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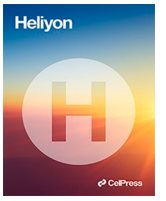

Research article

Handedness in autism spectrum disorders and intellectually disabled children and adolescents - Contrasting caregivers' reports with assessments of hand preference

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A R T I C L E I N F O

Keywords:
Handedness
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A B S T R A C T

Background: A higher rate of atypical handedness prevalence (non-right-handedness or left-, mixed-hand dominance) has been recurrently reported in individuals diagnosed with autism spectrum disorder (ASD) compared to individuals with other types of developmental disabilities. However, the exact magnitude of this difference as well as the presence of possible contributing factors remained unknown. The main aim of this study was to understand caregivers' impression of the handedness of their child with developmental disabilities and its relationship with assessments of the child using a hand preference scale.

Methods and procedures: The sample of the present study was 1116 individuals with developmental disabilities from two countries, 541 (51.5%) individuals from Iran and 575 (48.5%) individuals from the Kurdistan Region of Iraq (KRI). The handedness of the sample was evaluated based on the parental report and utilizing a standardized scale (The Hand-Preference Demonstration Test "HPDT").

Outcomes and results: There was a statistically significant difference between caregivers' reports on their dependents' handedness and the application of a valid hand preference scale and they do not necessarily overlap. There was a statistically significant relationship between handedness and type of developmental disabilities based on caregivers' reports and individuals with ASD were more non-right-handed compared to individuals with ID based on the caregivers' report. Hence similar difference was not seen between the ASD and ID groups when HDTP was applied as a diagnostic scale. While left-handedness in the ASD and ID group was similar (23–24%), mixed-handedness in the ASD group was 38% compared to 33% in the ID group.

Conclusions and implications: The Hand-Preference Demonstration Test (HPDT) was a valid way to determine the hand preference of individuals with ASD and ID. It is concluded that parental reports on their offspring with ASD's hand preference need to be approved through the application of a scale and caregivers and professionals need to be more aware of early motor symptoms such as handedness. Further research should focus on the role of handedness in the development of fine motor skills and eye-hand coordination in children with differing developmental disabilities and variations among those differing impairments.

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1. Introduction

Porac and Coren [1,2] described handedness as the practical preference of one hand over the other to perform manual activities. Right-handedness is reported to be consistently predominant, and it is said that about 90% of the general population is right-handed [3, 4]. The best estimate for the prevalence of left-handedness is 10.6%. However, depending on handedness measurement this value varies between 9.3% and 18.1% [5]. Studies on laterality and handedness face challenges such as a lack of consensus on general aspects in the context of laterality research that need to be done, hence, some general recommendations presented to improve, record, evaluate, and report laterality and handedness research for various methods [6].

Similarly, handedness has been controversial in intellectual disabilities (ID) and autism spectrum disorders (ASD) studies. Research about handedness among people with ASD has shown inconsistencies, mainly because of a lack of reliable and consistent measures of hand preference and the different hand preference classification criteria used in studies. Therefore, there are additional reports regarding handedness in this group of individuals compared to the neurotypically developing group. Although it is said that the hand preference in ASD is shifted towards left-handedness [7], at the same time, there are reports on the prevalence rate of non-right-handedness among the group of individuals with ID particularly in the ASD group [8–10] while some others argue that reported higher rate for non-right handedness is a misinterpretation of the data [11].

ASD is defined as disabilities with social communication and social interaction in different contexts, along with restricted and repetitive patterns of behavior, interests, or activities [12]. In contrast with developmental disorders that are associated with motor disabilities and language disorders, individuals with ASD generally exhibit integral or even enhanced visuospatial skills [13, 14, 15]. An autistic brain based on the theory of mind might be an extreme form of the male-dominant brain. Even the four times higher prevalence of males with ASD possibly reflects a powerful form of the male-dominant neurodevelopmental pattern. The wealth of data regarding left-handedness among males in the general population [16,17] could support this notion of a raised prevalence of left-handedness among individuals with ASD [7–10]. Corballis [18] indicates that genetic and environmental factors impact handedness. In a meta-analysis, it was reported that 45.4%, of non-right-handedness, 18.3%, of left-handedness, and 36.1% of mixed-handedness are among individuals with ASD [10]. Individuals with ID have also been found to exhibit elevated levels of non-right-handedness and left- and mixed-handedness were found by some studies to be about twice those reported for neurotypically developing control groups [19].

