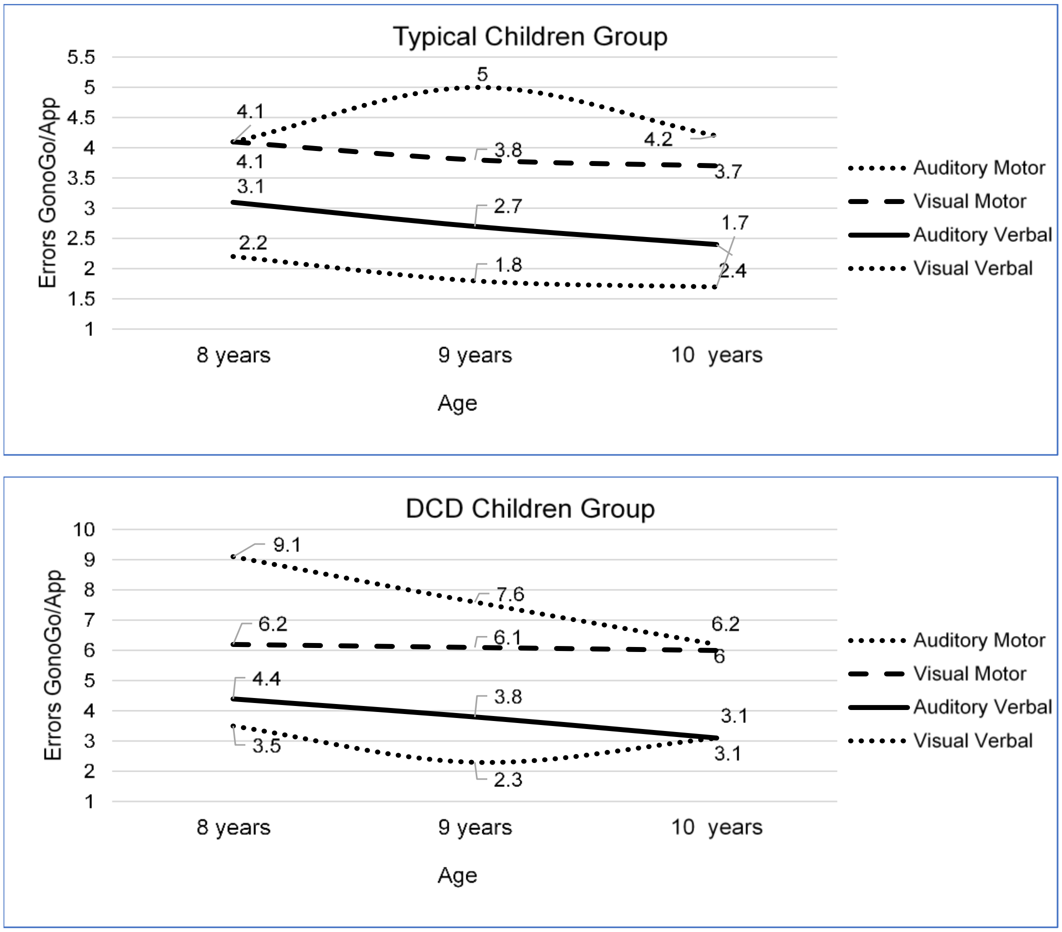

Figure 4. Mean errors in four different *Go/No-Go App* tasks by age for children with DCD and with typical development.

Discussion

In the present study, we designed a new set of tasks to assess inhibitory control in children. In addition, we had searched for evidence regarding its content, construct and criterion validity for children with DCD. The Go/No-Go inhibitory control test for children as an app for smartphones based on the Go/No-Go traditional neuropsychological paradigm has shown to be valid and useful for neuropsychological and educational goal assessment, contributing to mapping the development of executive functions as an essential part for developing preventive and remediation cognitive stimulation for children. One of the most pressing issues for clinicians in practice is the use of assessments on populations for whom it was not validated (Riley, Combs, Davis, & Smith, 2017).

Content Validity

In regard to clarity and pertinence, the results showed a strong coherence among the experts, as confirmed by the concordance coefficient (Nieswiadomy & Bailey, 2017). Regarding clarity, the instrument was considered by the judges as very easy for children to comprehend in both groups. Regarding pertinence, the judges considered that the tasks reflected the concepts involved and were adequate to measure the inhibitory control from different stimuli (auditory and visual) and with verbal and motor responses. Comparisons of the present results with previous studies are limited. Up to now, expert content validation was not reported in previous studies adopting the Go/No-Go paradigm (Votruba & Langenecker, 2013). However, its large use in research on inhibitory control across different populations reinforces the importance of this paradigm (Wright et al., 2014). Our results indicate that the Go/No-Go App showed high content validity indexes, with clear and pertinent tasks (Yun & Ulrich, 2002), both for the group of typical children and for the group of children with DCD. Previous studies have reported that children with DCD were less able to inhibit incorrect manual responses (Mandich, Buckolz, & Polatajko, 2002, 2003). This assumption is also in accordance with studies showing a global inhibition deficit in tasks not requiring a motor response in children with DCD (Leonard, Bernardi, Hill, & Henry, 2015; Wilson et al., 2017).

Construct Validity – Internal Consistency and Factorial Analysis

The combined use of EFA and confirmatory factorial analysis allowed the identification of the appropriate factorial explanation for the four tasks' model. The EFA results showed that all of the four tasks were relevant to represent the construct (Hair, Black, Babin, & Anderson, 2010). The four inhibitory control tasks, although different, were not completely independent and had a strong connection, therefore providing evidence for the one-dimensionality of the construct.

The CFA showed that the model evaluated explained 71% of the data variance. The four tasks were maintained in the model. All factorial loads obtained were between .66 and .83, and values above .40 have been accepted as acceptable representation of the factor (Hair et al., 2010)**.** The load factor (saturation) showed high correlations between the item and the factor (closer to 1.00), suggesting a strong representation of the latent trait measured by the factor. The CFA indexes provided further evidence for the model, and all the indexes adopted showed very strong results (Mulaik, 1972). The model is suitable for both typical children and children with DCD. Considering that children with DCD require a clearer diagnosis, the proposition of inhibitory control tasks with different demands (verbal and motor) seems to be an important point from the point of view of the early identification of difficulties presented in relation to this component of the executive functions.

In the present study, motor and verbal inhibitory control was assessed by the Go/No-Go tasks, assuming that each task, although they have diverse stimuli and response, would be related to a common inhibitory mechanism (Chambers, Garavan, & Bellgrove, 2009; Baddeley, 2003; Chambers et al., 2009; Logan, Van Zandt, Verbruggen, & Wagenmakers, 2014). The results in the factorial model provided support for this assumption. Language and the motor system are closely associated and have common cortical areas in the two cerebral hemispheres (Holden, 2004). A common co-activation of the inferior frontal cortex and the pre-supplementary motor area has been reported inhibition tasks with verbal responses and motor responses (Xue, Aron, & Poldrack, 2008). It is possible to assume that the relationship between the four tasks provide evidences about the importance of using different tasks to assess inhibitory control and that it may lead to a better understanding of executive functions in children. The analysis of this latent variables is a useful approach to study the organization and roles of executive functions (Miyake et al., 2000).

Criterion Validity - Convergent Validity

Regarding the convergent validity of the *Go/No-Go App* tasks, the Pearson correlation test indicated positive, moderate to small and significant correlation between HTC *and Auditory-Motor* scores on typically and DCD. Also, positive, small and significant correlation were observed between HTC and *Auditory-Verbal* both children groups. The *Go/No-Go App* tasks and the HTC, even though they possibly measure similar constructs, present different approaches in the assessment of inhibitory control due to the activation of other components of executive functions in the task. It is important to notice that the HTC included tasks with auditory stimulus that enable the assessment of different components of the executive functions, such as initiation, inhibition, planning, manipulation of information, selection, and evaluation of the response (Fonseca et al., 2010; Collette et al., 2001), whereas the Go/No-Go App was developed for inhibitory control only. Furthermore, lower correlations among executive functions variables were observed due also to the multidimensionality of this cognitive domain (Friedman et al., 2008). The results provided a fragile support for the convergent validity of the two *Go/No-Go App* tasks with HTC. Looking at the results, although only moderately related, it is possible to assume that the section B of the HTC and the auditory tasks of the *Go/No-Go App* provided similar information about the same construct (Cronbach & Meehl, 1976).

Criterion Validity is the degree to which variation on a test accurately predicts variation in a criterion of interest and when an assessment measure displays strong criterion validity (Riley et al., 2017). In this way, the *Go/No-Go App* is a test with adequate evidence of validity to evaluate inhibitory control in children. In this sense, it may be very helpful for a neuropsychological assessment of executive dysfunction for children with language and/or motor disabilities for its balanced distribution of input and output modalities.

Conclusion

The results of the present study prove that the *Go/No-Go App* test minimizes the motor bias for inhibitory control. The present results demonstrate that the *Go/No-Go App* is a test with adequate evidence of validity for the assessment of inhibitory control in typical children between 8 to 10 years old and in children with development coordination disorder. The *Go/No-Go App* may help clinicians and researchers to assess the capacity of inhibitory control since it is easy to use and may further provide more evidence related to the cognitive mechanisms of this executive functions. Specifically, these four Go/No-Go tasks may be helpful to assess executive subdomains related to different stimulus and responses, as well as the possible relations between motor abilities, executive functions and the learning processes across childhood.

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Artigo 3: Executive function in children with and without Developmental Coordination Disorder – A comparative study.

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Abstract

Background: Children with motor impairments also show poor performance in some executive functions' components. However, there is no consensus on which specific executive subdomain is more impacted. *Aim*: The objective of this study was to compare executive functions - working memory, inhibitory control, cognitive flexibility, in children with Developmental Coordination Disorder (DCD), at risk for DCD (r-DCD) and in children with Typical Development (TD). *Methods and procedures*: A sample of 397 children was assessed, distributed posteriori into the groups, with DCD (n = 63), at r-DCD (n = 31), and with TD (n = 63) based on the MABC-2, MABC-2 Checklist and WASI tests. Measures of executive function included verbal and nonverbal tasks for working memory (Odd-One-Out and Oral Word Span in Sentences), inhibitory control (Go/No-Go and Hayling tests), and cognitive flexibility (Five Digit Test and Trail Making Test) was tested. Multivariate analysis of variance followed by ANOVAS and Bonferroni tests were used to verify group effects on executive functions. *Results*: DCD group showed lower scores compared to TD group on the visuospatial and verbal working memory; inhibitory control (Go/No-Go tasks and Hayling Part B/errors) and verbal and nonverbal tasks of cognitive flexibility; r-DCD group showed lower scores compared to TD group for visuospatial working memory and for cognitive flexibility. *Conclusions and implications:* poor performance in several measures of executive functions in children with DCD emphasized the need of task specific interventions. Moreover, as far as children at r-DCD had disexecutive syndrome rosk as well, preventive executive functions stimulation should be developed especially for this subclinical group.

