Systematic Review of Interventions to Improve or Augment Handwriting Ability in Adult Clients

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ABSTRACT

This systematic review examined research related to interventions that addressed handwriting deficits in adults with impaired upper limb motor coordination resulting from central and peripheral nervous system injury or illness. The clinical question was, "Based on current research, what is/are the recommended intervention(s) to improve, augment, or replace handwriting skills among adult clients with upper limb motor deficits?" A research protocol was followed, which was modified to include pediatric literature after an initial search of interventions for adults proved limited. Four studies related to adults and 10 related to pediatrics were included in the review and all were evaluated for quality using standardized procedures. The adult studies addressed the use of voice recognition software and hand dominance transfer training. Available evidence for interventions with children with handwriting deficits centered around these clinical options: Cognition Orientation to Daily Occupational Performance, task-orientated self-instruction, ergonomic modifications to a desk, school-based intervention (emphasis on visual motor skills and practice), sensory diet with therapeutic listening, therapeutic practice, and a graphomotor program. Improvement in handwriting skill emerged from seven of the 10 pediatric studies. Direct practice of handwriting tasks was common to all successful studies and missing in studies that failed to show skill improvement. It may be logical to conclude that intervention strategies should include direct practice of handwriting, whether the client is an adult or a child. Further research on handwriting intervention programs specifically for adult clients and the inclusion of direct practice as intervention is warranted.

Occupational therapy practitioners often provide rehabilitation services for adults with impaired upper limb motor coordination resulting from central and peripheral nervous system injury or illness. Impairments in motor coordination of the dominant limb generally have a profound effect on a client's ability to perform occupations that require discrete motor function, such as handwriting. A robust literature base exists for children with handwriting problems, which has helped establish practice standards for assessment (Amundson, 1995; Diekema, Deitz, & Amundson, 1998; Feder & Majnemer, 2003) and intervention (Case-Smith, 2002; Weintraub, Yinon, Hirsch, & Parush, 2009). In contrast, practitioners addressing handwriting skills with adult clients have a scant literature base from which to construct an evidence-based practice.

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There may be several reasons for this deficit in literature related to adults and handwriting intervention. First, there may be an assumption that handwriting is a school-related skill that is relevant for children and not adults. Second, practitioners and researchers may focus efforts on computer keyboarding skills, assuming them to be more necessary for adults. Finally, from a cost-time efficiency viewpoint, practitioners may spend service delivery time addressing other occupations and simply recommend that clients work independently on handwriting.

However, handwriting is a skill that is used and valued by adults and, when affected by injury or illness, warrants occupational therapy intervention. In a cross-sectional survey of 523 healthy adults (ages 18 to 54 years) living in Australia, only 1.3% reported handwriting to be "not important at all"; 21% reported handwriting to be "extremely important"; and 38% reported a preference for handwriting more than other technologies (McMahon, 2008). College students, white-collar workers, and those older than 25 years were most likely to engage in handwriting activities. The top three most frequent handwriting activities were signing documents, writing notes and reminders, and writing "to-do" lists.

Similarly, as part of a Canadian study (Dixon, Kurzman, & Friesen, 1993), participants were asked about handwriting activities. Results showed that younger people wrote more than older people and women wrote more than men. There was also an interaction effect between gender and age, meaning that younger women wrote more. Respondents of young and old age reportedly spent 69% of "writing time" in handwriting activities compared with typing; however, it should be noted that this study was done in 1993 before a rise of personal computer use. Ultimately, a literature gap does not necessarily equate to a lack of clinical attention given to the motor skill of handwriting with adults; in other words, lack of evidence should not automatically be interpreted as evidence of a lack of actual practice patterns.

Currently, handwriting is included in many self-report questionnaires on adult hand function. For example, handwriting is a specific item listed on the Disabilities of the Arm, Shoulder, and Hand questionnaire (MacDermid & Tottenham, 2004) and relates to the category of activities and participation in the International Classification of Functioning, Disability, and Health (Drummond, Sampaio, Mancini, Kirkwood, & Stamm, 2007). Signing one's name is included in the physical domain portion of the Burn Specific Health Scale (Blades, Mellis, & Munster, 1982). Also, the Upper Limb Function Index includes the item, "I have difficulty writing or using a key board and/or 'mouse'" (Stratford, Binkley, & Stratford, 2001).

