The Prevalence of Left-Handedness Is Higher Among Individuals With Developmental Coordination Disorder Than in the General Population

Monica Darvik*, Håvard Lørås and Arve Vorland Pedersen

Department of Neuromedicine and Movement Science, Faculty of Medicine and Health Sciences, Norwegian University of Science and Technology, Trondheim, Norway

Many medical, psychiatric and neurological conditions have been characterized by a high prevalence of left-handedness or mixed-handedness. Several studies have indicated an elevated frequency of left-handedness in children with Developmental Coordination Disorder (DCD). However, there have been few studies explicitly exploring this relationship. The assumption is that the prevalence of left-handedness in individuals with DCD is higher compared with the prevalence in the general population and resembles the prevalence described in children with other developmental disorders.

Computerized searches were conducted in PubMed, PsycInfo and CINAHL databases. Thirty-eight studies were identified and included in the present review, containing handedness distributions across 1071 persons with DCD and 1,045 controls. The distribution of DCD participants across handedness-categories was proved to be significantly different from that of the control group, with 14.7 and 8.1% left-handers, respectively. The prevalence of left-handedness within the DCD-group is lower than that reported for ASD, and larger than in dyslexia. The elevated levels of left-handedness within the different developmental disorders supports the notion of an association between the different diagnoses. However, the present results are not sufficient to conclude anything about a common cause or underlying factor via the male hormone testosterone. The present results could act as a starting point for testing the hypothesis of such a common factor, as one of the requirements is an elevated prevalence of left-handedness, and without such considerable doubt would be cast upon the hypothesis.

Keywords: laterality, dextrality, sinistrality, clumsiness, dyspraxia, hand dominance, preference

INTRODUCTION

Among developmental disorders, Developmental Coordination Disorder (DCD) is less understood (Gomez and Sirigu, 2015). DCD is a neurodevelopmental motor disorder. Symptoms typically onset in the early developmental period, with motor skills substantially below expectations given the individual’s age. The deficits in motor skills impacts activities of daily living and are not...
attributable to a neurological condition affecting movement, nor can they be explained by visual impairment or intellectual disability (American Psychiatric Association, 2013). DCD is usually a permanent condition found in children, affecting between 5 and 8% between 6 and 12 years of age (Barnhart et al., 2003; Noten et al., 2014). A higher prevalence is found in boys than girls (Kadesjö and Gillberg, 1999; Barnhart et al., 2003). DCD is also more common in low-birth-weight children and those with prenatal exposure to alcohol (American Psychiatric Association, 2013).

DCD has a developmental rather than acquired origin, with difficulty in coordination and control of voluntary motor activity in the absence of intellectual impairment and neurological and/or physical disorder (Cermak et al., 2002; Gibbs et al., 2007). Other terms previously used to describe DCD include clumsy child syndrome, childhood dyspraxia and specific developmental disorder of motor function (American Psychiatric Association, 2013).

DCD is often associated with psychopathology (Gillberg and Kadesjö, 2003; Goez and Zelnik, 2008). A shared genetic effect has been proposed because of the co-occurrence of DCD with autism spectrum disorder, specific learning disabilities and attention-deficit/hyperactivity disorder (ADHD). However, such consistency in co-occurrence in twins appears only in severe cases (American Psychiatric Association, 2013). Several studies have shown a rate of about half of the children with ADHD also having DCD, and there is a growing idea that DCD may not be a uniform disorder (see Visser, 2003). An alternative view regarding the classification of developmental disorders, such as ASD, ADHD, and DCD, is that there is one group of children with heterogeneous, atypical brain development, rather than discrete groups of children (Gillberg and Kadesjö, 2003; Goez and Zelnik, 2008; Vaivre-Douret et al., 2016). An association between DCD and ADHD (Denckla, 1996) and motor control has been reported. Motor control problems may also be part of ASD (Gillberg and Kadesjö, 2003; Whyatt and Craig, 2013). The symptoms of the respective diseases also overlap, which is reflected in the earlier term Minimal Brain Dysfunction (MDB), labeling syndromes with various combinations of deficits in motor control, language, memory, perception, memory and impulse control (Gillberg and Kadesjö, 2003). According to the DSM V, the motor skills deficits should not be better explained by intellectual disability (intellectual developmental disorder) or visual impairment, and they should not be attributable to a neurological condition affecting movement (American Psychiatric Association, 2013). Still, neurological deficits have been reported in children with DCD, including slowed muscle force production and sensory organization deficits (Fong et al., 2015, see also Adams et al., 2014 for a review on internal modeling deficits). Furthermore, these children may demonstrate symptoms of neurological “soft signs” (Dewey, 2002). Such signs reflect minor neurological abnormalities and include dysdiadochokinesia, synkinesia, tactile localization deficits, reduced motor speed, mild dysfunction in muscle tone regulation, and asymmetric reflexes (Shaffer et al., 1985; Vaivre-Douret et al., 2016).

According to Geschwind and Behan (1982), there is an increased prevalence of left-handedness in patients with immune diseases, migraine and learning difficulties due to delayed growth in the left hemisphere caused by testosterone, which interferes with language functions and creates a shift of handedness toward the right hemisphere. Testosterone also accounts for the much greater prevalence of learning disabilities in boys. Also, according to Laurens et al. (2009), one underlying causal factor of left-handedness may be low birth weight, which is associated with perinatal difficulties. Prenatal factors have also been proposed to cause left-handedness (Geschwind and Behan, 1982; Laurens et al., 2009; Parma et al., 2017). Children with extreme low birth weights and children born prematurely have a significantly increased risk of demonstrating DCD (Barnhart et al., 2003; Gibbs et al., 2007; Kwok et al., 2018).