Mixed-handedness, similar to non-right-handedness, has been reported to be associated with different developmental disabilities. Mixed-handedness, in which both hands are preferred to be used, has been explained as a result of early bilateral hemisphere deficit. The bilateral brain dysfunction hypothesis has implications for various motor, cognitive, and language skills associated with mixed handedness [20]. Therefore, data indicates that mixed-handers have an increased risk of having different scholastic [21] and mental, language, and motor problems.

Hand preference presents early in life, and from 6 months onward, tendencies for using one hand can be detected [22]. It is reported that handedness becomes fixed around the third year of life. It stabilizes between 3 and 7 years of age [23] in neurotypically developing children, and no difference has been reported in the age at which individuals with ASD show hand preference.

Nevertheless, motor symptoms have rarely been considered a predictor factor of ASD; hence, some attempts to relate motor differences during infancy to the emergence of ASD symptoms have produced exciting findings [24]. Some related studies assessed motor behavior using home videos of children later diagnosed with ASD compared to TD children who demonstrated motor differences during their two years of life [25–27]. These findings indicate that different motor behaviors may underlie an apparent ASD core characteristic [28,29]. At the same time, they often go unnoticed compared to the core signs of autism [30]. Caregivers have rarely reported motor signs as their source of concern during infancy.

The main aim of this study was to understand handedness in children with developmental disabilities and how it can be assessed. To attain the main aim, the following research questions were investigated.

- Is non-right and mixed-handedness more common in individuals with ASD than in other types of developmental disabilities, particularly individuals with ID).
- Is mixed-handedness associated with more severe forms of ASD and ID?
- How do parents and caregivers report the handedness of their children with ASD and ID and how does this compare with the HDTP assessments?

2. Methodology

2.1. Participants

The overall sample of the present study was 1116 individuals with ASD (471, 42%) and ID (645, 58%) from two countries. Five hundred-forty-one (51.5%) individuals from Iran, Tehran, the capital city, and 575 (48.5%) individuals from the Kurdistan Region of Iraq (KRI). With a broad age range of 3–13 years (Mean = 5.8, SD = 1.8) in general. The age range for the KRI sample was 3–13 (Mean = 5.7 SD = 2.4), and 3 to 10 for the Iranian sample (Mean = 5.8, SD = 0.8).

2.2. Participants in Iran

Iranian data was sought from the Iranian Special Education Organization (ISEO) and adopted from annual screening for six-year-

old children. Data obtained from Tehran city was considered in this analysis. ISEO regulation in the early 1990s and its revised version in 2004 indicate that all Iranian children who want to be registered in the first grade of primary school are required to undergo a screening system to evaluate their ability to enroll in the educational system. Children who fail the screening are referred for a professional evaluation and are most likely to attend special schools. More than 90% of them registered in special schools for different groups of DDs [31]. Participants received ASD diagnosis based on Autism Diagnostic Interview-Revised (ADI-R) [32], with its Iranian validity [33]. A question regarding the individuals' handedness was asked at the evaluation session while no hand preference evaluation scale was considered for this sample.

2.3. Participants in KRI

Data were collected during a two-year project to establish healthcare services for individuals with ASD and their families in KRI. All caregivers were seen individually in the evaluation unit at their clinics by a trained team of clinicians. Data from four counties of KRI was considered, but it was mainly collected in Erbil, the capital city of KRI.

All sample members with ASD were evaluated utilizing GARS-3 [34] and its Kurdish validity [35]. The scale was used in a structured interview format with their caregiver(s) and the presence of the individual. The hand preference scale was administered after caregivers' reports regarding their child's handedness to determine the individual's preferred hand.