Beyond self-rated scales, there is only one handwriting assessment available for adults. The Handwriting Assessment Battery evaluates pen control and manipulation, writing speed, and writing legibility (Faddy, McCluskey, & Lannin, 2008) through a combination of eight subtests taken from three different assessments: Motor Assessment Scale (Carr, Shepherd, Nordholm, & Lynne, 1985), the Evaluation Tool of Children's Handwriting (Amundson, 1995), and the Jebsen-Taylor Test of Hand Function (Jebsen, Taylor, Trieschmann, Trotter, & Howard, 1969), which evaluates writing as one of seven functional dexterity tasks. Thus far, the Handwriting Assessment Battery has been pilot tested on 10 adults with brain injury.

The foregoing discussion implies that handwriting is an occupation of interest to practitioners and an occupation relevant to adults. Accordingly, a systematic review of literature related to handwriting intervention was considered relevant to the field of occupational therapy. However, despite significant differences between children and adults in experience and demand for handwriting competence, occupational therapy practitioners may be limited to generalizing pediatric research to adult clients due to limited available research on adults.

When working with adult clients with motor impairment in a dominant upper limb, practitioners may question the best intervention approach to address handwriting. Clinical questions may revolve around decisions to transfer hand dominance, use motor learning approaches to relearn handwriting tasks, constrain the unaffected limb, teach how to use a prosthetic device for handwriting, or prescribe assistive technology or adaptive equipment to compensate for handwriting. In general, practitioners may consider three distinct approaches for their adult clients: facilitate compensatory strategies to augment loss of ability, initiate hand dominance transfer training, or retrain the impaired upper limb. This systematic review examined research related to all three options with a subsequent modification to inclusion criteria to add pediatric literature to strengthen the amount of evidence reviewed.

Methods

The method proposed by Wright, Brand, Dunn, and Spindler (2007) of conducting and writing a systematic review was followed. The steps outlined in their suggested approach are to develop a research question, devise a research protocol, conduct a lit-

erature search, extract relevant data, appraise the quality of the studies selected for review, analyze the results of the study, and interpret findings and implications for practice or research.

Clinical Question

The following clinical question guided this review: "Based on current research, what is/are the recommended intervention(s) to improve, augment, or replace handwriting skills among adult clients with upper limb motor deficits?"

Research Protocol

A research protocol was created that included criteria for inclusion and exclusion. English-language studies published between 1998 and 2008 that examined interventions related to improving, augmenting, or replacing handwriting in adults with upper limb motor deficits were included. Intervention was defined for this review as "any method, modality, action, or mechanism employed by a therapist or researcher to improve, augment, or replace handwriting skill" (authors' definition). Included studies had to use handwriting as an outcome measure or had to have handwriting as a major component of the study. Exclusion criteria were set as non-English studies, non-published studies, basic science studies, and animal model studies. To best capture all relevant literature, published research of all levels of evidence was included from case studies to randomized clinical trials. However, this protocol was modified after an initial search of interventions for adults proved limited. The addendum added inclusion of current pediatric-based research studies in an attempt to glean meaningful inferences based on pediatric practice standards. An earlier literature review of the pediatric literature related to handwriting with summative information is available to clinicians (Case-Smith, 2002) and therefore this review only included pediatric studies from 2002 to 2008.

Databases searched through EBSCO Host portal included Medline, PubMed, CINAHL, Pre-CINAHL, PsychInfo, and ERIC. Google and Google Scholar were also searched. Terms used in each search included: handwriting or graphomotor AND intervention; hand dominance OR cross-dominance transfer; and constraint-induced therapy AND handwriting. Databases were also individually searched using specific names of known handwriting interventions, such as Loops and other Groups©, Callirobics©, Handwriting without Tears©, Constraint Induced Therapy (CIT), voice recognition software (VRS), and Cognition Orientation to Daily Occupational Performance (CO-OP). References of obtained studies were examined to find additional research.

Results

Abstracts of all studies found during the online database search were reviewed, and articles whose abstracts addressed the research question were retrieved, printed, and read in full (n = 25). Twelve studies were excluded because they failed to meet the inclusion criteria. Excluded studies included those that were basic science research (n = 5), not intervention studies (n = 2), related only to teaching methods (n = 4), and unpublished research (n = 1). Table 1 summarizes the four studies found related to adult interventions. Table 2 summarizes the 10 pediatric-based studies taken from nine articles.