Handedness is regarded as one of the most evident lateral behavioral traits (Triggs et al., 2000). Lateralization denominates the processes that lead to an asymmetrical nervous system (Geschwind and Galaburda, 1985), with the end-product often being referred to as laterality. Handedness, which can be defined as “the individual's preference to use one hand predominantly for unimanual tasks and the ability to perform these tasks more efficiently with one hand” (Brown et al., 2006, p.1). Hand preference can be defined as a greater preference of one hand over the other if a choice is possible (Peters, 1995). Roughly 90% of the healthy adult population prefers using their right hand for manual actions (Cavill and Bryant, 2003; Adamo and Taufig, 2011; Ooki, 2014; Scharoun and Bryant, 2014; Willems et al., 2014). However, inconsistent handedness is more prevalent among left-handers than right-handers, and males also tend to be more inconsistently handed than females (Pritchard et al., 2013).

Several studies have indicated an elevated frequency of left-handed DCD children, and left-handedness, crossed dominance, mixed preference and poorly established hand preferences have all been linked with clumsiness (Armitage and Larkin, 1993). However, there are few studies that explicitly explore such relationships. Hill and Bishop (1998) stated that handedness had not been investigated directly in the DCD population. In their study, groups of children with DCD and specific language impairment (SLI) did not differ in terms of hand preference. Ten years later, Cairney et al. (2008) also concluded that “we know of no published work that has used objective clinical assessments of both handedness and DCD” (p. 697). However, Goez and Zelnik (2008) investigated the distribution of hand dominance in 98 children with DCD. They concluded that children with DCD are more often left-handed compared with the general population. A more recent study investigated handedness and DCD in Portuguese children (Freitas et al., 2014). These authors reported a higher co-occurrence rate of left-handedness compared to right-handedness in DCD children. It should, however, be noted that Freitas et al. (2014) deliberately recruited left-handers. Nevertheless, there are also studies concluding there is no higher prevalence of left-handedness in clumsy children (e.g., Armitage and Larkin, 1993).

Freitas et al. (2014) emphasized that the "literature's general tendency suggests an association between DCD and left-handed children, but it still remains unclear" (p. 657). Handedness
found in other comorbid diagnoses may give an indication of what to expect in DCD. In a review of 12 studies including a total of 497 individuals diagnosed with ASD, Rystad and Pedersen (2016) found 16% left-handers and 44% mixed-handers, giving a total of 60% non-right-handers. Furthermore, in a meta-analysis of dyslexia, Eglinton and Annett (1994) reported a significant difference in handedness distribution between dyslectics and control groups. The proportion of left-handers was approximately equal in both groups, with 10.7 and 10.4% left-handers. However, there were more than twice as many dyslexics (11.7%) with mixed-handedness than in the control groups (5.4%), which means that the difference in mixed-handers alone accounts for the distribution differences between the groups (Eglinton and Annett, 1994). In ADHD, in contrast, the findings about the association between left-handedness and disease are inconsistent (Ghanizadeh, 2013). Left-handedness has been proposed as a risk-factor for ADHD and reported as markedly preferred (Niederhofer, 2005), while others have failed to confirm this association (Biederman et al., 1995; Ghanizadeh, 2013).

Given the association between left- and mixed-handedness and other developmental disorders, it seems plausible that left-handedness may frequently co-occur with DCD (Cairney et al., 2008). Therefore, the present study set out to identify whether an elevated frequency of left-handedness is a general trait of children with DCD when combining several small studies, to see if this relationship found in Cairney et al. (2008), Freitas et al. (2014), and Goez and Zelnik (2008) is robust across studies and different methodological approaches. The present study does not aim to test, or even discuss, the complete hypothesis of Geschwind and Behan (1982), as mentioned above, but instead tests one of the assumptions underlying that hypothesis: the elevated prevalence of left-handedness. Thus, it could be seen as a departure point for further testing given that an absence of such an elevated prevalence would cast considerable doubt upon the hypothesis.

### MATERIALS AND METHODS

The following methods and inclusion and exclusion criteria were adapted from Rystad and Pedersen (2016), who conducted a meta-analysis on non-right handedness among individuals within ASD. Computerized searches were conducted in PubMed, PsycInfo and Cinahl databases with the purpose of identifying all relevant articles published in English, without imposing limits on the time interval.

The initial searches were traditional and description based. The search terms “Developmental coordination disorder” and “DCD” were each used in combination with the term “hand,” “handedness, priority,” “dominant,” and “left, right, handed,” indicating the prefix “hand” and any extension of the word. The searches identified a total of 170 studies in PubMed, 299 studies in Psycinfo and 117 studies in Cinahl, as can be seen in Table 1. In the initial searches, the range of publication years examined were between 1993 and 2018, being effectively limited by the inclusion criterion that articles should include children with DCD, a term that was introduced around 1990 and included in the DSM IV in 1994.

| TABLE 1 | Description based search and findings. |
|----------------------------------------|---------------------------------------|
| Search strategy                        | Articles identified | Articles included |
|----------------------------------------|---------------------|------------------|
| 1 “Developmental coordination” and hand* (limits humans, English written) | | |
| PubMed                                 | 83                  | 12               |
| PsycInfo                               | 161                 | 17               |
| CINAHL                                 | 68                  | 8                |
| 2 “DCD” and hand* (limits humans, English written) | | |
| PubMed                                 | 87                  | 11               |
| PsycInfo                               | 138                 | 12               |
| CINAHL                                 | 49                  | 6                |
| Total                                  | 586                 | (66) 21*         |

*Due to a considerable overlap in the results of the use of different search terms and overlap between the databases, as well as duplication of data between articles, the total number of unique articles included amounts to 21.

Articles were considered relevant based on their titles and abstracts, as well as manual computerized searches in the full format articles with the key words “left,” “right,” “handedness,” “preference,” and “dominant.” The latter was done to secure that all studies reporting hand preference in DCD people without directly investigating the association would be identified.

Potentially relevant articles were obtained and assessed according to the following criteria:

**Inclusion criteria:**

1. Articles written in English
2. Empirical studies
3. Individuals with Developmental Coordination Disorder
4. Studies reporting distribution of left-handers versus right-handers in frequencies, or percent

**Exclusion criteria:**

1. Articles written in any other language than English
2. Reviews, books, theoretical papers, descriptive papers, theses
3. Diagnoses similar to DCD, including older terms, with somewhat similar but not identical diagnostic criteria.