Key Words: Developmental Coordination Disorder; Motor Impairments; Executive Functions

Introduction

Children with Developmental Coordination Disorder (DCD) demonstrate motor skills impairments (Valentini, Clark, & Whitall, 2014), that sometimes are associated with academic achievement (Asonitou, Koutsouki, Kourtessis, & Charitou, 2012; Gomez, Piazza, & Jobert, 2015), particularly with reading, writing and mathematics skills (Alloway, 2007; Pieters, Desoete, Van Waelvelde, Vanderswalmen, & Roeyers, 2012). The poor perceptions of movement and the lack of planning may prevent those children to acquire more complex skills (Brown-Lum & Zwicker, 2015; Zwicker, Missiuna, Harris, & Boyd, 2012). Social development are also affected as the child lack several skills to interact with peers (Cairney, Rigoli, & Piek, 2013; Karras, Morin, Gill, Izadi-Najafabadi, & Zwicker, 2018) and also deficits in executive function (LEONARD et al., 2015b; WILSON et al., 2017)

Deficits in cognitive functions have also been reported affecting behavioral inhibition, memory and cognitive flexibility in children with DCD (Bernardi, Leonard, Hill, Botting, & Henry, 2017; Leonard, Bernardi, Hill, & Henry, 2015a; Schott & Holfelder, 2015). Executive functions are necessary to the individual regulate, monitor, and control behavior toward a goal (Diamond, 2000); skills that are essential to evaluate the efficiency and adequacy of behaviors, abandon inefficient strategies in favor more efficient ones, and to solve immediate, medium and long-term problems (Miyake & Friedman, 2012).

Working memory, inhibitory control and cognitive flexibility improve across childhood for children with typical development (Diamond et al., 2012). Whereas, children with DCD have persistent deficits in some components of the executive function that may affect school performance and other child development (Bernardi et al., 2017; Leonard et al., 2015a; Schott & Holfelder, 2015). Although in the last decade a growing area of research occurs, scarce and contradictory results are provided, for children with DCD, regarding the specific components of executive function. Yet, although children at risk of DCD (r-DCD) also need professional support, little is known about their executive functions profile. Furthermore, it seems reasonable to assume that if across countries similar executive functions batteries of executive function tests would be used, and at some extension, similar methodological approach, a clearer comprehension of the mechanisms involved in those deficits could be obtained. The objective of this study was to assess and compare executive functions, regarding to inhibitory control, working memory and cognitive flexibility in children with DCD, at risk of DCD (r-DCD), and typically development children. We predict that children with DCD would demonstrate lower scores in executive function compared to typical develop children.

Method

Participants

A sample comprised of 397 children was randomly recruited from through 5 cities, 12 schools (private 28%; public schools 72%) from Brazil. The identification of children with DCD was conducted adopting recommended criteria (APA, 2013). The Movement Assessment Battery for Children – second edition (MABC-2; (Henderson, Sugden, & Barnett, 2007) was used to identify motor delays (Criterion A); scores $\leq 5^{th}$% were categorized as probable DCD. The MABC-2-Checklist (Henderson, Sugden, & Barnett, 2007) was used to assess if the motor delays meaningfully interfere in the daily activities (Criterion B); scores in the red zone were considered excessive difficulties. Parents and teachers completed a questionnaire regarding motor milestone acquisition, to assess if the onset of symptoms occurred early in the development period (Criterion C); early onset was considered when children demonstrated the difficulties in the first years of life. (American Psychiatric Association, 2013)

Children at r-DCD were identified as those scoring in the MABC-2 between 5^{th} to ≤ 16^{th} %. Children with scores above 16th percentile composed the typical development (TD) group. Each child in the DCD group (n = 63; 24 girls; 39 boys) (Mage = 8.74, SD=0.64) was randomly matched with a child with TD (n = 63; 24 girls; 39 boys) (Mage = 8.74, SD=0.64) and at r-DCD child, from the remaining sample. However less prevalence of r-DCD was observed in the general sample, leading to a smaller number of children in the r-DCD group (n = 31; 11 girls; 20 boys) (Mage = 8.90, SD=0.74). Nonetheless, the groups were similar regarding sex, age, school grade, Body Mass Index (BMI), and family socioeconomic status (p values ≥ .05). Children (n = 8) with borderline (scores from 70 to 79) or deficient (scores ≤ 69) intellectual level considering the WASI results, children that missed assessment (n = 17), and children with medical report of disabilities and Attention Deficit and Hyperactivity Disorder (ADHD) (n = 9) were excluded from the present study. Informed consent was obtained from each parent.

Instruments

Four instruments were used as screening tools for the exclusion criteria and mapping development:

Body Mass Index (BMI) - The weight was measured at the minimum coverage and without shoes using a digital scale with a precision of 100 g. The height was measured via a stadiometer. The body mass index, the most commonly accepted index, was calculated to estimate obesity and was based on the charts of the reference Center for Disease Control (CDC).

Daily Activities. The MABC-2 Checklist (Henderson et al., 2007) validated for Brazilian children (Ramalho, Valentini, Muraro, Gadens, & Nobre, 2013), answered by the classroom teachers, was used to assess daily life function.

Motor Skills. The instrument used was the Movement Assessment Battery for Children (MABC) (Henderson et al., 2007), which is a battery of tests widely recognized as important in the identification of DCD in children.

Cognitive Skills. Wechsler Abbreviated Scale of Intelligence-WASI (*Wechsler Abbreviated Scale of Intelligence Manual.*, 1999). The present study involved the reduced version of the instrument, which consists of the Vocabulary and Matrix Reasoning tasks only.

The following instruments in the study were used for executive functions assessment:

Working Memory. Verbal Working memory was assessed using *Oral Word Span* in Sentences. The test assesses children capability of memorizing and recalling the last sentence, after sets of two, three, four, and five sentences was read by the examiner (Fonseca, de Salles, & Parente, 2008). Scores (28 maximum) were obtained from a repeated correct sentence (correct order of the words; score 2) and out of order sentence (words repeated in a different order; score 1). The *Odd-One-Out* (Henry, 2001) was used to assesses children nonverbal working memory. In this test children are presented with a figure and an increasing amount of information about the figure and then the examiner asks if the child remember an aspect of each figure presented. The span score is the whole number corresponding to last length which the child got right. Maximum score is 24.

Inhibitory Control. The *Go/No-Go App* and *Hayling* tests were used to assess inhibitory control. The *Go/No-Go App* is a test that contains 60 numbers recorded within 4 tasks that provided two forms of stimuli (auditory; visual) and two forms of responses (motor; verbal). The scores are composed by the errors (child touch or say the No-Go stimulus - number 6) and are recorded on the smartphone. To measure verbal inhibition the Hayling test was used (Siqueira, Gonçalves, Hübner, & Fonseca, 2016). During the test, sentences are presented to the child with the last word is missing. The child has to properly complete 10 sentences according to the context (Part A) and another 10 sentences with a word that has no semantic relation (Part B). Error scores were used (Fonseca et al., 2010).

Cognitive Flexibility. To measure cognitive flexibility the *Trail Making Test* (TMT) part A and B were used (Montiel & Seabra 2012). In part A Letters (A to L) and numbers (1 to 12) randomly arranged on a single sheet were presented to the child. In the part B the child must connect items following an alternating numeric and alphabetic sequence, for one minute. Score were obtained by the number of items correctly connected in an unbroken sequence in part B. To measure cognitive flexibility the *Five Digits Test* (FDT) also was used (Paiva, Fialho, Costa, & de Paula, 2016) since it is a numerical test with Stroop effect, relatively independent of reading ability (Sedó, 2004). The FDT contain four tasks and the scores were obtained by time to complete the tasks and the mistakes made.

Procedures

The university ethical committee approved the study. The education boards of five cities agree to be a part of the study. Meetings were held with schools' administrators to explain the study; surveys and informed consents were sent home for the randomly selected children. The MABC-2 was administered at the school in sport courts and open spaces; the cognitive assessments and BMI were completed in a quiet room. The assessments of each child occur during three sessions of approximately 120 minutes. In the first session the MABC-2, BMI, *Go/No-Go App* and *Hayling* tests were conducted. In the second, the remained executive functions' tests were conducted. In the last section WASI was conducted. Before each session, children were given a brief explanation regarding the tests, were encouraged to ask questions, and reminded that they could stop the session at any time. All tests were administered and scored following the procedures recommended in the manuals by 5 trained professionals.

Statistical Analyses

One-way multivariate analyze of variance (MANOVA) was used to verify group effects on executive function. Asymmetry (sk) and kurtosis (ku) were adopted, with values the sk > 3 for and ku > 7 considered as violation of the multivariate normality (Maroco, 2014a). Variance-covariance homogeneity was assed using Box-M test. Wilks' Lambda was adopted as the criterion for the multivariate. Bonferroni multiple-comparison test was used to verify possible differences if main effects were found. Partial eta square (η^2) was adopted to estimate effect size with recognized cut-off values (η^2: $\leq$ .05 = small; from .06 to .25 = moderate; from .26 to .50 = high; > .50 = very high; (Cohen, 1988; Maroco, 2014b); $p \leq .05$ was adopted for all analysis.

Results

Working Memory

A significant group effect (Λ = .78, F (4, 360) = 10.12, $p \leq .001$, $\eta^2 = .12$), with moderate effect size, was found. Significant differences were found for the *Odd-One-Out* (F(2, 156) = 18.06, $p \leq .001$, $\eta^2 = .07$) and the *Oral Word Span* (F(2, 156) = 5.62, $p \leq .001$, $\eta^2 = .02$) tests, with moderate and small effect size, respectively. Bonferroni analysis showed that for the *Odd-One-Out* the DCD (p values $\leq$ .001) and r-DCD (p values $\leq$ .024) groups demonstrated lower scores compared to TD group.

Inhibitory Control

A significant group effect was found (Λ = .59, F (16, 294) = 5.48, $p \leq .001$, $\eta^2 = .23$) with moderate effect size. Significant differences, with moderate effect sizes, were found for the *Go/No-Go App; Auditory-Motor* (F(2, 156) = 19.16, $p \leq .001$, $\eta^2 = .20$), *Visual-Motor* (F(2, 156)

= 11.96, $p \leq .001$, $\eta^2 = .13$), *Auditory-Verbal* (F(2, 156) = 5.53, $p = .005$, $\eta^2 = .07$), *Visual-Verbal* (F(2, 156) = 7.18, $p \leq .001$, $\eta^2 = .08$), and for *Hayling* part B/errors (F(2, 156)=19.16, $p \leq .001$, $\eta^2 = .20$) tests. Bonferroni analyses showed that for the *Go/No-Go App* (p values $\leq .005$) and the *Hayling* part B/error ($p \leq .001$) tests the DCD group showed lower scores than the TD group. We do not find differences between r-DCD and TD groups for those tests.