Participants in both countries were asked about their sources of concern in the early stages of the development of their children, and they also filled out a demographic form.

2.4. Measures

The Hand-Preference Demonstration Test (HPDT) [9,36] was used to assess handedness. This scale evaluates participants' manual performance through eight simple but specific activities. The most significant advantage of HPDT is that it is easy to use even with very young children and individuals at different levels of communication and cognitive abilities. Activities consist of using an object with a preferred hand. Twice administration of the test in a random format of the item performance is recommended to increase the reliability of the final judgment. The test administrators were skillful in evaluating children with DDs and the participants performed eight specific activities: using a spoon, throwing a ball, using a toothbrush, drinking from a glass, hitting a wooden nail with a hammer (a wooden toy), drawing with a crayon, using scissors, and picking up a coin.

2.5. Procedure

To adopt a consistent approach for all those individuals with developmental disabilities whose dexterity was evaluated in this study, a particular protocol was followed. During the evaluation session, the test items were administered in a random order three times. Test administration took between 10 and 15 min. Participants were tested individually in the testing room, which was a quiet room by a professional in the field of clinical psychology, rehabilitation, or special education expert. The HPDT developers specified the scoring system. Each item was scored as performed by the individual's left, right, or both hands (bimanual) or as no response. The number of right-hand responses divided by all unimanual responses defines the laterality. The evaluation yielded scores between 0 (all

Table 1
The demographic information of the sample.

	Iranian Sample N = 541	KRI Sample N = 575	Overall Sample N = 1116
Gender			
Male	280 (52%)	438 (76%)	718(64%)
Female	261 (48%)	137 (24%)	398 (36%)
Developmental Disability Type			
ASD	91 (17%)	380 (66%)	471 (42%)
ID	450 (83%)	195 (34%)	645 (58%)
The ***severity of Symptoms Level***			
ASD group			
High Functioning	31 (6%)	261 (45%)	392 (26%)
Low Functioning	60 (11%)	118 (20.5%)	178 (16%)
ID Group			
The mild form of ID	272(50%)	101(18%)	373(33%)
The severe form of ID	178(33%)	95(16.5%)	273(24%)
Caregivers Who Participated			
Mother	341 (63%)	167 (29%)	508 (45.5%)
Father	0	56 (10%)	56 (5%)
Both Parents	83 (15.3%)	337 (59%)	420 (38%)
Siblings	117 (21.6%)	2 (0.3%)	119 (10.5%)
Grandparents	0	13 (2.3%)	13 (1%)
The Verbal Ability of the Individual			
Verbal	337 (62%)	289 (50.3%)	626 (56%)
Nonverbal	204 (38%)	286 (49.7%)	490 (44%)

left-hander responses) and 1 (all right-hander responses). Finally, the individual's performance score is manifested as right-hander if he/she scored between 0.9 and 1.0, classified as left-hander if he/she scored between 0.0 and 0.10, and classified as mixed-handed if his/her score fell at or between 0.11 and 0.98 [37]. All the caregivers in the study were asked about their child's hand preference during the registration process in a written form consisting of three choices (left hand, right hand, both hands).

2.6. Ethical considerations

Since this study used secondary analysis of anonymous data from Iran no formal ethical permission was sought for the Iranian data, but rather permission was given by ISEO. For KRI data ethical approval was obtained from the main center that the study initiated the New Breez Autism Center (Project identification code = NBAC14-2022) and in the absence of a clear national ethical protocol, the seventh revised version WMA of the Helsinki Declaration on Medical Research involving Human Subjects issued on October 19, 2013 was used. Caregivers in KRI were assured that all information was confidential to the researchers and that they would not be identified in any reports. Moreover, they could choose not to answer any questions. They indicated their consent by completing the demographic questionnaire and returning it to the data collection centers in a written and signed format. Declining to participate in the study did not affect the services they were requesting to receive.