Based on the results of the description-based searches, citation-based searches were conducted using Google Scholar. This strategy had previously proven to be much more effective in identifying relevant papers, compared with more traditional searches (see Rystad and Pedersen, 2016 for details). Google Scholar includes articles from every other database and reports the citations for each article. All English written articles citing each of the already identified were examined using the same procedure as above in order to identify additional articles to include. The articles identified through the description-based searches had been cited by other articles a total of 889 times, as can be seen in Table 2. Twenty of these articles were ultimately included in the present dataset. Thus, to escape our description-based search and not be included, a paper would have to be published in a journal that is not indexed in any of the PsycInfo,
Thirty-eight studies were included in the present review, containing handedness distributions across 1071 persons with DCD, as presented in Table 3. The earliest of the studies was published in 1993, and the most recent were published in 2017. The ages of the participants varied between 4 and 43 years, but the vast majority of the studies included children between 7 and 12 years. Three studies included adults. On closer inspection, it was detected that four papers by the same group of authors included the same participants, or samples of participants that had almost complete overlap. Thus, only one of the studies (Adams et al., 2016) was included in the present dataset.

Only four studies reported mixed-handedness. Participants with mixed-handedness were omitted from the analysis. This was the case for a total of 44 mixed-handers (2.0% of the total sample). Thirty-two belonged to the DCD-groups and 12 were controls. The studies defined mixed-handedness differently. Regardless of the categorization used in a study, however, DCD-individuals and controls were categorized in the same manner, so the relative distribution of left- and right-handers across these groups would not seem to be affected.

The controls of the studies including such groups were used for comparison, as can be seen in Table 4. Four studies did not provide data on such, namely Cairney et al. (2008), Goez and Zelnik (2008), Maleki and Zarei (2016), and Rodger et al. (2003). Several studies also included more than one control group (e.g., younger controls, adults or both). In those cases, only one—preferably the one matched by age and sex and other possible variables with the study participants—were included for the purpose of the present study, as can be found in Table 4. Across 24 studies, 1,045 control participants were included.

A male-female ratio in favor of the male distribution was evident in both the DCD group and control group. However, specific gender analyses were not possible because most of the studies lacked reports of the gender distribution across handedness-categories.

Among 1,071 participants with DCD, 14.7% were classified as left-handers, compared to 8.1% among 1045 participants in the control groups. The handedness distribution varied some: the highest reported number of left-handers in a DCD-group was found in Cairney et al. (2008), with 36.8%, while Rosenblum et al. (2013) identified only 3.4% left-handers. The distribution of DCD participants across handedness-categories proved to be significantly different from that of the control group, $\chi^2 = 22.2345$, $p = 0.000002$.

### DISCUSSION

An overrepresentation of left-handers in DCD children has repeatedly been assumed. However, due to primarily small individual samples reporting handedness within this population, no other study has been large enough to conclude that there is actually an elevated prevalence of left-handers in this group, and no one has yet combined the results in a meta-analysis or review. Sample sizes varied across the studies, with the smallest sample size found in Lust et al. (2006) ($N = 7$) and the largest in Smyth and Mason (1997) ($N = 96$). Twenty-eight out of the 38 studies had sample sizes of 30 participants or below, with the vast majority including fewer than 20 participants. The results

### Statistical Approaches

Combined handedness distributions of left- and right-handers across the included studies were calculated as percentages and absolute numbers for the DCD (Table 3) and control groups (Table 4). The absolute numbers were compared by means of a chi-square test.

### RESULTS

| Study                        | Citations | Articles included |
|------------------------------|-----------|------------------|
| Adams et al., 2017           | 3         | 2                |
| Armitage and Larkin, 1993    | 51        | 0                |
| Asmussen et al., 2014        | 14        | 1                |
| Cairney et al., 2008         | 28        | 0                |
| Chang and Yu, 2010           | 56        | 3                |
| Coats et al., 2015           | 3         | 0                |
| Cox et al., 2015             | 7         | 0                |
| Ferguson et al., 2014        | 15        | 2                |
| Fuescher et al., 2015        | 12        | 4                |
| Goez and Zelnik, 2008        | 35        | 2                |
| Hill, 1998                   | 163       | 1                |
| Hill and Bishop, 1998        | 54        | 1                |
| Hodgson and Hudson, 2017     | 5         | 0                |
| Hyde and Wilson, 2011a       | 44        | 8                |
| Kashuk et al., 2017          | 0         | 0                |
| Lust et al., 2006            | 38        | 2                |
| Roche et al., 2011           | 9         | 0                |
| Rodger et al., 2003          | 89        | 2                |
| Rosenblum and Regev, 2013    | 14        | 0                |
| Rosenblum et al., 2013       | 12        | 0                |
| Smyth and Mason, 1997        | 99        | 5                |
| van Swieten et al., 2010     | 74        | 2                |
| Volman and Geuze, 1998       | 64        | 1                |

Total 889 (36) 20$

* Unique papers, due to considerable overlap. Six articles identified through citation-based searches had already been identified and included in the description-based searches. In addition, a few papers were excluded due to duplication of data.

PubMed or CINAHL databases, or not be identified by the chosen search terms. In order to escape our citation-based search, a paper would not have been cited by any of the papers that had already been identified as relevant from the description-based searches (which is definitely possible). However, neither would it have cited even one of the relevant papers (which would be highly unlikely).