Evaluation of Research Quality

Quantitative clinical trials were evaluated using the 10-point PEDro Scale (Maher, Sherrington, Herbert, Moseley, & Elkins, 2003), which enabled the researcher to assign a score based on multiple, distinct criterion. A high score indicated high internal validity. The scale assessed the following 10 factors: random allocation, concealed allocation, baseline similarity, blinding of participants, therapists, and assessors, measures of key outcomes from more than 85% of participants reported, intention to treat analysis, between group statistical comparison, reports point measures, and measures of variability. For studies that were not clinical trials, PEDro was not used. Those studies were instead examined for quality of study design, analysis of results, and extensive and appropriate interpretation of key findings.

The Critical Review Form-Qualitative Studies© by Wilkins et al. (2007) was used to rate the rigor of the qualitative studies included in this review. Qualitative studies are perceived as having higher internal than external validity and are therefore valuable within special populations to gain in-depth descriptions of participants' experiences (Babbie, 2008).

Handwriting Intervention for Adults

Available evidence for interventions with adults with handwriting deficits centered on the three clinical options: compensating with voice recognition software, hand dominance transfer training, and retraining the injured upper limb.

Compensation Through VRS. Three studies were found that used VRS to augment or replace handwriting. VRS converts speech to text within a computer word processing system. Technically, VRS replaces keyboarding and not handwriting, but it does offer an alternative outlet for written expression.

A pilot study was performed at a large medical center with military service members who sustained

Table 1
Studies Included That Relate to Adult Interventions

Authors and Year	Sample	Intervention	Findings
Bruce et al. (2003)	Client with aphasia, dyslexia, and limited writing ability (n = 1)	VRS training using DNS and 3 months of use with program	Speech recognition accuracy of VRS improved by 8% following intervention; comparison of pre-treatment to post-treatment writing samples: 30 minutes to produce 12 words (4 correct) compared to post-treatment output of 4 minutes to dictate 84 words with 76 correct
Roberts & Stodden (2005)	Adult students enrolled in secondary education programs receiving services for learning disabilities (n = 15)	4-hour training on VRS, ongoing VRS training, technical support, information provision, and provision of DNS	5 subjects did not attempt to use software following initial training; 5 subjects attempted to use DNS after initial training but did not continue; 3 subjects reported getting work done faster by typing and were not sure of DNS; 2 subjects continued to use DNS
Walker & Henneberg (2007)	Adults without writing deficits (n = 21)	Cross-dominance transfer training: daily practice over 28-day time period	All subjects were able to transfer manual performance skill without decrement for age
Yancosek et al. (2008)	Combat-injured military service members (n = 15)	10-hour training on VRS, ongoing VRS training, technical support, and provision of laptop computer with DNS loaded	7 of 15 participants continued to use DNS at 12-month follow-up questionnaire

VRS = voice recognition software; DNS = Dragon Naturally Speaking©.

either upper limb amputations or severe peripheral nerve damage from combat wounds. Fifteen service members were provided with and trained on Dragon Naturally Speaking (DNS) version 7.0, a speech-to-text computer software program (Yancosek, Daugherty, & Cancio, 2008). All service members received a minimum of 8 hours of training on DNS. This study did not lend itself to PEDro scale rating and was instead examined using the Critical Review Form-Qualitative Studies© (Wilkins et al., 2007). This study was weak in explaining sampling techniques, study design, and content of questionnaire. Results were based on nine service members who completed the follow-up surveys that asked questions about continued use of the software. Overall, seven participants continued to use the software for various computer operation procedures to replace keyboarding tasks. No information was available about the extent to which VRS had replaced other forms of written expression.

In a qualitative study performed by Roberts and Stodden (2005), 15 adults who were enrolled in post-secondary education and receiving services for learning disabilities were trained on VRS, specifically DNS. Qualitative methods used were focus groups, phone interviews, surveys, and field observations. This study explored contributing variables that influenced use or non-use of VRS. Eleven participants believed the software to be more time-consuming than time-saving, and subsequently did not use the software. The other four participants used the software and found it helpful. The researchers suggested that personality disposition (specifically, having a high tolerance to frustration), speaking English as a first language (DNS had difficulty with accents), severity of learning disability and higher need of assistance in producing written text, and lack of existing compensatory strategies to overcoming written language deficits all improved use of VRS.