3. Result

The Iranian sample was mainly first-born individuals (336, 62%), 172 (32%) second-born children and 200 (37%) parents became concerned about their children before age two generally because of their problems with language 230 (42.5%) and behavioral 184 (34%) issues. Whereas the KRI sample was generally first-born individuals (231, 40%) and 156 (27%) were second-born children in which 219 (37%) caregivers were concerned about their children before age two generally because of their problem with language 256 (43%) and behavioral 192 (32%) issues. The demographic information of the sample is presented in Table 1.

Child hand preference based on caregivers' reports for both groups is presented in Table 2.

The results of the application of the HPDT scale for the KRI sample (N = 575) indicated the degree of the difference between caregivers' reports on handedness and application of the HPDT (Table 3).

There was a statistically significant difference between caregivers' reports on their dependent's handedness and the results of the application of the HPDT scale "X2(df = 4, N = 575) = 469, p < .000 Effect size (Cramer's V) = 0.63" in general, for ASD group "X2(df = 4, N = 380) = 311, p < .000 Effect size (Cramer's V) = 0.64" and for ID group "X2(df = 4, N = 195) = 159, p < .000 Effect size (Cramer's V) = 0.69".

There was a statistically significant relationship between handedness and type of developmental disabilities based on caregivers' report "X2(df = 1, N = 1116) = 75, p < .000 Effect size (Cramer's V) = 0.26" and individuals with ASD were more non-right-handed compared to individuals with ID. Hence similar difference was not seen between the ASD and ID groups when HDTP was applied as a diagnostic scale.

Although 701(63%) caregivers became concerned about the individuals'' development by age two, only 12 (1.1%) of them mentioned motor symptoms as a source of concern. There was a significant difference between caregivers' report of the caretakers' handedness and their actual handedness when it was evaluated X2 (df = 4, N = 575) = 833.00, p < .00, Effect size (Cramer's V) = 0.59. Caregivers tend to label mixed-handed caretakers' as lefthanded while mixed-handed (13 mixed-handed individuals were labeled as lefthanded). A similar significant difference existed for ASD group X2(df = 6, N = 478) = 384.50, p < .000, Effect size (Cramer's V) = 0.62.

Although there was a significant difference between individual gender and his/her handedness according to caregivers' report "X2 (df = 3, N = 1116) = 70.09, p < .00, Effect size (Cramer's V) = 0.51", the difference was not significant when HPDT scale is administered "X2 (df = 2, N = 575) = 0.627, p = .731, Effect size (Cramer's V) = 0.04".

There was no statistically significant difference between handedness and developmental disability type based on HPDT (X2 (df = 2, N = 575) = 1.09, p = .408, Effect size (Cramer's V) = 0.04). However, a low-functioning group of individuals with ASD and individuals with severe forms of ID were statistically significant as being diagnosed as mixed-handed "X2 (df = 2, N = 575) = 275.98. p < .00 Effect size (Cramer's V) = 0.58". Verbal ability had a statistically significant relationship with being diagnosed as mixed-handed "X2(df = 2, N = 575) = 19.28 p < .00 Effect size (Cramer's V) = 0.18", and nonverbal individuals were more diagnosed as mixed-handed and most mixed-handed individuals (94, 40%) were nonverbal.

Individuals' age at the time of diagnosis was also statistically significantly correlated with the handedness based on the parental report "X2(df = 48, N = 575) = 13.64, p < .000, Effect size (Cramer's V) = 0.25", particularly children under 5 (as the median for age) years old significantly diagnosed as the mixed-handed.

With regards to the birth order, it was revealed that there was a significant relationship between handedness and birth order in both

Table 2
The caregivers report on their dependents' hand preferences before the application of a dexterity scale.

	Iranian Sample N = 541	KRI Sample N = 575	Overall Sample N = 1116
Left-handed	32(6%)	269(47%)	301(27%)
Right-handed	489(90%)	267(46%)	756(68%)
Mixed handed	20(4%)	39(7%)	59(5%)

Table 3
The caregivers report on their dependents' hand preferences and the results of the application of the HPDT scale for the KRI sample.