Thus, the present dataset would be more than representative of papers on DCD, and it is difficult to imagine that papers not included would have a systematically different distribution of participants’ handedness across groups compared with those included.
### TABLE 3 | Studies reporting distributions of handedness for individuals with Developmental Coordination Disorder.

| Study | Participants | Inclusion criteria | Measurement | Right-handed | Left-handed |
|-------|--------------|--------------------|-------------|--------------|-------------|
| Adams et al., 2016 | N = 30 (20 male, 10 female); age = 6–10 years | DSM-V criteria, MABC-2 ≤5th centile | Writing hand, Procedure described in the MABC-2 | 93.3% (28) | 6.7% (2) |
| Armitage and Larkin, 1993* | N = 27; age = 5–9 | Referred to or involved in movement program | Drawing, erasing, throwing a ball, and dealing cards (Porac and Coren, 1981) | 92.6% (25) | 7.4% (2) |
| Asmussen et al., 2014 | N = 10 (10 male); age = 9–12 years | DSM-IV criteria DSDQ MABC | Observed hand to write name and hand used to catch a ball | 70.0% (7) | 30.0% (3) |
| Bonney et al., 2017 | N = 57 (29 male, 28 female); age = 6–10 years | DSM-V criteria | Not explicitly stated | 93.0% (53) | 7.0% (4) |
| Cairney et al., 2008 | N = 19; age = 11 years | MABC BOTMP-SF test ≤5th centile Kaufman Brief Intelligence Test | Observed hand preference throughout the testing process | 63.2% (12) | 36.8% (7) |
| Chang and Yu, 2010 | N = 33 (18 male, 15 female); age = 6–8 years | MABC, DCDQ | Not explicitly stated | 87.9% (29) | 12.1% (4) |
| Coats et al., 2015 | N = 10 (6 male, 4 female); age = 7–10 years | DSM-IV criteria | Writing hand | 90.0% (9) | 10.0% (1) |
| Cox et al., 2015 | N = 20 (15 male, 5 female); age = 6–12 years | DSM-V criteria MABC-2 ≤15th centile | The Edinburgh Handedness Inventory (Oldfield, 1971) | 85.0% (17) | 15.0% (3) |
| de Oliveira et al., 2014 | N = 116 (male, 5 female); age = 16–26 years | Previously diagnosed with DCD, MABC-2 | Not explicitly stated | 81.8% (9) | 18.2% (2) |
| Debrabant et al., 2013 | N = 17 (14 male, 3 female); age = 7–10 years | MABC-2 ≤5th centile The Wechsler Intelligence Scale for children | Not explicitly stated | 82.4% (14) | 17.6% (3) |
| Engel-Yeger and Hanna Kasis, 2010 | N = 37 (26 male, 11 female); age = 5–9 years | Diagnose by pediatrician/developmental neurologist DSM-IV criteria MABC ≤15th centile | Demographic questionnaire, not explicitly stated who completed these | 94.6% (35) | 5.4% (2) |
| Ferguson et al., 2014 | N = 70 (86 male, 34 female); age = 6–10 years | Problematic daily life motor function according to teacher and/or parent MABC-2 ≤5th centile | Not explicitly stated | 91.4% (64) | 8.6% (6) |
| Ferguson et al., 2015 | N = 30 (19 male, 14 female); age = 6–10 years | DSM-IV criteria MABC-2 ≤5th centile | The hand normally used for writing or drawing | 93.3% (28) | 6.7% (2) |
| Fuelscher et al., 2015 | N = 17 (8 male, 9 female); age = 8–12 | DSM-V criteria McCarron Assessment of Neuromuscular Development ≤15th centile | Not explicitly stated | 88.2% (15) | 11.8% (2) |
| Goez and Zeinik, 2008* | N = 85 age = 5–17 years | DSM-IV criteria | Examinations of the preferred writing hand, preferred hand for throwing a ball, and preferred hand for holding a table spoon | 64.7% (55) | 35.3% (30) |
| Hill, 1998 | N = 11 (8 male, 3 female); age = 5–13 years | Diagnosed with DCD | Not explicitly stated | 72.7% (8) | 27.3% (3) |
| Hill and Bishop, 1998 | N = 12 (9 male, 3 female); age = 7–11 years | M-ABC ≤15th centile Raven’s Progressive Matrices ≥ 80 CELF-R Repeating Sentences ≥ 80 | Writing hand, Handedness questionnaire based on the Edinburgh Handedness Inventory (Oldfield, 1971), completed by the children’s parents | 83.3% (10) | 16.7% (2) |
| Hodgson and Hudson, 2017 | N = 12 (4 male, 8 female); age = 15–43 years | Self-report on the Adult Developmental Coordination Disorder Checklist | 21-item handedness questionnaire (Flowers and Hudson, 2013) | 75.0% (9) | 25.0% (3) |
| Hyde and Wilson, 2011a | N = 17 (8 male, 9 female); age = 7–12 years | DSM-IV criteria McCarron Assessment of Neuromuscular Development ≤10th centile | Not explicitly stated (but see Hyde and Wilson, 2011b, below) | 76.5% (13) | 23.5% (4) |