Cognitive Flexibility and Inhibitory Control

A significant group effect was found ($\Lambda = .60$, F (22, 288) = 3.74, $p \leq .001$, $\eta^2 = .22$), with moderate effect size. Significant differences were found, with moderate effect sizes, regarding processing speed (FDT Part 2/time: F(2, 156)=10.52, $p \leq .001$, $\eta^2 = .12$), cognitive flexibility and inhibitory control measured by the *Five Digit Test* (FDT Part 3/errors: F(2,156) = 12.81, $p \leq .001$, $\eta^2 = .14$; FDT Part 3/time: F(2, 156) = 6.05, $p = .003$, $\eta^2 = .07$; FDT Part 4/errors: F(2, 156)=21.37, $\leq .001$, $\eta^2 = .02$; FDT Part 4/time: F(2, 156) = 4.48, $p = .013$, $\eta^2 = .05$) and cognitive flexibility measured by the *Trail Making Test* Part B, (F(2, 156) = 7.79, $p = .001$, $\eta^2 = .09$). Bonferroni analyses showed that DCD group presented lower scores than TD Group at FDT Part 2/errors ($p \leq .001$), FDT Part 2/time ($p \leq .001$), FDT Part 3/errors ($p \leq .001$), FDT Part 3/time (p = .006), FDT Part 4/errors ($p \leq .001$), FDT Part 4/time ($p = .011$), and TMT B ($p \leq .001$). The (2) r-DCD group showed lower scores than the TD group at the FDT Part 3/errors ($p = .010$) and FDT Part 4/errors ($p = .010$).

In summary, (1) DCD children showed lower scores compared to TD group on the visuospatial (*Odd one Out*) and verbal (*Oral Word Span*) working memory; (2) DCD group showed lower scores compared to TD group in inhibitory control (*Go/No-Go App* tasks and *Hayling* part B/errors) and cognitive flexibility (FDT Parts, 3 and 4 and *Trail Making Test*); (3) r-DCD group showed lower scores compared to TD children for working memory (*Odd one Out*) and for cognitive flexibility (FDT Part 3 and 4/errors). No differences were found between DCD and r-DCD children. Table 1 shows executive functions means and standard deviation by groups.

Table 1. Sample characteristics & executive functions: groups mean, standard deviation and statistics results.

	Sample characteristics & Executive Function by Groups M(SD)		
	DCD (n=63)	r-DCD (n=31)	TD (n=63)
Age (years)	8.70(0.6)	8.90(0.7)	8.70(0.6)
BMI (Kg/m^{2})	17.30(3.3)	18.70(3.5)	17.40(2.6)
WASI	99.10 (10.02)	102.06(12.21)	103.32(15.10)
Working Memory			
Odd One Out	8.11(2.60) [a]	9.55(2.73) [b]	11.30(3.40) [ab]
Oral Word Span	11.02(3.59) [a]	10.68(3.38)	12.78 (3.37) [a]
Inhibitory Control: Go-No-Go Test			
Auditory-Motor	7.27(3.12) [a]	6.51(3.13)	4.25(2.23) [a]
Visual-Motor	6.09(3.65) [a]	4.68(2.98)	3.48(2.19) [a]
Auditory-Verbal	3.33(2.03) [a]	3.12(2.10)	2.29(1.43) [a]
Visual-Verbal	2.39(1.90) [a]	2.70(1.78)	1.61(1.29) [a]
Processing Speed: Hayling Test			
Part A time	12.85(6.81)	14.06(7.39)	11.81(6.18)
Part A errors/10	.46(.82)	.38(.68)	.25(.44)
Inhibitory Control & Cognitive Flexibility: Hayling Test			
Part B errors/10	5.05(1.91) [a]	4.35(2.12)	2.50(1.85) [a]
Part B time	28.14(21.79) [a]	30.03(21.11)	26.87(19.57) [a]
Processing Speed: Five Digit Test			
Part 1 Errors	.22(.41)	.19(.40)	.95(.29)
Part 1 Time	40.16(14.45)	39.39(11.40)	34.41(7.28)
Part 2 Errors	.61(.91)	.51(.71)	.19(.39)
Part 2 Time	61.11(22.38) [a]	50.58(15.94)	46.31(14.79) [a]
Inhibitory Control & Cognitive Flexibility: Five Digit Test			
Part 3 Errors	5.25(3.03) [a]	5.58(4.06) [b]	2.92(2.19) [ab]
Part 3 Time	91.7 3(29.65) [a]	77.90(15.73)	78.28(20.67) [a]
Part 4 Errors	7.33(4.32) [a]	7.97(4.24) [b]	3.73(02.23) [ab]
Part 4 Time	104.81(29.76) [a]	95.87(21.99)	91.70(20.48) [a]
Inhibitory Control & Cognitive Flexibility: Trail Making Test			
Part B (sequences)	6.33(6.08) [a]	7.90(5.79)	8.50(4.40) [a]

Note. In the same row letters alike [a, b] represents statistical differences between specific groups.

Discussion

Executive functions in children with DCD, r-DCD and TD were investigated in the present study. As predicted, in general, children with DCD performed significantly worse than TD children on all measures of working memory, inhibitory control and cognitive flexibility, similar to previous studies (Leonard, Bernardi, Hill, & Henry, 2015b; Tsai, Pan, Chang, Wang, & Tseng, 2010; Wuang, Su, & Su, 2011). When comparing the differences between groups at risk for DCD with the TD group, differences in spatial visual memory and cognitive flexibility were found. The results show that the r-DCD group is heterogeneous regarding some more cognitive resilience to compensate for executive dysfunction or not. However, regarding the differences between motor delay groups no differences between DCD and r-DCD were found. These results provided support for the contention that standard deficits in some executive function components do not vary with severity of motor disorder, indicating some similarities in part of the executive function components regardless of the severity of motor impairment (Chen, Wilson, & Wu, 2012). Our results suggested that children with DCD and at r-DCD performed similarly, supporting that for this specifics component of executive functions no significant differences are observed although they showed different levels of motor impairments (Leonard et al., 2015a). Regardless of the diagnosis of DCD or r-DCD, motor delays in children seem to imply, at least in part, on the ability related to the components of executive functions.

Working Memory

The results showed that children with DCD and r-DCD performed significantly worse than TD children on measures of working memory (*Odd-One-Out*), that contain visuospatial challenges. Previous studies suggested that visuospatial executive functions tasks are more difficult than verbal tasks for children with DCD (Leonard et al., 2015b), reinforcing the case for a relationship between poor motor skills and visuospatial difficulties. It is important to note that the *Odd-One-Out* task present very limited motor demands, but performance in children with motor impairments was nevertheless reduced compared to the typically develop children, similar to previous finds using the same assessment (Leonard et al., 2015b) and also using different one (Alloway & Temple, 2007).

The interdependency between motor deficits and visuospatial working memory has important implications. Visuospatial working memory consistently activates areas of motor preparation and planning, including the premotor cortex (in special, the left hemisphere), inferior frontal gyrus, supplementary and pre-supplementary motor areas (Koziol & Lutz, 2013). Likewise, in the cerebellum, motor planning regions are also activated during the use of the visuospatial working memory (Ito, 2008). Therefore, during working memory tasks, both planning and preparation regions of the movement are strategically recruited (Koziol et al., 2013). Therapists and teachers may consider this co-activation process when planning specific tasks to implement in interventions for children with DCD.

Inhibitory Control

Children with DCD performed worse than TD children in all inhibitory control tasks (*Go/No-Go App* and *Hayling* part B tests), similar to previous studies (Leonard & Hill, 2015; Mandich, Buckolz, & Polatajko, 2002, 2003; Michel, Roethlisberger, Neuenschwander, & Roebers, 2011; Querne et al., 2008). The singular contribution of the present study was show that the differences between DCD and TD group occurred in the inhibition tasks with motor and also with verbal responses. Language and motor system are closely associated and have common cortical areas in the two cerebral hemispheres (Holden, 2004); and, a common co-activation of the inferior frontal cortex and pre-supplementary motor area has been reported in inhibition tasks with verbal and motor responses (Xue, Aron, & Poldrack, 2008), a possible explanation for the present findings.

Regarding to visuospatial attention and reaction time in tasks that require inhibition (e.g. *Simon Test* and *Covert orienting of visuospatial attention task* - COVAT), children with DCD exhibit inhibition control dysfunction (Mandich et al., 2002) due probably to attention impairment, leading them to spend more time to assimilate the stimuli presented in the tasks (Tsai, Pan, Cherng, Hsu, & Chiu, 2009; Tsai, Wang, & Tseng, 2012); similar to our results during the 4 tasks of *Go/No-Go App* and *Hayling* test. It is important to notice, that in some previous studies children with DCD did not showed inhibition difficulties (Dyck & Piek, 2010; Livesey, Keen, Rouse, & White, 2006; Piek et al., 2004). A possible explanation resigns on methodological different approaches.

It is important to highlight that, although motor and inhibition difficulties combined prevent the child to participate in several motor activities (Pesce et al., 2016), attention and inhibition processes are trainable during development (Diamond, Barnet, Thomas, & Munro, 2007). It seems possible that cognitive demands during motor tasks lead to improvements in executive functions (Best, 2010). As example, positive association between motor performance and inhibitory control in children with DCD, after intervention periods, has been suggested as a result of a better motor learning experiences (Tsai, 2009; Tsai et al., 2014). Therefore, the adequacy of motor practices involving cognitive inhibition demands may generate a potential of trainability for children with DCD.

Cognitive Flexibility

Children with DCD in the present study, in both tests of cognitive flexibility (FDT and TMT) showed poor performance, similar to previous studies (Michel et al., 2011; Piek, Dyck, Francis, & Conwell, 2007b; Toussaint-Thorin et al., 2013). Specifically, children with DCD and r-DCD were significantly less accuracy in cognitive flexibility, in relation to the time used to discriminate elements in the FDT tasks, suggesting that the visuospatial processing is impaired in this group of children, similar to previous studies (Piek, Dyck, Francis, & Conwell, 2007a).

Furthermore, the results of TMT suggested that, children with DCD in the present study, had more difficulties to connect numeric and alphabetic displayed apart in a page; slower visual scanning in children with motor deficits has been reported early (Toussaint-Thorin et al., 2013) and may be the case in the present study. It is possible that the deficiencies in cognitive flexibility may be related with disturbances in the visuospatial processing for children with DCD, affecting reaction time, and not as a result of its own capacity of this component of the executive function (Toussaint-Thorin et al., 2013). Yet, children with DCD have difficulty in recognizing the similarities or differences in certain motor tasks, therefore they pay more visual attention and devote more time to complete the tasks (Missiuna et al., 2014). Consequently, this leads to difficulties in the ability to change perspective when thinking, acting and analyzing an information, considering different aspects of a person's behavior or the possibilities forms of an object (Diamond, 2013) and participating in motor activities (Wuang et al., 2011).