The quality of this study was also assessed using the Critical Review Form-Qualitative Studies© (Wilkins et al., 2007). This study proved of high quality based on the review form's criteria; however, their suggestion of a hypothetical "user profile" should be taken cautiously based on the general concerns of external validity related to qualitative research.

A case study with a 57-year-old man who sustained a left parietal cerebrovascular accident and accompanying handwriting deficits was presented as evidence (Bruce, Edmundson, & Coleman, 2003). The client began working with VRS (specifically DNS) through a community clinic and after 3 months of guided training he dramatically improved his written communication ability. The researchers concluded that VRS was beneficial for this client. The

Table 2
Summary of Included Pediatric-Based Studies

Authors and Year	Sample	Intervention	Findings
Bernie & Rodger (2004)	Children with DCD (n = 4)	CO-OP	Method was useful for all children to address handwriting goals during therapy session
Case-Smith (2002)	Students from 5 schools in Ohio and Illinois with poor handwriting (intervention: n = 29; control: n = 9)	School-based occupational therapy intervention with emphasis on visual-motor skills and handwriting practice	Significant increase in in-hand manipulation and position-in-space scores in students in intervention group; improved handwriting legibility; no improvement in numerical legibility or speed
Denton et al. (2006)	Children with handwriting dysfunction (Group 1: n = 15; Group 2: n = 14, control: n = 9)	Two intervention groups met four times per week over a 5-week period; Group 1: therapeutic practice; Group 2: sensorimotor intervention	Improvements in sensorimotor components did not generalize to improvements in handwriting; improvements in handwriting occurred in Group 1, indicating direct practice was effective; statistically significant differences between sensorimotor and therapeutic practice group; no difference between either treatment group and control
Hall & Case-Smith (2007)	Children with sensory processing disorders (n = 10)	4-week sensory diet; 8-week therapeutic listening intervention	Intervention facilitated substantial improvements in behaviors; handwriting legibility improved
Jongmans et al. (2003)	Students in regular education program with poor handwriting (intervention: n = 7; control: n = 7)	Task-oriented self-instruction intervention; one-on-one intervention for 3 months	Descriptive statistics only: an increase in quality of handwriting of subjects in intervention group, a decline in quality of handwriting of control group subjects; both groups improved handwriting speed
Jongmans et al. (2003) (Study 2 within same manuscript)	Students in special education with poor handwriting (intervention: n =18, control: n = 18); average handwriting subgroup (intervention: n = 18; control: n =18)	Task-oriented self-instruction intervention; group intervention for 6 months	Statistically significant difference in three of four subgroups; no statistically significant differences between groups related to dependent variable of speed
Ratzon et al. (2007)	First-graders with low scores on Visual-Motor Integration test (intervention: n = 24; control: n = 28)	Graphomotor program developed by graduate student at Tel Aviv University in Israel; 45 minutes of intervention per week for 12 weeks	Significant difference in improvement scores between control and intervention groups in copying, eye–hand coordination, spatial relationship, and visual perception
Shen et al. (2003)	Students in Taiwan with cerebral palsy (n = 32)	Desk modifications	No change in accuracy scores between horizontal and inclined desk surface; motor writing accuracy (adjusted for speed) was better at the cutout desk surface
Sudsawad et al. (2002)	First-graders from 24 schools in Boston who scored below 25th percentile on KST (n = 45)	Kinesthetic training group, handwriting practice group, control group	No significant improvements in handwriting following kinesthetic training
Woodward & Swinth (2002)[a]	School-based occupational therapists from schools across the nation; 63.3% response rate, n = 198	Mail survey with 3 parts: Part I = training, education, and experience; Part II = list of 25 multi-sensory modalities and activities and 5-point scale to indicate frequency; Part III = comment section	More than 130 different multi-sensory modalities and activities were documented: 25 listed on the survey and 114 were written in by survey respondents; most respondents reported using five or more modalities and activities per student; the most-used modality was chalk and chalkboard

DCD = developmental coordination disorder; CO-OP = Cognition Orientation to Daily Occupational Performance; KST= Kinesthetic Sensory Test.
[a]Survey study related to use interventions; not a direct intervention study.

quality analysis of this study was also rated using the Critical Review Form-Qualitative Studies©. This was a high-quality study based on clearly stated methods and procedures. Data were analyzed in a straight-forward fashion and explicitly described. This case study showcased positive results based on a well-described intervention using VRS to compensate for written communication deficits. To complement VRS training, or when VRS is not appropriate for a client, practitioners must consider other options, such as facilitating handwriting skill development in the unimpaired, contralateral upper limb.