(Continued)
TABLE 3 | Continued

| Study                      | Participants                                                                 | Inclusion criteria                                                                 | Measurement                                                                 | Right-handed | Left-handed |
|----------------------------|------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|----------------------------------------------------------------------------|--------------|-------------|
| Hyde and Wilson, 2011b     | N = 13 (6 male, 9 female); age = 8–12 years                                   | DSM-IV criteria; McCarron Assessment of Neuromuscular Development ≤ 10th centile    | McCarron Assessment of Neuromuscular Development                           | 69.2% (9)    | 30.8% (4)   |
| Hyde and Wilson, 2013      | N = 18 (7 male, 11 female); age = 8–12 years                                 | DSM-IV criteria; McCarron Assessment of Neuromuscular Development ≤ 10th centile    | Reaching hand                                                               | 77.8% (14)   | 22.2% (4)   |
| Kashuk et al., 2017        | N = 12 (6 male, 7 female); age = 18–40 years                                 | McCarron Assessment of Neuromuscular Development Adult Dyspraxia/Developmental Coordination Disorder Checklist | Not explicitly stated                                                       | 75.0% (9)    | 25.0% (3)   |
| Lust et al., 2006*         | N = 7; age = 9–11 years                                                      | M-ABC ≤ 15th centile                                                              | Handedness Inventory (Van Strien, 1992)                                      | 85.7% (8)    | 14.3% (1)   |
| Maleki and Zarei, 2016     | N = 53 (32 male, 21 female); age = 7–11 years                                | Persian version of motor observation questionnaire for teachers Diagnosis by psychiatrists | Not explicitly stated                                                       | 83.0% (44)   | 17.0% (9)   |
| Roche et al., 2011         | N = 10 (7 male, 3 female); age = 6–8 years                                   | Diagnosed with DCD; MABC ≤ 15th centile Woodcock-Johnson Psycho-Educational Battery | Annett Handedness Questionnaire (1970)                                       | 90.0% (9)    | 10% (1)     |
| Rodger et al., 2003        | N = 20 (12 male, 8 female); age = 4–8 years                                  | MABC ≤ 15th centile                                                              | Observed hand preference during writing tasks                                | 70.0% (14)   | 30.0% (6)   |
| Rosenblum and Regev, 2013  | N = 21 (13 male, 8 female); age = 7–10 years                                 | Educators’ or clinicians’ reports based on DSM-IV criteria MABC ≤ 15th centile    | Not explicitly stated (but see Rosenblum et al., 2013, 2017, below)         | 95.2% (20)   | 4.8% (1)    |
| Rosenblum et al., 2013     | N = 29 (24 male, 5 female); age = 11–12 years                                | DSM-IV criteria; MABC ≤ 5th centile                                              | Demographic questionnaire completed by the children’s parents               | 96.6% (28)   | 3.4% (1)    |
| Rosenblum et al., 2017*    | N = 27; age = 4–6 years                                                       | Diagnosed according to DSM-V criteria and MABC ≤ 5th centile                      | Demographic questionnaire completed by the children’s parents               | 92.6% (25)   | 7.4% (2)    |
| Ruddock et al., 2016       | N = 62; age = 6–12 years                                                     | McCarron Assessment of Neuromuscular Development ≤ 15th centile                  | Manual dexterity items of McCarron Assessment of Neuromuscular Development Hand used during writing | 91.9% (57)   | 8.1% (5)    |
| Schoemaker et al., 2001    | N = 19 (11 male, 8 female); age = 6–11 years                                 | MABC ≤ 15th centile and ≤ 5th centile                                            | Not explicitly stated                                                       | 73.7% (14)   | 26.3% (5)   |
| Sinani et al., 2011        | N = 45 (29 male, 16 female); age = 9–11 years                                | DSM-IV-TR criteria; MABC ≤ 15th centile                                          | Hand used for holding a pen                                                | 88.9% (40)   | 11.1% (5)   |
| Smits-Engelsman et al., 2016| N = 17 (9 male, 8 female); age = 6–10 years                                 | DSM-V criteria; MABC ≤ 5th centile                                               | Not explicitly stated, (but see same authors in Ferguson et al., 2015, above) | 94.1% (16)   | 5.9% (1)    |
| Smyth and Mason, 1997      | N = 96 (59 male, 37 female); age = 4–8 years                                 | MABC ≤ 5th centile; The British Ability Scale                                    | Not explicitly stated                                                       | 89.6% (86)   | 10.4% (10)  |
| van Swieten et al., 2010   | N = 27 (20 male, 7 female); age = 6–13 years                                 | DSM-IV criteria; MABC ≤ 5th centile                                              | Writing hand                                                               | 88.9% (24)   | 11.1% (3)   |
| Van Waalwede et al., 2006  | N = 36 (22 male, 14 female); age = 9–10 years                                 | MABC ≤ 5th centile                                                              | Indicated by the children                                                  | 86.1% (31)   | 13.9% (5)   |
| Volman and Geuze, 1998     | N = 24 (21 male, 3 female); age = 7–12 years                                 | MABC ≤ 15th centile                                                              | Hand used for writing                                                       | 79.2% (19)   | 20.8% (5)   |
| Whitall et al., 2008       | N = 10 (7 male, 3 female); age = 6–7 years                                   | Diagnosed with DCD; MABC ≤ 15th centile DCDQ                                     | Not explicitly stated                                                       | 90.0% (9)    | 10.0% (1)   |

Total N = 1071

* The study included mixed-handers, who were omitted from the current study. N = sample excluding mixed-handers.
TABLE 4 | Distribution of handedness in control groups.