Despite of the possible reasons, the reduced capability observed in working memory, inhibition and cognitive flexibility in children with DCD and r-DCD in the present study, suggest that those children need further assistance. It is possible that not only motor skills, but also the executive functions could impact their daily activities, and specifically physical activity participation. Participation in motor activities depends on the understanding of different ways of playing a game or trying different strategies in resolving conflicts with other children or adults (Diamond, 2012), imposing a high skill demands on children with DCD. Our results revealed of distinctive profiles for executive function in children with DCD and r-DCD when compared with TD children and emphasized the need for tasks specific interventions program that implement the executive/motor challenges for the development of learning mechanisms in children with motor disorder.

The neuropsychological assessment and the motor abilities examination cannot be isolated from each other anymore. we need to have more interdisciplinary teams to asses and, for consequence, to promote more effective program interventions. Children with DCD and even with r-DCD require early intervention to help them learn strategies to compensate for their executive functions and coordination difficulties, to feel better about themselves as individuals, and to prevent other secondary issues from developing. Those programs should also include motor and cognitive executive tasks altogether for both educational and clinical for the near future.

Conflict of interest statement

The authors have no financial or personal relationships with other people or organizations that could inappropriately influence or bias their work in this study.

Key Messages

- This study presents results of several tests of components of executive functions comparing children with DCD, risk for DCD and typical children.
- The groups' comparisons on the performance of working memory, inhibitory control, and cognitive flexibility provided different profiles of executive function in children with DCD, r-DCD and TD.

- The results suggest that children with motor disorder also have lower performance in a series of EF tasks.
- Motor and verbal inhibitory control seems to be affected in children with DCD.
- There is a need for intervention processes that meet the executive/motor demands to help children with DCD development learning mechanisms.

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Artigo 4: Could executive functions and the motor skills, predict writing and mathematical' performances of children with DCD, at risk of DCD and typically develop?

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Abstract

The aim of this study was to examine whether executive functions (working memory, inhibition, and cognitive flexibility), locomotor skills, and object control motor skills are meaningful predictive factors for writing and math performance in children with DCD, at risk for DCD (r-DCD) and with typical development (TD). Children (n = 397) were randomly recruited in 5 cities, 12 schools from Brazil. Children at r-DCD group (n = 31; 11 girls; 20 boys) were identified as those scoring in the MABC-2 between 5^{th} to ≤ 16^{th} %. Children with scores above 16th percentile composed the typical development (TD) group. Each child in the DCD group (n = 63; 24 girls; 39 boys) was randomly matched with a child with TD. The Movement Assessment Battery for Children and the Checklist was used. Measures of executive function included verbal and nonverbal tasks for working memory (Odd-One-Out and Oral Word Span in Sentences), inhibitory control (Go/No-Go and Hayling tests), and cognitive flexibility (Five Digit Test and Trail Making Test) was tested. In addition, TGMD to assess fundamental motor skills and TDE II to assess the performance of writing and mathematics were used. A multivariate multiple linear regression analysis and equation model were used. Regarding to the children with DCD, the results showed that the model explained 39% and 31% of the variability in the performance of math and writing, respectively. Significant results were found for the inhibitory control tests in the *Go/No-Go App* test. The *Auditory-Motor* (β = 0.36, *p* = .009) and *Auditory-Verbal* (β = .38, *p* = .023) tasks were the best predictors for math performance. The *Auditory-Motor* task was a predictor of writing skills (β = -.41, *p* = .005). Significant results were also found for the *Odd One Out.* The visuospatial working memory test predicted the writing performance (β = -.33 p = .011). Regarding children at r-DCD group, the model explained 52% of math and 57% of writing performances. The scores of the *Visual-Motor* task (inhibitory control) predicted writing performance (β = -.47; p = .015). *Auditory-Motor* (β = .67; p = .002) and *Verbal-Motor* (β = -.40; p =.048) predict math performance. The results of this study suggest that the poor performance in measures of inhibition and visuoespacial working memory test in children with DCD and r-DCD predict writing and mathematical' performances.

Key Words: Developmental Coordination Disorder; Executive Functions; writing and mathematical' performances

Introduction

Some children seem to go through a daily struggle during the tasks proposed in the classroom. Several times, difficulties are related to process visuospatial information or to complete a motor task (such as writing) while, at the same time, receiving new information regarding the tasks. In addition, they struggle to inhibit some pre-potent responses and even plan their actions when try to solve math problems, for example. Some of these children presented delays in the acquisition of motor milestones as well as difficulties in the execution of motor tasks throughout the childhood, especially those that involve daily activities (Valentini et al., 2012; Wilson, Ruddock, Smits-Engelsman, Polatajko, & Blank, 2012; Zwicker, Missiuna, Harris, & Boyd, 2012); therefore, the organization and planning of movements and the time management seems to be negatively affected (Brown-Lum & Zwicker, 2015; Zwicker et al., 2012). All these difficulties combined may have negative repercussions in school related to learning. A large group of those children have being diagnosed with Developmental Coordination Disorder (DCD; (American Psychiatric Association, 2013).

Since the prevalence of the disorder is associated with difficulties in writing, reading, and mathematics (Alloway, 2007; Missiuna, Rivard, & Pollock, 2004; Pieters, Desoete, Van

Waelvelde, Vanderswalmen, & Roeyers, 2012) academic (Asonitou, Koutsouki, Kourtessis, & Charitou, 2012a; Gomez, Piazza, & Jobert, 2015) and/or cognitive performance (Leonard, Bernardi, Hill, & Henry, 2015a) are affected; and, very often they lack social skills to interact with peers and seems more fragile emotionally (Cairney, Rigoli, & Piek, 2013). Children with DCD, besides experience all the motor coordination difficulties, reporting executive function deficits related to inhibition of unwanted behavior (Leonard, Bernardi, Hill, & Henry, 2015b; Pratt, Leonard, Adeyinka, & Hill, 2014; Querne et al., 2008; Rahimi-Golkhandan, Steenbergen, Piek, & Wilson, 2014; Tsai, 2009), working memory (Alloway & Temple, 2007; Biotteau, Albaret, Lelong, & Chaix, 2016; Leonard et al., 2015b; Piek et al., 2004; Tsai, Chang, Hung, Tseng, & Chen, 2012; Williams, Omizzolo, Galea, & Vance, 2013), and cognitive flexibility (Leonard et al., 2015b; Michel, Roethlisberger, Neuenschwander, & Roebers, 2011; Piek, Dyck, Francis, & Conwell, 2007; Wuang, Su, & Su, 2011) that seems also to negatively affected those children (Leonard et al., 2015a; Michel, Molitor, & Schneider, 2016; Piek et al., 2004; Wilson et al., 2012), which may continue into adulthood (Bernardi, Leonard, Hill, Botting, & Henry, 2017).

It is important to notice that executive functions have been identified as a strong predictor of academic achieve in typically developing children (Best, Miller, & Naglieri, 2011; Yeniad, Malda, Mesman, Van Ijzendoorn, & Pieper, 2013),as well as in children with DCD (Bernardi et al., 2017; Gomez et al., 2015; Prunty, Barnett, Wilmut, & Plumb, 2016; Zwicker et al., 2012). However, few studies have attempted to identify which components of the executive functions can predict the performance of writing and math in children with DCD. In addition, understanding if the variation of the motor impairment implies differences in relation to the predictive role of the executive functions on writing and math skills, to our knowledge, has not been yet addressed. Thus, the aim of this study was to examine whether executive functions (working memory, inhibition, and cognitive flexibility), locomotor skills, and object control motor skills are meaningful predictive factors for writing and math performance in children with DCD, at risk for DCD (r-DCD) and with typical development (TD). Considering that children with DCD demonstrated less activation in the prefrontal and parietal-cerebellar networks (Zwicker, Missiuna, Harris, & Boyd, 2011), regions of the brain involved in motor planning, inhibitory control (Brown-Lum & Zwicker, 2015), and visuospatial information process (Zwicker et al., 2011) we hypothesized that executive functions would predict the performance of writing and math skills in children with DCD since these skills require more effort no management of cognitive resources for academic achievement.

Method

Participants

Children (n = 397) were randomly recruited through 5 cities, 12 schools (private 28%; public schools 72%) from Brazil. The identification of children with DCD was conducted adopting recommended criteria (APA, 2013). The Movement Assessment Battery for Children – second edition (MABC-2; (Henderson, Sugden, & Barnett, 2007) was used to identify motor delays (Criterion A; APA 2013); children scores ≤ 5^{th}% were categorized as having DCD. The MABC-2-Checklist (Henderson, Sugden, & Barnett, 2007) was used to assess if the motor delays meaningfully interfere in the daily activities (scores in the red zone were considered excessive motor difficulties) and school reports to assess if the motor delay interfere in academic performance (Criterion B; APA 2013). Parents and teachers completed a questionnaire regarding motor milestone acquisition, to assess if the onset of symptoms occurred early in the development period (Criterion C; APA 2013); early onset was considered when children demonstrated the difficulties in the first years of life. To assess if the coordination difficulties were relate or not to a medical condition school medical records was used (Criterion D; APA 2013). The WASI- Wechsler Abbreviated Scale of Intelligence was used to assess intellectual capabilities (Criteria D; APA 2013).

Children at r-DCD group were identified as those scoring in the MABC-2 between 5th to ≤ 16th %. Children with scores above 16th percentile composed the typical development (TD) group. Each child in the DCD group (n = 63; 24 girls; 39 boys)) (Mage = 8.74, SD=0.64) was randomly matched with a child with TD (n=63; 23 girls; 40 boys)) (Mage = 8.74, SD=0.64) and at r-DCD child, from the remaining sample. However less prevalence of r-DCD was observed in the general sample, leading to a smaller number of children in the r-DCD group (n = 31; 11 girls; 20 boys)) (Mage = 8.90, SD=0.74). Nonetheless, the groups were similar regarding sex, age, school grade, Body Mass Index (BMI), and family socioeconomic status (p values ≥ .05). Children (n=12) with borderline (scores from 70 to 79) or deficient (scores ≤ 69) intellectual level assessed using the WASI, and children (n = 17) that missed assessment, and children with medical report of disabilities and *Attention Deficit and Hyperactivity Disorder* (n = 9) were excluded from the present study. Informed consent was obtained from each parent. Refers to Table 1 for children demographic information.

Instruments and procedures

Body Mass Index (BMI) - The weight was measured at the minimum coverage and without shoes using a digital scale with a precision of 100 g. The height was measured via a stadiometer. The body mass index, the most commonly accepted index, was calculated to estimate obesity and was based on the charts of the reference Center for Disease Control (CDC).

Daily Activities. The MABC-2 Checklist (Henderson et al., 2007) validated for Brazilian children (Ramalho, Valentini, Muraro, Gadens, & Nobre, 2013), answered by the classroom teachers, was used to assess daily life function.

Motor Skills. The Movement Assessment Battery for Children - second edition (MABC-2; (Henderson et al., 2007) validated for Brazilian children (Valentini, Ramalho & Oliveira, 2014) was used for assess motor delay and the identification of children with DCD.