Developmental Disability Type	Handedness Type	The HPDT Scale Results	Parental Report
ASD group (N = 380)	Left-handed	88(23%)	181(41%)
	Right-handed	149(39%)	171(45%)
	Mixed handed	143(38%)	28(7%)
ID Group (N = 195)	Left-handed	47(24%)	88(45%)
	Right-handed	83(43%)	96(49%)
	Mixed handed	65(33%)	11(6%)
Both ASD and ID group (N = 575)	Left-handed	135(23.5%)	269(47%)
	Right-handed	232(40%)	267(46%)
	Mixed handed	208(36%)	39(7%)

ASD and ID group "X2(df = 21, N = 1116) = 159.15, p < 000, Effect size (Cramer's V) = 0.29" while this significant difference was not seen when evaluated by the HPDT scale "X2(df = 21, N = 575) = 51.08, p = .137, Effect size (Cramer's V) = 0.08".

Binary logistic regression was used to predict handedness based on the possible predictors.

The possible predictor variables for handedness included individual characteristics such as age, DD type, gender, verbal ability, and the severity of ASD (ASD level of functioning) based on caregivers' reports and HDPT administration considered. A binary logistic regression model was performed to understand handedness predicting factors from caregivers' perspective. The overall model found to be statistically significant (X2 (df = 7, N = 1116) = 146.15, p < .05), with Nagelkerke R-squared value of 0.172.

Handedness-predicting factors based on HDPT administration provided another model. The overall model found to be statistically significant (X2 (df = 7, N = 575) = 14.05, p < .05), with Nagelkerke R-squared value of 0.102. The result of the regression analysis is shown in Table 4.

The included figure (Fig. 1) displays the relationship between the predictor variables of individuals' handedness based on caregivers' reports and the application of a valid handedness scale.

4. Discussion

The present study's findings, in general, indicated that similar to the reported findings in the meta-analysis studies that have been undertaken non-right-handedness and particularly mixed-handedness were reported to be higher in individuals with ASD compared to neurotypically developing and individuals with ID [10,38] based on the caregivers' report. Nevertheless, similar significance was not discovered in this study sample when a dexterity scale was used.

Therefore, it is found that a handedness assessment that consists of the direct performance of various unimanual activities is the best way to determine the hand preference of individuals with ASD and ID. Caregivers' report about hand preference was not necessarily confirmed after administering the assessment scale in the clinic setting, although children may perform differently in the home context and familiar routines. When the handedness was mixed, they tended to categorize the individual as left-handed. Therefore, the percentage of left-handers in the present sample of individuals within the both ASD and ID groups was higher based on the caregivers' report of 269 (47%) compared to the time they were evaluated using a scale of 135(23.5%). As it was previously found [7,39] the ASD handedness was distributed towards the left hand, in the present study for the ASD group, with the rate of the HPDT 88 (23%) and much higher than that reported by Rysstad and Pedersen [7] which was 16% but even higher when caregivers were asked about the individual handedness (301, 27%).

Regarding the mixed-handed group in the ASD group, the rate after administration of HPDT increased to 143(38%), while caregivers' reports regarding the mixed-handedness were 28,7%. The available reports indicate 44% of mixed-handers among individuals with ASD [7]. The general rate for non-right-handedness was 61% (231) close to what was reported by Rysstad and Pedersen [7] as 60%. There is an association between ASD and non-right-handedness, as previously had been reported by other researchers.

However, the hand preference pattern of individuals with ASD is not the same as a sample of children with ID. The present findings indicated that mixed-handedness is more common in individuals with ASD than individuals with ID or other developmental disabilities such as Developmental Coordination Disorder [40]. This finding has already been presented and Rysstad and Pedersen [7] in a review of 12 studies, including a total of 497 individuals diagnosed with ASD compared to other DDs.

Binary regression analysis in the present study indicated that for handedness based on caregivers' reports and application of HDTP,

Table 4
Summary of Binary Logistic regression for predicting individuals' handedness based on caregivers' reports and application of the HPDT scale.