| Study                        | Participants of control group | Measurement                                                                 | Right-handed | Left-handed |
|------------------------------|-------------------------------|-----------------------------------------------------------------------------|--------------|-------------|
| Adams et al., 2016           | N = 90 (50 male, 40 female)   | Matched by age                                                              | 96.7% (87)   | 3.3% (3)    |
| Armitage and Larkin, 1993    | N = 31 age 5–9 years          | Grouped according to coordination and age                                     | 93.5% (29)   | 6.5% (2)    |
| Asmussen et al., 2014        | N = 9 (9 male)                 | Typically developing children from the school system                          | 88.9% (8)    | 11.1% (1)   |
| Bonney et al., 2017          | N = 54 (28 male, 26 female)   | Typically developing children from the same school as the DCD children       | 96.3% (52)   | 3.7% (2)    |
| Cairney et al., 2008         |                               |                                                                             |              |             |
| Chang and Yu, 2010           | N = 22 (12 male, 10 female)    | Matched by age and sex                                                      | 86.4% (19)   | 13.6% (3)   |
| Coats et al., 2015           | N = 10 (5 male, 5 female)      | Matched by age                                                              | 90.0% (9)    | 10.0% (1)   |
| Cox et al., 2015             | N = 18 (6 male, 10 female)     | Typically developing children                                               | 87.5% (14)   | 12.5% (2)   |
| de Oliveira et al., 2014     | N = 11 (6 male, 5 female)      | Matched by sex and similar age                                              | 100.0% (11)  | 0.0% (0)    |
| Debrabant et al., 2013       | N = 17 (14 male, 3 female)     | Matched by age and sex                                                      | 88.2% (15)   | 11.8% (2)   |
| Engel-Yeger and Hanna Kasis, 2010 | N = 37 (26 male, 11 female)   | Matched by sex, age and socio-economic status                               | 91.9% (34)   | 8.1% (3)    |
| Ferguson et al., 2014        | N = 70 (35 male, 35 female)    | Matched by age and sex                                                      | 92.9% (65)   | 7.1% (5)    |
| Ferguson et al., 2015        | N = 30 (15 male, 15 female)    | Matched by age and sex                                                      | 93.3% (28)   | 6.7% (2)    |
| Fueilscher et al., 2015      | N = 17 (8 male, 9 female)      | Matched by age                                                              | 88.2% (15)   | 11.8% (2)   |
| Goez and Zelnik, 2008**      |                               |                                                                             |              |             |
| Hill, 1998                   | N = 25 (14 male, 11 female)    | Matched by age, sex, non-verbal IQ, and language ability                    | 88.0% (22)   | 12.0% (3)   |
| Hill and Bishop, 1998        | N = 26 (15 male, 11 female)    | Matched by age, sex ratio, and non-verbal ability                           | 80.8% (21)   | 19.2% (5)   |
| Hodgson and Hudson, 2017     | N = 12 (5 male, 7 female)      | General student and staff population                                         | 91.7% (11)   | 8.3% (1)    |
| Hyde and Wilson, 2011a       | N = 27 (14 male, 13 female)    | Matched by age                                                              | 96.3% (26)   | 3.7% (1)    |
| Hyde and Wilson, 2011b       | N = 13 (7 male, 6 female)      | Matched by age                                                              | 100.0% (13)  | 0.0% (0)    |
| Hyde and Wilson, 2013        | N = 18 (8 male, 10 female)     | Matched by age                                                              | 94.4% (17)   | 5.6% (1)    |
| Kashuk et al., 2017          | N = 11 (6 male, 5 female)      | General student and staff population                                         | 72.7% (8)    | 27.3% (3)   |
| Lust et al., 2006*           | N = 5                         | Matched by age and sex                                                      | 100% (5)     | 0.0% (0)    |
| Maleki and Zarei, 2018**     |                               |                                                                             |              |             |
| Roche et al., 2011           | N = 10 (7 male, 3 female)      | Matched by age and sex                                                      | 90.0% (9)    | 10.0% (1)   |
| Rodger et al., 2003**        |                               |                                                                             |              |             |
| Rosenblum and Regev, 2013    | N = 21 (13 male, 8 female)     | Matched by age, sex, and school                                              | 95.2% (20)   | 4.8% (1)    |
| Rosenblum et al., 2013       | N = 29 (24 male, 5 female)     | Matched by age, sex, and school                                              | 93.1% (27)   | 6.9% (2)    |
| Rosenblum et al., 2017*      | N = 33                        | Matched by age, sex and socio-economic status                               | 90.9% (30)   | 9.1% (3)    |
| Ruddock et al., 2016         | N = 109 (48 male, 61 female)   | Matched by age and sex                                                      | 94.5% (103)  | 5.5% (6)    |
| Schoemaker et al., 2001      | N = 19 (11 male, 8 female)     | Matched by age and sex                                                      | 84.2% (16)   | 15.8 (3)    |
| Sinini et al., 2011          | N = 24 (16 male, 8 female)     | Matched by age, sex, ethnicity and academic ability                         | 87.5% (21)   | 12.5% (3)   |
| Smits-Engelsman et al., 2016 | N = 18 (9 male, 9 female)      | Matched by age                                                              | 94.4% (17)   | 5.6% (1)    |
| Smyth and Mason, 1997        | N = 91 (54 male, 37 female)    | Matched by age, sex, and performance on the The British Ability Scale       | 91.2% (83)   | 8.8% (8)    |
| van Swieten et al., 2010     | N = 70 (35 male, 35 female)    | Typically developing children                                               | 87.1% (61)   | 12.9% (9)   |
| Van Waeselde et al., 2006     | N = 36 (22 male, 14 female)    | Matched by age and sex                                                      | 97.2% (35)   | 2.8% (1)    |
| Volman and Geuze, 1998       | N = 24 (20 male, 4 female)     | Individually matched                                                        | 83.3% (20)   | 16.7% (4)   |
| Whitall et al., 2008         | N = 10 (7 male, 3 female)      | Matched by age and sex                                                      | 90.0% (9)    | 10.0% (1)   |
| Total                        | N = 1,045                     |                                                                             | 91.9% (960)  | 8.1% (85)   |

* The study included mixed-handers, who were omitted from the current study. N = sample excluding mixed-handers.
** No control group/not included in the analysis.
also appear to be robust across studies and do not seem to be related to differences with respect to measures of handedness, categorizations of participants for inclusion in the DCD-group, or participants’ age or sex. Therefore, it should be possible to conclude that an elevated frequency of left-handedness is a general trait of individuals within DCD.

Participants’ handedness was classified as right-handed or left-handed based on a variety of measures across studies, such as writing or drawing hand, The Edinburgh Handedness Inventory (Oldfield, 1971), the Movement ABC (Henderson and Barnett, 1992), the Annett Handedness Questionnaire (Annett, 1970), Porac and Coren’s (1981) questionnaire or observed hand throughout the testing process. There is, seemingly, no trend related to classification of handedness, as the handedness distributions varied across samples even when using the same measure of handedness, indicating that differences across measures are not systematic.

Diagnostic criteria for DCD varied across the included studies, with the vast majority using DSM-IV criteria and/or a version of the MABC. The cut-off value of the MABC varied somewhat between ≤16th (Cairney et al., 2008) and 5th centile (e.g., Debrabant et al., 2013). Even when using the same criteria for DCD, handedness distributions varied across samples without there, seemingly, being any trend related to inclusion criteria of the respective samples.

Most participants were between the ages of 4 and 12 years old (see Table 3 for details) and there is no evidence for the effects of age upon the distributions across handedness categories. Also, most studies included control participants who were age matched with the DCD-groups.

More boys than girls (2:1) are diagnosed with DCD (Barnhart et al., 2003) and there are also more left-handed boys than girls, with an estimate of 1.23 for the ratio of male to female left- to right-handedness odds (Papadatou-Pastou et al., 2008). This could lead one to believe that the difference between the groups would be due to the sex ratio. However, although the samples’ skewed sex ratios, in part, could explain why there are more left-handers in the DCD-group, the differences in handedness distributions are still much larger than what might be expected based on sex differences alone. Furthermore, and even more importantly, the majority of the studies matched their controls by both sex and age; thus, there were equally as many boys among the controls. Moreover, there seems to be no clear trend across the studies that handedness distribution is dependent on the sex ratio.