Hand Dominance Transfer Training. Hand dominance transfer training is a logical option for clients who sustain central or peripheral nervous system injuries that result in permanent loss of function in a dominant upper limb while sparing the contralateral limb. Diagnoses that might create this clinical presentation include amputation, brachial plexus injury, stroke, complex regional pain syndrome, or limb salvage following burn, mutilating, or crush injuries that produce multi-tissue injury.

There was no literature found related to hand dominance transfer training for handwriting in a clinical setting with an impaired adult population. However, Walker and Henneberg (2007) did describe an experiment that met inclusion criteria with non-impaired adults that evaluated handwriting ability following a cross-dominance intervention. Twenty-one subjects repeated a handwriting task every day for 4 weeks using their non-dominant hand. Results demonstrated that all adult participants ages 20 to 56 years gained proficiency in handwriting using their non-dominant hand with no decrement from increasing age. This study demonstrated adults can adequately transfer hand dominance for intricate fine-motor tasks such as handwriting.

The study used a within-subject experimental design that does not yield to PEDro scale evaluation. The methods and procedures were explained in detail and each participant supplied a baseline handwriting sample to serve as his or her own control for comparison. The statistics were represented by scatter-plot diagrams, and the discussion was appropriate for pertinent study findings. This was a simple and well-done study with positive results related to cross-dominance training. Additionally, the article included dated writing samples of one participant. A limitation related to external validity and clinical inference was the lack of task variability within intervention, as noted by participants reproducing the same text every day throughout the training period.

Before transferring hand dominance, many clients will likely want to attempt retraining the impaired limb. More specifically, many clients may not be motivated to participate in cross-dominance transfer without a thorough attempt at retraining the impaired limb. However, retraining is not a viable option in amputation or other significant multi-tissue injuries. Ultimately, retraining should be initiated based on diagnosis, prognosis of functional recovery, and time allotted for a rehabilitation program (Chan & LaStayo, 2003).

Retraining the Impaired Limb. This final section relates to the third intervention option: retraining the impaired limb. Retraining the impaired limb is a type of "forced use" intervention similar in concept to CIT. Interestingly, the use of CIT to facilitate return of fine motor coordination needed for handwriting skills was not found in the literature, so no articles were included in this review. However, there is some descriptive literature available related to retraining an impaired limb for handwriting. An adult handwriting retraining intervention created by an occupational therapist, Liora Laufer, called Callirobics© is available for use with children and adults. The Callirobics© handwriting program uses music to retrain handwriting in children and adults. The idea of using auditory cues from music to promote or pace a motor behavior is familiar to occupational therapy practitioners. Callirobics© consists of a workbook and an accompanying music CD. Clients complete handwriting worksheets while listening to corresponding music with an appropriate tempo.

The program has been used with clients with acquired brain injury, Alzheimer's disease, stroke, and Parkinson's disease, but validation is limited to patient and therapist testimonials. A Master's thesis related to an intervention study using Callirobics© for adults with Parkinson's disease (Schroeder, 1994) did not meet inclusion/exclusion criteria for this systematic review because it was unpublished; however, the results are briefly outlined here because it was the only evidence of research examining handwriting retraining with impaired adult clients. Schroeder (1994) used Callirobics© with 18 clients with Parkinson's disease to address handwriting deficits, namely micrographia. Clients attended nine treatment sessions and demonstrated statistically significant improvements in handwriting on four of 10 outcome measures.

Discussion

The results of this review were limited because only four studies were found that met inclusion criteria and none was a clinical trial. The lack of literature related to this topic was surprising given the num-

Table 3
PEDro Scores for Included Clinical Trials

Study	1	2	3	4	5	6	7	8	9	10	Total PEDro Score[a]
Case-Smith (2002)	0	0	1	0	0	0	1	0	1	1	4
Denton (2006)	1	0	0	1	0	1	1	0	1	1	6
Jongmans et al. (2003)	0	0	1	0	0	0	1	1	1	0	4
Jongmans et al. (2003)[b]	0	0	0	0	0	0	1	1	1	1	4
Ratzon et al. (2007)	1	0	1	0	0	0	1	0	1	1	5
Sudsawed et al. (2002)	1	0	1	0	0	1	1	0	1	1	6