Variable	Caregivers' Report					The *HPDT Administration*				
	B	SE B	Wald	df	p	B	SE B	Wald	df	p
Individuals' gender	−.458	.153	8.974	1	.003	−.145	.201	.518	1	.471
Individuals' diagnosis	−1.89	.434	18.925	1	.000	.118	.513	.053	1	.818
Individuals functioning level	.325	.143	5.174	1	.023	.119	.513	.054	1	.817
Individuals age	−.137	.039	12.400	1	.000	−.119	.037	10.174	1	.001
Individuals' verbal ability	−.334	.145	5.318	1	.021	−.094	.176	.286	1	.593
Birth Order	.262	.060	19.323	1	.000	.045	.064	.504	1	.478

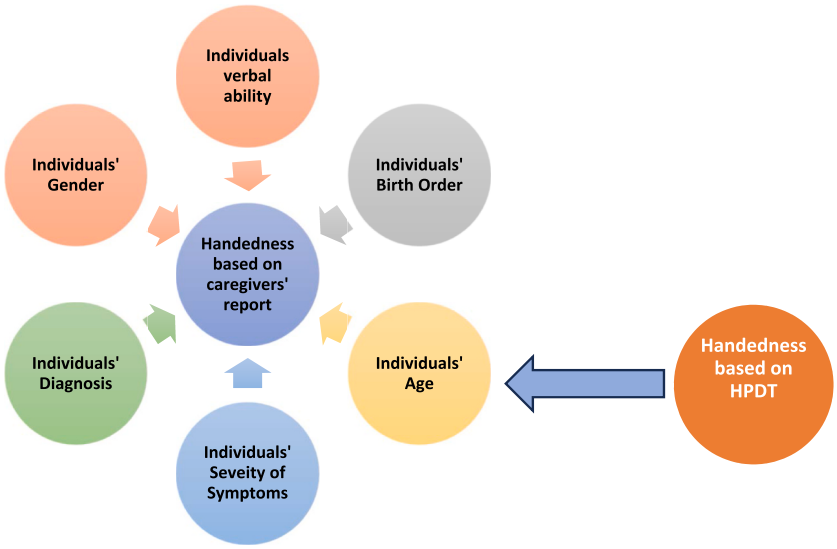

Fig. 1. Variables predicting handedness in individuals with ASD and ID based on caregivers' reports and application of HPDT.

there was only one common predicting factor which was the age of the individual. Still, factors such as individuals with ASD and ID level of functionality and severity of the symptoms were among the predictors of handedness. Floris et al. [41] findings also showed a significant correlation between mixed-handedness and severe forms of ASD, particularly individuals with low-functioning, and that the severity of ASD symptoms is associated with lateralization. A growing wealth of data indicates that reduced cognitive function and non-right or mixed-handedness are generally [42] correlated particularly in individuals with ASD [9] and, some findings reported that individuals with low-functioning ASD tend to be less efficient in cognitive, language, and motor skills [14,41,43,44] and this diagnosis is associated with a more atypical pattern of hand preference [4] such as mixed handedness [45]. Similar findings reported on language impairment and atypical lateralization [46] were manifested in hand preferences. It may be that lower functioning of ASD correlated with lower abilities of kinematic and cognitive motor skills and a dominant pattern of mixed hand preference and handedness played a mediating role in language lateralization in the brain hemisphere [47]. This finding is speculative and present findings add little to this point.

The present study found that Mixed-handed individuals are generally considered non-right-handed, particularly left-handed, by their parents and caregivers. Rysstad and Pedersen [7] suggested that if more specific criteria were applied to determine left or right-handedness, more individuals would migrate towards the mixed-handed type. Our finding indicated that most of what caregivers considered left-handers were ambidextrous or mixed-handed. This finding stressed the importance of the application of handedness scales in hand preference diagnosis to approve the parental reports.

Regardless of its integrity with most of the behavioral aspects of ASD, motor function differences are not considered diagnostic criteria of ASD by most clinicians. However, motor functions are included in the clinical features of ASD based on diagnostic sources such as DSM 5 [12] and ICD-11 [48].