The prevalence of left-handedness within the DCD-group was somewhat smaller than the prevalence found for ASD in Rydstad and Pedersen (2016), with 16% pure left-handers. However, four of the studies in the current analysis included participants reporting mixed- or ambidextrous handedness. Although mixed- and ambidextrous handedness was not included in the data material, these studies indicate that non-right-handedness may be an even more prominent trait of DCD children than left-handedness. In Goez and Zelnik (2008), 13% of the children were classified as ambidextrous, giving a total of 44% non-right-handers. Armitage and Larkin (1993) reported 30% mixed-handers in 5- to 6-year-olds and 35% in 8- to 9-year-olds, giving a total of 40% non-right-handed in the younger group, while Lust et al. (2006) also reported 30% ambidextrous handedness, totalling 40% non-right-handed.

Thus, DCD has a slightly lower proportion of left-handers than found in ASD, and there are also indications of less mixed- and ambidextrous handedness in DCD than in ASD (Rydstad and Pedersen, 2016). However, there is a higher proportion of left-handers in the DCD group than was found in dyslexics (Eglinton and Annett, 1994), as well as indications of a much larger proportion of mixed- and ambidextrous handedness compared with this group. Although a higher proportion of left-handers in these groups have been found in comparison with healthy controls, there is a markedly higher rate of mixed- and ambidextrous handedness, which indicates that inconsistent handedness may be a bigger problem than consistent left-handedness in these groups, as was argued by Prichard et al. (2013).

In the current meta-analysis, we have established there is an elevated frequency of left-handers in DCD, thus supporting the theory of Geschwind and Behan (1982). However, the results say nothing about the direction of the association between the variables. One could, for example, speculate that some diagnostic criteria for DCD favor right-handers, thereby giving left-handers an elevated risk of being diagnosed with DCD. The inclusion of matched control groups (with a few exceptions) that have undergone the same testing procedures as the DCD-groups makes this rather unlikely, as well as the fact that the findings seem robust across different inclusion criteria.

The fact that handedness distributions of DCD children are compared with the corresponding distributions within the groups of controls included in each study is, in fact, a major strength of the present study. This secures that whatever differences found across studies with respect to measures, handedness categorization, sex, age, and other possible confounders would be accounted for, and thus should not affect the present results. Another major strength is that the included studies from which handedness distributions were extracted did not generally have the scope to study handedness in DCD-children per se. Rather, they studied a host of other more or less related topics, and reported handedness (with only a very few exceptions) as a background variable. Hence, the handedness distributions reported in each individual paper would appear relatively unbiased with respect to the bigger picture of a general elevated prevalence of left-handedness.

In summary, the current study gives support to a notion that there is a link between left-handedness and several developmental disorders, including DCD. The data, however, cannot further the discussions about a shared underlying mechanism, as proposed by Geschwind and Behan (1982).

**CONCLUSION**

The distribution of DCD participants across handedness-categories was significantly different from that of the control groups. As discussed, the number of participants in each individual study was too small for any generalizations to be
made, but the combined number of participants gives the largest sample addressing the association between handedness and DCD currently available. Results appear robust across inclusion criteria for DCD and measures of handedness, as well as age and sex. This suggests that an elevated prevalence of left-handedness in individuals with DCD has been proved valid in the current study and gives support for an assumption of a shared underlying mechanism of disorders in some clinical groups. The prevalence of left-handedness within the DCD-group is lower than that reported for ASD, and larger than in dyslexia. However, no data in the present study can support or contradict the proposed assumption of a common cause of the various disorders. The present results could, however, constitute a starting point for testing the hypothesis of such a common factor, as one of the requirements would be an elevated prevalence of left-handedness, and without such the hypothesis could more or less be rejected.

**AUTHOR CONTRIBUTIONS**

MD, AP, and HL contributed to the conception and design of the study. MD carried out the searches, but conferred and discussed with AP throughout the process. MD, AP, and HL analyzed and/or interpreted the data. MD wrote the first draft of the manuscript and AP wrote sections of the manuscript. All authors contributed to manuscript revision and read and approved the submitted version.

**REFERENCES**

Adamo, D. E., and Taufiq, A. (2011). Establishing hand preference: why does it matter? *Hand 6*, 295–303. doi: 10.1007/s11552-011-9324-x

Adams, I. L., Ferguson, G. D., Lust, J. M., Steenbergen, B., and Smits-Engelsman, B. C. (2016). Action planning and position sense in children with Developmental Coordination Disorder. *Hum. Mov. Sci. 46*, 196–208. doi: 10.1016/j.humov.2016.01.006

Adams, I. L., Lust, J. M., Wilson, P. H., and Steenbergen, B. (2014). Compromised motor control in children with DCD: a deficit in the internal model? A systematic review. *Neurosci. Biobehav. Rev. 7*, 225–244. doi: 10.1016/j.neubiorev.2014.08.011

Adams, I. L., Lust, J. M., Wilson, P. H., and Steenbergen, B. (2017). Testing predictive control of movement in children with developmental coordination disorder using converging operations. *Br. J. Psychol. 108*, 73–90. doi: 10.1111/bjop.12183

American Psychiatric Association (2013). *Neurodevelopmental disorder*, in *Diagnostic and Statistical Manual of Mental Disorders*, 5th Edn. Arlington, VA: American Psychiatric Association.