Fundamental Motor Skills. The third edition of the TGMD (TGMD-3; Ulrich 2017) validate for Brazilian children (Valentini, Zanella, & Webster, 2016) was used to assess children's locomotor (run, gallop, skip, hop, jump, slide) and object control (two hand strike, forehand strike, dribble, catch, kick, overhand throw, underhand throw) performance. Each skill in the TGMD- 3 has several components that reflect the most efficient movement, each component of the skill is scored a ‘1’ if it is present or a ‘0’ if the component is absent. Raw scores were used with a range from 0 to 46 for locomotor and from 0 to 54 for object control.

Cognitive Skills. Wechsler Abbreviated Scale of Intelligence-WASI (*Wechsler Abbreviated Scale of Intelligence Manual.*, 1999). The present study used the reduced version of the instrument, which consists of the Vocabulary and Matrix Reasoning tasks.

School Performance. The subtests of writing and arithmetic of the Test of School Performance - TDE II (Stein, Fonseca & Giacomoni, in preparation, Athayde, Giacomoni, Mendonça, Fonseca & Stein, 2016) was used to assess school performance. The writing subtest is composed of 40 dichotomous items of words with levels of difficulty relates to the school grades. Ten consecutive errors were used as interrupt criteria. The arithmetic subtest is composed of items involving the four basic operations, writing decimal numbers, notions, and simple operations with fractions. The application was individual, with no time limit. Six consecutive errors were used as interrupt criteria

Executive Functioning Tasks. Several tests were used to assess working memory, inhibitory control and cognitive flexibility.

The verbal working memory was assessed using the Oral Word Span in Sentences. The test assess children capability of memorizing and recalling the last sentence, after sets of two, three, four, and five sentences was read by the examiner (Fonseca, de Salles, & Parente, 2008). Scores (28 maximum) were obtained from a repeated correct sentence (correct order of the words; score 2) and out of order sentence (words repeated in a different order; score 1). The Odd-One-Out (Henry, 2001) was used to assesses children nonverbal working memory. In this test children are presented with a figure and an increasing amount of information about the figure and then the examiner asks if the child remember an aspect of each figure presented. The range score is the number of items that the child answered right; maximum score is 24.

Inhibitory Control. The *Go/No-Go App* and *Hayling* tests were used to assess Inhibition. The *Go/No-Go App* is a test that contains 60 numbers recorded within 4 inhibitory control tasks, visual stimulus and motor response (*Visual-Motor*), visual stimulus and verbal response (*Visual-Verbal*), auditory stimulus and motor response (*Auditory-Motor*), auditory stimulus and verbal response (*Auditory-Verbal*). The child will be present with a sequence of 60 numbers, one at a time at random order, and has to identifying each of the numbers heard, unless the number is six. The scores are composed by the errors (child touch or say the No-Go stimulus - number 6) and are recorded on the smartphone. To measure verbal inhibition *Hayling* test was used (Siqueira, Gonçalves, Hübner, & Fonseca, 2016). This test comprises of sentences that are presented to the child with the last word missing. The child has to properly complete 10 sentences according to the context (Part A) and another 10 sentences with a word that has no semantic relation (Part B). Error scores were used (Fonseca et al., 2010).

Cognitive Flexibility. To measure cognitive flexibility the Trail Making Test (TMT) part A and B were used (Montiel & Seabra, 2012). Letters (A to L) and numbers (1 to 12) were randomly arranged on a single sheet presented to the child. The child has to connect items following an alternating numeric and alphabetic sequence, for one minute. Score were obtained by the number of items correctly connected in an unbroken sequence in part B. To measure the cognitive flexibility the Five Digits Test (FDT) was also used (Paiva, Fialho, Costa, & de Paula, 2016) since it is a numerical test with Stroop effect with relatively independent of reading skills (Sedó, 2004). The FDT contain four tasks and the scores were obtained by the time use to complete the tasks and the mistakes made. Parts 1 and 2 involve automatic processes such as *reading* (the Arabic algorisms 1,2,3,4 and 5) and *counting* (quantities from one-to-five). The Part 3 (*choosing)* involves interference control since an automatic numerical transcoding (i.e., naming - transform a number from the Arabic digital format to the oral verbal format) has to be inhibited in favor of a controlled one (i.e., count Arabic digits that not represent the set cardinality) (e.g., stimulus = “1,1,1” and response =“three”). Part 4 (*shifting*) involves a set-shift from rules of Part 1 to Part 3 and vice-versa depending on an explicit marker. The executive components of each assessment are presented in Table 1.

Table 1. Executive components predominantly assess in the instruments selected for this study

	Inhibition Control	Working memory	Cognitive flexibility	Processing speed
Odd One Out		X		
Oral Word Span in Sentences		X		
Go/No-Go App Visual-Motor	X			
Go/No-Go App Visual-Verbal	X			
Go/No-Go App Auditory-Motor	X			
Go/No-Go App Auditory-Verbal	X			
Hayling Test Part A time				X
Hayling Test Part A errors/10				X
Hayling Test Part B time				X
Hayling Test Part B errors/10	X		X	
Five Digit Test Parte 1 Errors				X
5 Digit Test Parte 1 Time				X
5 Digit Test Parte 2 Errors				X
5 Digit Test Parte 2 Time				X
5 Digit Test Parte 3 Errors	X		X	
5 Digit Test Parte 3 Time	X		X	
5 Digit Test Parte 4 Errors	X		X	
5 Digit Test Parte 4 Time	X		X	
Trail Making Test Parte B sequences	X		X	

Procedures

The university's ethical committee approved the study. The education boards of five cities agreed to be a part of the study. Meetings were held with the schools' administrators to explain the study. Surveys and informed consent were sent to the homes of the randomly selected children. The MABC-2 and TGMD-3 was administered at the schools in sport courts and open spaces; the cognitive assessments and BMI were completed in a quiet room. The assessments of each child occurred during three sessions of approximately 150 minutes. In the first section, the MABC-2, BMI, *Go/No-Go App*, and Hayling tests were conducted. In the second, the remaining executive functions' tests and the academic achievement tests were conducted. In the last section, the WASI and TGMD-3 were conducted. Before each section, children were given a brief explanation regarding the tests, were encouraged to ask questions, and reminded that they could stop at any time. All tests were administered and scored following the procedures recommended in the manuals by 5 trained professionals.

Statistical analysis

Mean and standard deviations were provided. To verify which variables of executive function and motor skills would be predictive of school performance (writing and math) related to the groups of children (DCD, r-DCD, TD), a multivariate multiple linear regression analysis was used. The parameters were estimated using the maximum likelihood method. The existence of multivariate outliers was assessed by the square distance of Mahalanobis (D^2). An outlier was detected and eliminated. Normality was assessed by the asymmetry (sk) and univariate and multivariate kurtosis coefficients, considering values greater than 3 for sk and greater than 7 for ku as a severe violation of the normal distribution. Multicollinearity was assessed by the VIF (variance inflation factor) test. Values above 5 were adopted as indicators of the presence of multicollinearity (Maroco, 2014). The SPSS 21 with the AMOS graphic package was used. The significance was $\alpha < 0.05$

Results

The results of mean and standard deviation of executive function components, inhibitory control, working memory and cognitive flexibility according to the DCD, r-DCD and TD groups are presented in table 2. In addition, the TGMD test scores for the locomotor and object control skills are also presented.

Table 2. Sample characteristics & executive functions: groups mean and standard deviation.

Variables of executive function and motor skills	DCD group (n=63) M(SD)	DCD Risk Group (n=31) M(SD)	TD Group (n=63) M(SD)
Working Memory			
Odd One Out	08.11(2.60)	09.55 (2.73)	11.3 (3.40)
Oral Word Span	11.02(3.59)	10.68 (3.38)	12.78 (3.37)
Inhibition			
GonoGo App			
Auditory Motor	7.27 (3.12)	6.51 (3.13)	4.25 (2.23)
Visual Motor	6.09 (3.65)	4.68 (2.98)	3.48 (2.19)
Auditory Verbal	3.33 (2.03)	3.12 (2.10)	2.29 (1.43)
Visual Verbal	2.39 (1.90)	2.70 (1.78)	1.61 (1.29)
Hayling Test			
Part A time	12.85 (6.81)	14.06 (7.39)	11.81 (6.18)
Part A errors/10	.46 (.82)	.38 (.68)	.25 (.44)
Part B time	28.14 (21.79)	30.03 (21.11)	26.87 (19.57)
Part B errors/10	5.05 (1.91)	4.35 (2.12)	2.50 (1.85)
Cognitive Flexibility			
5 Digit Test			
Part 1 Errors	00.22 (.41)	.19 (.40)	.95 (.29)
Part 1 Time	40.16 (14.45)	39.39 (11.40)	34.41 (7.28)
Part 2 Errors	.61 (.91)	.51 (.71)	.19 (.39)
Part 2 Time	61.11 (22.38)	50.58 (15.94)	46.31 (14.79)
Part 3 Errors	5.25 (3.03)	5.58 (4.06)	2.92 (2.19)
Part 3 Time	91.7 3 (29.65)	77.90 (15.73)	78.28 (20. 67)
Part 4 Errors	7.33 (4.32)	7.97 (04.24)	3.73 (2.23)
Part 4 Time	104.81(29.76)	95.87 (21.99)	91.70 (20.48)
Trail Making Test			
Part B sequences	6.33 (6.08)	7.90 (5.79)	8.50 (4.40)
Motor Skills			
TGMD			
Locomotor Skills	31.00 (7.94)	25.85 (6.98)	35.51 (6.62)
Object Control Skills	25.55 (7.13)	23.39 (6.05)	30.36 (6.66)
School Performance			
Mathematics	19.00 (3.07)	21.71 (3.62)	21.95 (3.98)
Writing	25.26 (6.82)	28.97 (4.42)	29.26 (4.94)

Regarding predictive analyses, normal distribution was found for all variables (univariate asymmetry: values between -1.01 and 2.90; univariate kurtosis: values between 1.96 and -.024; multivariate kurtosis: values between 7.90 and - .47). No multicollinearity values were observed higher than 5. Regarding to the children with DCD, the results showed that the model explained 39% and 31% of the variability in the performance of math and writing, respectively. Significant results were found for the inhibitory control tests in the *Go/No-Go App*. The *Auditory-Motor* (β = .36, p = .009) and *Auditory-Verbal* (β = .38, p = .023) tasks were the best predictors for math performance. The *Auditory-Motor* task was a predictor of writing skills (β = -.41, p = .005). Significant results were also found for the *Odd One Out.* This visuospatial working memory test predicted the writing performance (β = -.33, p = .011); as well as for processing speed test (part 2 of the Five Digit Test) predict math performance (β = -.42, p = .005).

Regarding children at r-DCD group, the model explained 52% of math and 57% of writing performances. The scores of the *Visual-Motor* task (inhibitory control) predicted writing performance (β = -.050, p = 0.015). *Auditory-Motor* (β = .67, p = .002) and *Visual-Motor* (β = -.40, p = .048) predict math performance.