The present study showed that caregivers rarely consider atypical motor symptoms as a source of concern for their caretakers' developmental differences. Although 486 (43%) caregivers indicated speech and language symptoms (verbal and nonverbal, regression) and 376 (33%) behavioral concerns such as social, play, behavioral problems, repetitive behaviors/restricted interests, and rituals as their main source of early concern about the individuals' development only 12 caregivers (1%) indicated atypical motor symptoms as their early source of concern. Other studies also indicated that caregivers' recollection of early symptoms is under the influence of behaviors that are introduced to have been linked to ASD, such as language delay or showing no eye contact. It is concluded that caregivers pay less attention to motor delays or sensory sensitivities because they are less aware of a link with ASD [49]. Hence, a growing literature suggests that early sensory and motor symptoms might be considered the red flags of ASD in the first six months of life. Atypicality in various aspects of motor functioning has been reported to be associated with ASD [15,50,51]. A growing number of studies indicate the emergence of subtle motor impairments or atypicality in the development of children with ASD that might be detectable even before the manifestation of other known ASD core symptoms [30]. Bolton et al. [52] also found that children who received a diagnosis of ASD later in life, from the early stages of development, showed differences in fine motor skills based on caregivers' reports.

The initial results of the present study show the value of using a standardized tool in determining the handedness in children with ASD and ID. The finding of this study also shows a lack of caregivers' and professionals' attention to the motor symptoms, such as hand preferences in developmental disabilities or as a red flag of ASD. Two important points that need to be considered in this regard are caregivers and professional awareness programs regarding the importance of motor symptoms in the early stages of development and, secondly, the importance of early detection that will facilitate the early intervention programs for service provision. In summary, these findings might indicate the importance of handedness in predicting later diagnostic outcomes in children at high risk for ASD. Further

studies need to understand caregivers' and professionals' increasing awareness regarding screening tools with a focus on dexterity and lateralization and the way that it might contribute to caregivers' and professionals' observations regarding early ASD-related symptoms.

5. Limitation

The present study's findings need to be considered regarding its limitations. First of all, although there are various degrees of similarities regarding the cultural aspect of the two neighboring countries the diagnostic scale used for ASD in the two countries was not similar. This difference might reduce the generalization of the findings. Secondly, the sample recruiting approach in the two areas was not similar. The KRI sample was a clinical sample, while the Iranian sample was obtained from children registered with the special education system. Also, ASD diagnosis services and available scales in Iran are more advanced than the limited and underdeveloped diagnosis services in the KRI. Hence, the author has been engaged in diagnostic and educational service provisions for individuals with ASD in both areas and is familiar with both countries' contexts. The present study's most important advantages are its sample size and reporting data from cultures in which little is known about ASD diagnosis and its predictor factors. Investigating the relationship between handedness in siblings and individuals with ASD and parental handedness and its impacts on the offspring with ASD's hand preferences are other possible topics for further studies to understand the different aspects of handedness in ASD.

6. Conclusion

The results of this study support the finding of increased levels of non-right-handedness among individuals with ASD. It also stressed the importance of dividing left-handers from the mixed-handed group. The reason for separating these two groups is that those who have not developed a definite hand preference compared to those who are labeled as right or left-handed showed lower levels of functioning and more language problems, such as being non-verbal. The increase of low-functioning individuals in the mixed-handed group might indicate a greater degree of dysfunction in this group. It was also found that male individuals in the general DD group were correlated with being both non-right-handed and mixed-handed. However, no similar significance was reported for the ASD group.

This finding has some implications for practice. While further research is needed to understand additional factors that might be associated with handedness, the application of the findings in rehabilitation and training or educational placement services, as well as the early diagnosis, might improve the present situation for diagnosis and placement in educational and training services for this group of individuals.

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CRediT authorship contribution statement

Sayyed Ali Samadi: Writing – review & editing, Writing – original draft, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e25935.

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