Annett, M. (1970). A classification of hand preference by association analysis. *Br. J. Psychol. 61*, 303–321. doi: 10.1111/j.2044-8295.1970.tb01248.x

Armitage, M., and Larkin, D. (1993). Laterality, motor asymmetry and clumsiness in children. *Hum. Mov. Sci. 12*, 155–177. doi: 10.1016/0167-9457(93)90414-M

Asmussen, M. J., Przyuscha, E. P., and Dounskaia, N. (2014). Intersegmental dynamics shape joint coordination during catching in typically developing children but not in children with developmental coordination disorder. *J. Neurophysiol. 111*, 1417–1428. doi: 10.1152/jn.00762.2013

Barnhart, R. C., Davenport, M. J., Epps, S. B., and Nordquist, V. M. (2014). *Clinical information in adolescents and young adults with developmental coordination disorder*. Exp. Brain Res. 232, 2989–2995. doi: 10.1007/s00221-014-3983-0

Dehrabrant, J., Ghysens, F., Caeyenberghs, K., Van Waalvelde, H., and Vingerhoets, G. (2013). Neural underpinnings of impaired predictive motor timing in children with Developmental Coordination Disorder. *Res. Dev. Disabil. 34*, 1478–1487. doi: 10.1016/j.ridd.2013.02.008

Denckla, M. B. (1996). Biological correlates of learning and attention: what is relevant to learning disability and attention-deficit hyperactivity disorder? *J. Dev. Behav. Pediatr. 17*, 114–119. doi: 10.1097/00004703199604000-00011

Dewey, D. (2002). “Subtypes of developmental coordination disorder,” in *Developmental Coordination Disorder*, eds S. A. Cermak, S. A., and D. Larkin. (Albany, NY: Delmar Thomson Learning), 63.

Egilnton, E., and Annett, M. (1994). Handedness and dyslexia: a meta-analysis. *Percept. Motor Skills 79*(3 Suppl.), 1611–1616. doi: 10.2466/pms.1994.79.3f.1611

Engel-Yeger, B., and Hanna Kassis, A. (2010). The relationship between Developmental Co-ordination Disorders, child’s perceived self-efficacy and preference to participate in daily activities. *Child Care Health Dev. 36*, 670–677. doi: 10.1111/j.1365-2214.2010.01073.x

Ferguson, G., Wilson, P., and Smits-Engelsman, B. (2015). The influence of task paradigm on motor imagery ability in children with Developmental Coordination Disorder. *Hum. Mov. Sci. 44*, 81–90. doi: 10.1016/j.humov.2015.08.016

Ferguson, G. D., Aertsen, W. F., Rameckers, E. A., Jelsma, J., and Smits-Engelsman, B. C. (2014). Physical fitness in children with developmental coordination disorder: measurement matters. *Res. Dev. Disabil. 35*, 1087–1097. doi: 10.1016/j.ridd.2014.01.031

Flowers, K. A., and Hudson, J. M. (2013). Motor laterality as an indicator of speech laterality. *Neuropsychology 27*, 256. doi: 10.1037/a0031664

Fong, S., Ng, S., and Yiu, B. (2015). Slowed muscle force production and sensory organization deficits contribute to altered postural control strategies in children with developmental coordination disorder. *Res. Dev. Disabil. 34*, 3040–3048. doi: 10.1016/j.ridd.2013.05.035
Sinani, C., Sugden, D. A., and Hill, E. L. (2011). Gesture production in school vs. clinical samples of children with Developmental Coordination Disorder (DCD) and typically developing children. *Res. Dev. Disabil.* 32, 1270–1282. doi: 10.1016/j.ridd.2011.01.030

Smits-Engelsman, B. C., Jelsma, L. D., and Ferguson, G. D. (2016). The effect of exergames on functional strength, anaerobic fitness, balance and agility in children with and without motor coordination difficulties living in low-income communities. *Hum. Mov. Sci.* 55, 327–337. doi: 10.1016/j.humov.2016.07.006

Smyth, M. M., and Mason, U. C. (1997). Planning and execution of action in children with and without developmental coordination disorder. *J. Child Psychol. Psychiatry* 38, 1023–1037. doi: 10.1111/j.1469-7610.1997.tb01619.x

Triggs, W., Calvanio, R., Levine, M., Heaton, R., and Heilman, K. (2000). Predicting hand preference with performance on motor tasks. *Cortex* 36, 679–689. doi: 10.1016/S0010-9452(08)70545-8

Vaivre-Douret, L., Lalanne, C., and Golse, B. (2016). Developmental coordination disorder, an umbrella term for motor impairments in children: nature and co-morbid disorders. *Front. Psychol.* 7:502. doi: 10.3389/fpsyg.2016.00502

Van Strien, J. (1992). *Classificatie van links-en rechtshandige proefpersonen. Nederlands Tijdschrift voor de Psychol. en haar Grensgebieden.* 47, 88–92.

Van Swieten, L. M., van Bergen, E., Williams, J. H., Wilson, A. D., Plumb, M. S., Kent, S. W., et al. (2010). A test of motor (not executive) planning in developmental coordination disorder and autism. *J. Exp. Psychol. Hum. Percept. Perform.* 36, 493. doi: 10.1037/a0017177

Van Waedelde, H., De Weerd, W., De Cock, P., Janssens, L., Fys, H., and Engelsman, B. C. S. (2006). Parameterization of movement execution in children with developmental coordination disorder. *Brain Cogn.* 60, 20–31. doi: 10.1016/j.bandc.2005.08.004

Visser, J. (2003). Developmental coordination disorder: a review of research on subtypes and comorbidities. *Hum. Mov. Sci.* 22, 479–493. doi: 10.1016/j.humov.2003.09.005

Volman, M. C. J., and Geuze, R. H. (1998). Relative phase stability of bimanual and visuomanual rhythmic coordination patterns in children with a developmental coordination disorder. *Hum. Mov. Sci.* 17, 541–572. doi: 10.1016/S0167-9452(97)00013-X

Whitall, J., Chang, T.-Y., Horn, C., Jung-Potter, J., McMenamin, S., Wilms-Floet, A., et al. (2008). Auditory-motor coupling of bilateral finger tapping in children with and without DCD compared to adults. *Hum. Mov. Sci.* 27, 914–931. doi: 10.1016/j.humov.2007.11.007

Whyatt, C., and Craig, C. (2013). Sensory-motor problems in Autism. *Front. Integr. Neurosci.* 7:51. doi: 10.3389/fnint.2013.00051

Willems, R. M., Van der Haegen, L., Fisher, S. E., and Francks, C. (2014). On the other hand: including left-handers in cognitive neuroscience and neurogenetics. *Nat. Rev. Neurosci.* 15, 193–201. doi: 10.1038/nrn3679

**Conflict of Interest Statement:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Copyright © 2018 Darvik, Lorås and Pedersen. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.