For children with typical development, the model explained 31% of math and 26% of writing performances. Significant results were found for *Auditory-Motor* (β = .41, p = .004) and the *Visual-Motor* (β = .32, p = .048) tasks of the *Go/No-Go App* Test predicting math performance. Yet, *Auditory-Motor* task significantly predicted writing performance (β = .30, p = .038) and working memory test (*Oral Word Span*) predicted the writing performance (β = -.30, p = .005). Regarding processing speed, Hayling test part A predict math performance (β = .27, p = .030). Table 2 shows the results of the multivariate multiple linear regression analysis with the standardized regression coefficient and R^2 (determination coefficients) by groups (DCD, r-DCD, TD).

Table 02. Multivariate multiple linear regression analysis with the standardized regression coefficient and R^2 (determination coefficients).

Executive Functions & Motor Skills	**DCD children**				**Risk of DCD**				**Typical children**			
	Math		Writing		Math		Writing		Math		Writing	
	$R^2 = 0.39$		$R^2 = 0.31$		$R^2 = 0.52$		$R^2 = 0.57$		$R^2 = 0.31$		$R^2 = 0.26$	
	β	p	β	p	β	p	β	p	β	p	β	p
Inhibition Control												
Auditory-Motor	-0.40	.009*	-0.40	.048*	-0.67	0.02*	0.02	0.93	-0.40	.004*	-0.30	.038*
Visual-Motor	-0.10	0.32	0.09	0.55	-0.40	0.04*	-0.50	.015*	-0.32	.048*	0.31	0.07
Auditory-Verbal	0.38	.023*	0.10	0.56	0.04	0.80	-0.30	0.09	-0.01	0.8	0.07	0.60
Visual-Verbal	-0.30	0.06	0.23	0.12	0.25	0.27	0.01	0.10	-0.10	0.71	-0.20	0.17
Hayling Test Part B	0.09	0.45	-0.10	0.45	-0.10	0.77	0.21	0.35	0.17	0.14	0.13	0.27
Work memory												
Odd One Out	0.13	0.30	-0.30	.011*	0.16	0.43	-0.10	0.86	0.08	0.53	0.01	0.98
Oral Word Span in Sentences	-0.10	0.33	-0.20	0.24	-0.20	0.32	-0.10	0.71	-0.20	0.08	0.30	0.05*
Cognitive Flexibility												
5 Digit Test Parte 3	-0.20	0.27	-0.01	0.93	0.43	0.16	0.09	0.75	-0.10	0.44	-0.20	0.35
*5 Digit Test*Parte 4	0.01	0.95	-0.11	0.76	-0.40	0.19	0.39	0.14	-0.01	0.79	0.12	0.50
Trail Making Test Part B	-0.10	0.59	-0.10	0.52	-0.10	0.52	-0.20	0.22	-0.20	0.08	-0.20	0.06
Processing speed												
*Hayling Test*Part A	0.18	0.13	0.01	0.93	-0.30	0.06	-0.30	0.08	0.27	0.03*	0.12	0.33
5 Digit Test Part 1	-0.20	0.31	0.05	0.78	0.03	0.92	0.07	0.79	-0.1	0.33	-0.10	0.52
5 Digit Test Part 2	0.42	.005*	0.16	0.31	-0.30	0.15	-0.10	0.49	-0.2	0.21	-0.10	0.54
Fundamental motor skills												
Locomotor	-0.10	0.70	0.18	0.17	-0.10	0.54	0.22	0.29	-0.01	0.93	0.12	0.34
Object control	0.14	0.28	-0.10	0.49	0.19	0.45	0.26	0.27	-0.10	0.66	-0.10	0.70

Nota: R^2= coeficiente de determinação; β= coeficiente de regressão; p = significant value.

Discussion

The aim of this study was to examine whether executive functions (working memory, inhibition, and cognitive flexibility), locomotor skills, and object control motor skills are meaningful predictive factors for writing and math performance in children with DCD, at r-DCD and TD. The results showed that some components of executive functions, specifically inhibition and visuospatial working memory, are predictors of writing and math skills in children with DCD. However, for children with r-DCD and TD the predictability was restrict inhibition tasks. Previous studies have highlighted the difficulties showed by children with DCD in academic tasks (Bernardi et al., 2017; Gomez et al., 2015; Prunty et al., 2016; Zwicker et al., 2012) and the higher risk, presented by those children, of showing academic deficits compared to typical developing learners (Alloway & Archibald, 2008; Gomez et al., 2015; Pieters et al., 2012). A concern has been establishing that the motor and cognitive problems showed by children with DCD are very likely to be associated with learning problems in different academic areas and therefore present a significant risk of failing school (Asonitou, Koutsouki, Kourtessis, & Charitou, 2012b). Our study advances in the present knowledge by provided evidences of the specific components of executive function seems to affect more children with DCD, r-DCD and DT and that the extension of motor deficits are associate differently with specific components of executive function.

The degree of the disorder lead to different outcomes

Inhibition control was the stronger predictor of the academic writing and math performance of children with DCD, r-DCD and DT. The study also advances in the current knowledge showing that children at r-DCD may have EF problems. Children at-risk of DCD constantly lack diagnose and referral to appropriate interventions (Leonard et al., 2015b); leading those children probably to fall behind in the classroom without a full comprehension of their difficulties. In this regard, an important theoretical issue that is still unclear is if the standard deficits of the components of the executive functions and academic performance vary with the severity of the motor disorder. The results show that both groups of children with DCD and r-DCD significantly took more time on the tasks, make mores mistakes in the Go/No-Go App and in the Odd-One-Out test, indicating that the deficits of writing and mathematics do not vary significantly depending on the severity of the motor impairment (Chen, Wilson, & Wu, 2012). Similar data were found in the groups of children with DCD and the group of children with motor delays in the nonverbal tests of the executive functions (Leonard et al., 2015b), showing no significant differences of the EF in groups with different levels of motor delay. Clinical and research indications reflect an overlap between the organizational difficulties experienced by individuals with DCD, particularly planning, and activity execution that cannot be explained by the degree of motor impairment (Green & Payne, 2018). Children with mild as well as with severe motor disabilities have difficulties in the domain of mathematics, but this is more obvious in the group of children with severe DCD (Pieters et al., 2012).

The role of working memory in visuospatial in children with DCD.

Our study provided evidences indicated that visuospatial working memory is closely related to academic performance in children with DCD (Alloway, 2007, 2011; Alloway & Archibald, 2008). Two hypotheses can be proposed based on the results found in our study; the first is that in children with typical development the writing and mathematics skills would be better consolidated and would require less requirement in terms of executive functions. The second hypothesis points out that visuospatial working memory engagement is a compensatory strategy for children with DCD, in that, being slower for writing skills or having greater difficulty in this process, they would require more working memory to maintain until motor planning and execution occurred. In the writing tests (e.g., TDE II) children needed to translate the sound of a word into its visual form before producing it by hand movement (Cheng, Chen, Tsai, Shen & Cherng, 2011). Difficulties in transcription and manipulation of information in the central nervous system have real implications for the quality of the text produced by the children with DCD (Prunty et al., 2016). The difficulty of listening and then writing would lead to learning difficulties in the school context for the DCD group. In addition, it is pointed out that children with DCD who presented low visuospatial working memory abilities obtained significantly worse results in subtests of numerical operations (addition, subtraction, division, multiplication, fractions, and algebra) and mathematical reasoning (*Wechsler Objective Numerical Dimensions*) when compared with children who had better results in visuospatial working memory skills (Vaivre-Douret, 2014; Vaivre-Douret et al., 2011). In this sense, the visuospatial working memory may play an important role in the writing performance of children with DCD.

The role of inhibitory control in school performance in children with DCD and at r-DCD

Our results also indicated that, in addition to the visuospatial working memory, inhibition is the most important predictor for the performance of writing and mathematical skills in children with DCD and r-DCD. Children with DCD and children with typical development have the same brain regions involved while performing the Go/NoGo tasks (Querne et al., 2008). However, it is suggested that the connectivity of the neural system in children with DCD is less efficient than in typical development children (Querne et al., 2008). In the DCD group, there was a strong involvement of the inhibition component in Auditory Motor and Auditory Verbal tasks as predictors of writing and mathematical skills.

For the group of r-DCD children, the Visual-Motor task of inhibition is a predictor of writing ability, and Auditory-Motor and Verbal-Motor predict math performance. Specifically, inhibition is essential in effective goal-directed executive function that inhibits irrelevant verbal or motor behavior (Diamond & Lee, 2011). Therefore, inhibition plays a critical role in the self-regulation (Tsai, 2009), internalization of the speech (Barkley, 2001), and for the acquisition of proficient motor and cognitive skills (Adele Diamond, 2013). This maintains the focus on relevant stimuli in the presence of distractors and the capacity of completing a long, multi-step task, which is essential in writing and mathematical skills.

Throughout childhood, inhibition develops at a constant pace and more evident changes happen later in childhood (Best et al., 2011; Pureza, Jacobsen, Grassi-Oliveira, & Fonseca, 2011). The demands of everyday experiences, such as school assignments (Bernardi et al., 2017), peer interactions (Satta, Ferrari-Toniolo, Visco-Comandini, Caminiti & Battaglia-Mayer, 2017), and inhibition of behaviors that lead to inappropriate action (Tsai, 2009) requires constant inhibitory control function and are a challenge for children. Yet, the demands are greater for children with a disability like DCD. As example, children with attention deficit/hyperactivity disorder (Verbruggen & Logan, 2008) or with developmental coordination disorder (Querne et al., 2008) show inhibitory control deficits that negatively affect their capacity to suppress a response, resist temptations, and not act prematurely (Adele Diamond, 2000), resulting in difficulties in school tasks (Best et al., 2011). Therefore, the assessment of this executive function is critical to provide appropriate opportunities for children to learn in the school context and it is important both for children with DCD and children with risk for movement disorder.

The role of inhibitory control in mathematical performance

It is important to note that the results of our study also indicate that mathematical skills outcomes were influenced by the inhibitory control performance in the tasks of Auditory-Motor, Visual-Motor, and Auditory-Verbal for the group of children with DCD and for r-DCD children. A study reported that, among 43 children with DCD, 88% showed academic underachievement in mathematics (Vaivre-Douret et al., 2011), in our study those children were also underachieved in math. No studies were found pointing to a relation of mathematical performance with inhibitory control in children with DCD. However, studies showed that children with DCD with low visuospatial memory skills performed significantly worse on numerical operations, such as addition, subtraction, division, multiplication, fractions, and algebra (Alloway, 2007; Alloway & Temple, 2007). Alloway (2007) showed that deficits in the recalling of numerals and process calculations are also associated with motor deficits in children with DCD (Pieters et al., 2012). Children with DCD seems to have also impairments in processing both symbolic and nonsymbolic numbers (Gomez et al., 2015), suggesting that educational interventions that tap into both nonsymbolic and symbolic systems could be efficient for children with DCD who struggle with mathematics in school.

Identification of children with DCD and motor delays: Importance and intervention' propositions

Children with DCD have motor and cognitive problems that are associated with learning difficulties in different academic areas, and are at risk of failing school (Asonitou et al., 2012a), this contention was supported by the present study results . Cognitive planning and attention deficits in the group of children with DCD indicate a relationship to poor academic performance (e.g. problems in mathematics or comprehending information for reading and writing processes) (Sumner, Pratt, & Hill, 2016), similar to our results. Early identification of cognitive-motor difficulties is essential to provided intervention in motor and academic areas that children presented more difficulties (Asonitou et al., 2012a). Efficient detection of DCD and at-risk of DCD across clinical and educational settings is needed to ensure those children will reach their potential, or at least, minimizing the functional impairments and secondary consequences of DCD; since the disorder can have a significant impact on a child's quality of life and academic achievement (Spittle, FitzGerald, Mentiplay, Williams, & Licari, 2018).

In addition to identifying children with DCD and at-risk of DCD, understanding the relations between the perceptual-cognitive (executive functions) and motor development domains is a vital step in helping to plan for early intervention that focus specifically on the learning difficulties (Leonard & Hill, 2015). Motor skill interventions are effective in improving motor competence as well as performance on cognitive, emotional, and other psychological aspects in children with DCD in the short term (Zanella, Souza, & Valentini, 2018). These effects are more robust in interventions using a large training dose and a practicing schedule of high frequency (Yu, Burnett, & Sit, 2018).

Overall, the results of this study suggest that the poor performance in measures of inhibition and visuoespacial working memory test in children with DCD and r-DCD predict writing and mathematical' performances. These findings emphasized the need of task specific interventions to help them learn strategies to compensate for their executive functions deficits and coordination difficulties. For children with DCD and r-DCD, for example, strategies aimed at using motor/executive tasks in the physical education classes may have an impact in enhancing their capacity to achieve in these academic areas.

Conflict of interest statement

The authors have no financial or personal relationships with other people or organizations that could inappropriately influence or bias their work in this study.

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7.1 CONSIDERAÇÕES FINAIS

Os resultados obtidos por meio dos métodos propostos para responder as finalidades e objetivos dessa pesquisa, apontam para algumas conclusões gerais e específicas para cada um dos estudos. Na revisão sistemática encontramos que cada medida do componente executivo, bem como o tipo de população, tem diferentes características. Nos diferentes testes ou tarefas que foram utilizados nos estudos entre 2002 e 2017, as crianças necessitam de processamento visuoespacial ou não, habilidade verbal ou não verbal, com ou sem demanda motora envolvida em tarefas simples ou complexas. Em algumas destas tarefas, essas diferentes demandas ou diferentes tipos de estímulos envolvidos nos testes podem causar perda secundária na execução o que parece ser um ponto importante como conclusão deste estudo. Em relação aos principais resultados das funções executivas em crianças com DCD a maior parte dos estudos indica que existe um déficit de inibição e de mémória de trabalho nas crianças com DCD. Esta grande heterogeneidade de testes e tarefas pode gerar problemas de definição e mensuração dentro deste campo de estudo. Sem um conjunto de termos claramente definidos e um conjunto consistente de medidas, será muito difícil chegar a conclusões definitivas sobre como a função executiva se relaciona com crianças com DCD sobretudo no Brasil, onde há um menor número de testes validados para avaliação das funções executivas em crianças.

No sentido de estabelecer mais instrumentos de avaliação neuropsicológica, foi proposto como segundo objetivo desta tese o desenvolvimento e validação de um conjunto de tarefas de controle inibitório para crianças. Os presentes resultados deste estudo demonstram que o *Go/No-Go App* é um teste com evidência adequada de validade para a avaliação do controle inibitório em crianças de 8 a 10 anos de idade tanto para crianças típicas como para crianças com DCD. O aplicativo *Go/No-go App* pode ajudar clínicos e pesquisadores a avaliar, já que é um isntrumento de fácil utilização e fornece mais evidências relacionadas aos mecanismos cognitivos do controle inibitório. Especialmente, as quatro tarefas apresentadas com estímulos auditivos e visuais com respostas motoras e verbais, podem ser úteis para avaliar subdomínios executivos relacionados a diferentes estímulos e respostas, bem como as possíveis relações entre habilidades motoras e funções executivas e os processos de aprendizagem durante a infância.

No terceiro artigo, como previsto nas hipóteses, as crianças com DCD tiveram desempenho significativamente pior que as crianças com dsenvolvimento típico em todas as medidas de memória de trabalho (Odd-One-Out), controle inibitório (tarefas não verbais do teste *Go/No-Go*) e flexibilidade cognitiva (Teste de Cinco Dígitos). Os resultados mostram que o grupo de crianças com r-DCD é heterogêneo, no entanto, em relação às diferenças entre DCD e r-DCD, não foram encontradas diferenças estatísticas entre estes grupos. Esses resultados forneceram suporte para a alegação de que os déficits em alguns componentes das funções executivas não variam com a gravidade do distúrbio motor, indicando algumas semelhanças em parte dos componentes da função executiva, independentemente da gravidade do comprometimento motor. Independentemente do diagnóstico de DCD ou r-DCD, dificuldades motoras em crianças parecem implicar, pelo menos em parte, na capacidade relacionada aos componentes das funções executivas.

As conclusões desta Tese apontam que as funções executivas das crianças com DCD tendem a estar associados a problemas de aprendizagem na escrita e matemática e nesse sentido, essas crianças correm o risco significativo de fracassar na escola. Os resultados do quarto estudo sugerem que o baixo desempenho do controle inibitório e de memória de trabalho visuoespacial em crianças com DCD e r-DCD predizem o desempenho da escrita e matemática. Esses resultados enfatizam a necessidade de intervenções específicas apontando a partri destes resultados que programas de intervenção motora seria uma saída para ajudar crianças com atraso motor a aprender estratégias para compensar seus déficits de funções executivas. Para as crianças com DCD e r-DCD, por exemplo, as estratégias destinadas a usar tarefas motoras/executivas nas aulas de educação física podem ter um impacto no aumento de sua capacidade de atingir essas áreas acadêmicas.

A identificação precoce de dificuldades cognitivo-motoras pode ser essencial para intervenção em áreas motoras e acadêmicas. É necessário um melhor reconhecimento da DCD e da mesma forma identificar precocemente aquelas crianças com risco para esta desordem tanto nos contextos clínicos como educacional. Esta identificação perimite garantir que as crianças atinjam seu potencial, pois os prejuízos funcionais e as conseqüências secundárias do DCD tem um impacto significativo no desempenho acadêmico dessas crianças em relação a matemática e a escrita. (Spittle, FitzGerald, Mentiplay, Williams, & Licari, 2018) assim como os resultados percebidos em nosso estudo.

A Tese de que crianças com DCD apresentam deficits nas funções executivas que predizem o baixo desempenho escolar para as habilidades de escrita e matemática, aponta para a necessidade de se pensar o funcionamento executivo/motor como parte dos processos de intervenção. Os resultados deste estudo podem impactar de forma importante os processos metodológicos e as estratégias de intervenção que são utilizadas para atender crianças com DCD e em de r-DCD, considerando as funções executivas combinadas com tarefas motoras especificas. Estas estratégias referidas apontam para a ideia de que o ambiente de aprendizagem e intervenção possa proporcionar atividades e tarefas em que a criança possa criar uma resposta diferente e tomar uma decisão diferente a cada momento da prática de atividades motoras. Esse tipo de resposta requer controle cognitivo de ordem superior e também pode ser chamado de manifestação dos componentes das funções executivas, e assim como as habilidades motoras, são desenvolvidas ao longo do curso da infância.

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APÊNDICES

Apêndice 1 – Parecer do Comitê de Ética em Pesquisa com Seres Humanos

UFRGS - PRÓ-REITORIA DE PESQUISA DA UNIVERSIDADE FEDERAL DO RIO GRANDE DO

PARECER CONSUBSTANCIADO DO CEP

DADOS DO PROJETO DE PESQUISA

Título da Pesquisa: FUNÇÕES EXECUTIVAS, HABILIDADES MOTORAS E DESEMPENHO ESCOLAR EM CRIANÇAS COM DESORDEM COORDENATIVA DE DESENVOLVIMENTO

Pesquisador: Nadia Cristina Valentini

Área Temática:

Versão: 3

CAAE: 79339517.2.0000.5347

Instituição Proponente: Universidade Federal do Rio Grande do Sul

Patrocinador Principal: Financiamento Próprio

DADOS DO PARECER

Número do Parecer: 2.532.309

Considerações Finais a critério do CEP:

Aprovado.

Este parecer foi elaborado baseado nos documentos abaixo relacionados:

Tipo Documento	Arquivo	Postagem	Autor	Situação
Informações Básicas do Projeto	PB_INFORMAÇÕES_BÁSICAS_DO_PROJETO_979614.pdf	03/03/2018 14:26:29		Aceito
Outros	CartaResposta2018.docx	03/03/2018 14:25:35	Nadia Cristina Valentini	Aceito
Projeto Detalhado / Brochura Investigador	Projeto28Fevereiro2018.pdf	03/03/2018 14:22:13	Nadia Cristina Valentini	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	TermoAssentimentoAlunos2018.pdf	03/03/2018 14:21:46	Nadia Cristina Valentini	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	TCLEpaisouresponsaveislegais2018.pdf	03/03/2018 14:21:29	Nadia Cristina Valentini	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	TCLEINSTITUCIONAL2018.pdf	03/03/2018 14:20:40	Nadia Cristina Valentini	Aceito
TCLE / Termos de Assentimento /	TCLEArtigos3e4_2018.pdf	03/03/2018 14:20:23	Nadia Cristina Valentini	Aceito

Apêndice 2 – TCLE - **TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO (TCLE)**

UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL
PROGRAMA DE PÓS-GRADUAÇÃO EM CIÊNCIAS DO MOVIMENTO HUMANO
TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO AOS RESPONSÁVEIS LEGAIS DA CRIANÇA

O Grupo de Avaliações e Intervenções Motoras da Escola de Educação Física da Universidade Federal do Rio Grande do Sul (UFRGS), sob orientação da professora Nadia Cristina Valentini, pede a participação de meu filho(a) (ou protegido legal) em pesquisa que busca investigar as associações entre funções executivas e as habilidades motoras fundamentais em crianças com desordem coordenativa Desenvolvimental no anos de 2017/2018.

A participação de meu filho(a) (ou protegido legal) será através da participação em atividades motoras (como por exemplo, brincar com bolas ou outros materiais, equilíbrio), avaliação do estado nutricional (ex.: peso e altura) e avaliações cognitivas (ex.: testes de memória). Entendo que a avaliação motora ocorrerá na escola e no período do turno escolar do meu filho(a) (ou protegido legal), sem que sejam prejudicadas as atividades escolares desenvolvidas. A avaliação acontecerá de forma individual ou em duplas, em um ambiente calmo especialmente preparado para este fim.

Os resultados do estudo da pesquisa podem ser publicados, mas o nome e a identidade de meu filho(a) (ou protegido legal) não serão revelados. A orientadora Profª Nadia Cristina Valentini manterá sigilo sobre os registros de meu filho(a) (ou protegido legal), sendo responsável pelo armazenamento dos dados. Os dados serão armazenados no laboratório de pesquisa da professora, na Escola de Educação Física, Fisioterapia e Dança (ESEFID) – UFRGS, durante o período de 5 anos. Após esse período as imagens serão excluídas/apagadas.

Em caso de possíveis imprevistos, como um entorse ou desconforto (calor, cansaço para a realização das atividades), espero o cuidado necessário dos responsáveis pela pesquisa. Fui informado que não serei remunerado pela participação do meu filho(a) (ou protegido legal) na pesquisa podendo, a qualquer momento, retirar meu consentimento por qualquer motivo e sem nenhum prejuízo para mim ou para meu filho(a) (ou protegido legal). Compreendo que os pesquisadores se comprometem a explicar para meu filho(a) (ou protegido legal) como será a sua participação na pesquisa, não sendo obrigatória a sua participação, podendo a criança se recusar a participar em qualquer momento.

Sob estas condições:

Autorizo a participação do meu filho(a) (ou protegido legal)____
____ **(nome da criança)** a participar deste estudo. Recebi informações a respeito da avaliação que será realizada e esclareci minhas dúvidas. Sei que em qualquer momento poderei solicitar novas informações e modificar minha decisão se eu desejar. Fui certificado de que todos os dados desta pesquisa referentes ao meu filho(a) (ou protegido legal) serão confidenciais, assim como suas as atividades escolares não serão prejudicadas em razão desta pesquisa e terei liberdade de retirar meu consentimento de participação na pesquisa a qualquer momento.

Porto Alegre, ________ de ______________________ de 2017.

____
Assinatura do Responsável

<u>Telefones para contato e esclarecimentos</u>:
Orientadora Profª Drª Nadia Cristina Valentini – (51) 3308.5856
Rodrigo Flores Sartori – (51) 3308.5856 ou (54) 98401.2902

Apêndice 3 – TALE - **TERMO DE ASSENTIMENTO LIVRE E ESCLARECIDO**

UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL
PROGRAMA DE PÓS-GRADUAÇÃO EM CIÊNCIAS DO MOVIMENTO HUMANO
TERMO DE ASSENTIMENTO LIVRE E ESCLARECIDO

Título do projeto: FUNÇÕES EXECUTIVAS, HABILIDADES MOTORAS E DESEMPENHO ESCOLAR EM CRIANÇAS COM DESORDEM COORDENATIVA DE DESENVOLVIMENTO.
Pesquisador responsável: Prof. Rodrigo Flores Sartori
Instituição: Universidade Federal do Rio Grande do Sul – UFRGS
Telefone celular do pesquisador para contato (inclusive a cobrar): (51) 98514 8434

Você está sendo convidado (a) para participar da pesquisa **Funções Executivas, Habilidades Motoras e Desempenho Escolar em Crianças com Desordem Coordenativa de Desenvolvimento**. Seus responsáveis permitiram que você participe.

Seus responsáveis já autorizaram você a participar, mas caso não se sinta confortável você não precisa aceitar participar. Você também pode conversar com alguém antes de tomar uma decisão. Você poderá desistir em qualquer momento das atividades e isso não irá trazer nenhum prejuízo

Queremos saber como estão as habilidades motoras e algumas funções cognitivas relacionadas com o desempenho na escola das crianças de escolas de Caxias do Sul e região e também de Porto Alegre e região metropolitana. As crianças que irão participar dessa pesquisa têm de 8 à 10 anos de idade.
Você não precisa participar da pesquisa se não quiser, é um direito seu e não terá nenhum problema se desistir.

A pesquisa será feita na própria escola e pediremos que vocês saia da sala de aula por alguns minutos (15 a 20) para fazer algumas atividades. Ninguém saberá que você está participando da pesquisa, não falaremos a outras pessoas, nem daremos a estranhos as informações que você nos der. Os resultados da pesquisa vão ser publicados, mas sem identificar as crianças que participaram. Quando terminarmos a pesquisa os resultados serão divulgados para seus responsáveis. Se você tiver alguma dúvida, você pode me perguntar ou ao pesquisador (a).

Eu _________________________________ aceito participar da pesquisa **Funções Executivas, Habilidades Motoras e Desempenho Escolar em Crianças com Desordem Coordenativa de Desenvolvimento**. Os pesquisadores tiraram minhas dúvidas e conversaram com os meus responsáveis. Recebi uma cópia deste termo de assentimento e li e concordo em participar da pesquisa.

Caxias do Sul, ____de _________de 2017.

____________________________ ____________________________
Assinatura do menor Assinatura do(a) pesquisador(a)

Apêndice 4 **TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO -** ***INSTITUIÇÃO***

UFRGS

UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL

PROGRAMA DE PÓS-GRADUAÇÃO EM CIÊNCIAS DO MOVIMENTO HUMANO

TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO - *INSTITUIÇÃO*

Título da Pesquisa: FUNÇÕES EXECUTIVAS, HABILIDADES MOTORAS E DESEMPENHO ESCOLAR EM CRIANÇAS COM DESORDEM COORDENATIVA DE DESENVOLVIMENTO.
Pesquisador responsável: Prof. Rodrigo Flores Sartori
Orientadora: Prof. Dr. Nadia Cristina Valentini
Instituição Proponente: Universidade Federal do Rio Grande do Sul - UFRGS
CAAE: 79339517.2.0000.5347

O Grupo de Avaliações e Intervenções Motoras da Escola de Educação Física da Universidade Federal do Rio Grande do Sul (UFRGS), sob orientação da professora Dra. Nadia Cristina Valentini, através do Pesquisador Rodrigo Flores Sartori, convida a instituição de ensino para participar de pesquisa relacionada as relações entre funções executivas e habilidades motoras como preditoras do desempenho acadêmico em crianças com idades entre 8 e 10 anos durante o ano de 2017.

As atividades programadas preveem a avaliação de habilidades motoras de manipulação de objetos (receber uma bola, chutar, rebater, quicar, rolar e arremessar) e habilidades motoras de locomoção (correr, saltar). Também serão feitas avaliações do comportamento cognitivo relacionado a flexibilidade cognitiva, memória de trabalho e controle inibitório que são variáveis cognitivas que serão realizadas de forma individual. A avaliação destas variáveis permite que possam ser verificadas características dos processos de aprendizagem escolar e o retorno das avaliações será dado ao fim de cada fase do estudo em cada turma investigada. Os resultados deste estudo podem ser publicados, mas o nome da instituição, assim como o nome dos alunos envolvidos não serão revelados. A orientadora Profª Nadia Cristina Valentini manterá sigilo sobre os registros, sendo responsável pelo armazenamento dos dados. Os dados serão armazenados no laboratório de pesquisa da professora, na Escola de Educação Física (ESEF) – UFRGS, durante o período de 5 anos. Após esse período as imagens serão excluídas/apagadas. Os pesquisadores serão responsáveis pelos possíveis custos referentes à pesquisa. A instituição e os pesquisadores não serão remunerados pela participação na pesquisa podendo, a qualquer momento, retirar o consentimento por qualquer motivo e sem nenhum prejuízo para a instituição ou para os demais participantes da pesquisa.

Os pesquisadores estão cientes que as atividades irão influenciar na rotina diária de alguns professores durante as semanas do estudo, portanto, se colocam a disposição para qualquer esclarecimento. A qualquer momento, a instituição poderá retirar o consentimento, caso julgue que o estudo esteja trazendo algum transtorno para a escola.

As crianças que aceitarem participar do estudo poderão, eventualmente, estar expostos ao constrangimento de não conseguir realizar com eficiência as atividades motoras ou neuropsicológicas, o que será amenizado com total discrição em relação ao local de práticas. Os critérios de exclusão serão rigorosamente cumpridos a fim de evitar qualquer risco referente às condições de saúde não adequadas ao estudo. Além disso, o pesquisador principal do estudo se responsabiliza por qualquer eventualidade que comprometa física e moralmente os participantes do estudo.

UFRGS

Os benefícios do estudo estão relacionados ao conhecimento científico sobre o tema em questão e às possibilidades de estar oportunizando o conhecimento sobre os processos de saúde e educação de cada criança que serão repassados a todas as professoras das turmas investigadas. A instituição, bem como o pesquisador responsável, garante o sigilo das informações que assegurem a privacidade dos sujeitos quanto aos dados confidenciais envolvidos na pesquisa. Os dados obtidos com a mesma terão somente fins acadêmicos e serão divulgados apenas dados diretamente relacionados aos objetivos da pesquisa.

Sob estas condições:

Eu, ____, responsável pela instituição de ensino ____ no turno ____________________, autorizo a realização da pesquisa. Recebi informações a respeito da avaliação que será realizada e esclareci minhas dúvidas. Sei que em qualquer momento poderei solicitar novas informações e modificar minha decisão se eu desejar. O Grupo de Avaliações e Intervenções Motoras sob a orientação da Profª Nadia Cristina Valentini, certificaram-me de que todos os dados desta pesquisa referentes à instituição e aos alunos serão confidenciais. Caso tenha novas perguntas sobre este estudo, posso contatar o Prof. Rodrigo Flores Sartori, pesquisador responsável pelo projeto, no telefone (51) 98514 8484 ou ainda pelo e-mail rodrigo73@hotmail.com. Para qualquer pergunta sobre os meus direitos, ou se penso que fui prejudicado por esta autorização, posso entrar em contato com o CEP-UFRGS (Comitê de Ética em Pesquisa da UFRGS), situado à Av. Paulo Gama, 110 - Sala 317 do Prédio Anexo 1 da Reitoria - Campus Centro e telefone (51)3308-3738, para qualquer esclarecimento. O Comitê de Ética em Pesquisa funciona de segunda à sexta-feira das 08h00min até às 12h e das 13h30min às 17h.

Porto Alegre, _______ de ____________________ de 2015.

____

Assinatura do Responsável pela Instituição

DECLARAÇÃO DE RESPONSABILIDADE DO REALIZADOR DA PESQUISA

Expliquei o objetivo, os riscos e benefícios e a natureza da pesquisa. Esclareci todas as dúvidas dos participantes da pesquisa. O participante compreendeu e aceitou participar da pesquisa.

______________________________ ____________________

Assinatura do Pesquisador Data

______________________________ ____________________

Assinatura da Professora Responsável/Orientadora Data

<u>Telefones para contato e esclarecimentos:</u>

Orientadora: Profª Drª Nadia Cristina Valentini – (51) 3308.5856

Rodrigo Flores Sartori – (54) 98401 2902