[a]Criterion Key, 1-10: 1 = random allocation; 2 = concealed allocation; 3 = baseline similarity; 4, 5, 6 = blinding of participants, therapists, assessors; 7 = measures of key outcomes from more than 85% of participants; 8 = intention to treat analysis; 9 = between-group statistical comparisons; 10 = point measures and measures of variability.
[b]Refers to Study 2 reported in the manuscript.

ber of central or peripheral nervous system injuries that potentially affect adult hand function. However, the available studies do provide some evidence to support clinical decisions to improve, augment, or replace handwriting of adults.

VRS may provide an adequate means of compensation for written communication deficits, but the technology has several limitations. The time needed for training, the reduced speed of communication, and the impact of learning disability or speaking English as a second language all contributed to limited proficiency using the software (Roberts & Stodden, 2005). This technology necessitates advanced cognitive skills, such as learning command codes that drive computer operations. The high-order cognitive demands require a willingness from the client to commit to the learning process through software training, which may limit its clinical usefulness as an intervention for adults.

Cross-dominance training is another potential option for intervention, although only one study was found to support its use in handwriting (Walker & Henneberg, 2007). This study showed positive results with all subjects being successful in the transfer, regardless of age. Results demonstrated achievement in skill acquisition and retention of motor memory for repeated performance; however, caution is warranted in assuming these subjects could generalize handwriting skills because the intervention was to repeatedly copy the same text during the session each day.

Although no published studies were found to support retraining of the upper limb for handwriting tasks, this area of intervention is obviously the most direct approach that may be used by the clinician to restore dominant hand function. Considerable research using CIT as a means of retraining the upper limb is available (Dickerson & Brown, 2007; Taub et al., 1993; Wolf et al., 2006; Wolf et al., 2008), although none were found that use handwriting as an outcome.

Handwriting Intervention for Children

The vast majority of research on handwriting intervention has focused on a pediatric population. Most handwriting programs, such as Handwriting without Tears© and Loops and Other Groups©, are geared to children. Given the lack of available evidence for adult handwriting interventions, a review of the pediatric evidence may be useful to consider generalization of findings to an adult population. A total of 10 studies from nine articles were reviewed. Table 2 is a summary of the pediatric studies. Five of the studies were clinical trials and were rated on the PEDro Scale, with an average score of 4.8 across all five studies (Table 3).

Available evidence for interventions with children with handwriting deficits centered around these clinical options: CO-OP (Bernie & Rodger, 2004), task-orientated self-instruction (Jongmans, Linthorst-Bakker, Westenberg, & Smits-Engelsman, 2003), ergonomic modifications to a desk (Shen, Kang, & Wu, 2003), school-based intervention (emphasis on visual motor skills and practice) (Woodward & Swinth, 2002), sensory diet with therapeutic listening (Hall & Case-Smith, 2007), therapeutic practice (Denton, Cope, & Moser, 2006), and a graphomotor program (Ratzon, Efraim, & Bart, 2007). Despite heterogeneity of subjects and a variety of intervention methods among experiments, improvement in handwriting skill emerged from seven of the 10 studies. Only the kinesthetic training program and a sensorimotor intervention failed to show statistically significant changes in handwriting skills. Direct practice of handwriting tasks was the variable common to all successful studies and missing in studies

that failed to show skill improvement. Considering this, it may be logical to conclude that intervention strategies should include direct practice of handwriting whether the client is an adult or a child.

Clinical Implications

Evidence-based practice improves clinical decision making; however, little evidence is available to guide intervention selections when addressing handwriting deficits in adult populations. In this review, attempts were made to explore the evidence related to intervention options available to practitioners who wish to remediate impaired hand function, facilitate transfer of hand dominance, or compensate for written communication deficits. The four studies on adult interventions did not generate substantial data to answer the clinical question that prompted this review.

The inclusion of pediatric studies proved useful in exposing the direct practice of handwriting as a common denominator to all successful pediatric interventions. Despite obvious differences in age and developmental maturity between populations, this finding may be generalizable to adults. The Walker and Henneberg (2007) study supported the idea of repeated practice based on successful outcome of hand dominance transfer in non-impaired adult subjects. The implication for occupational therapy practitioners is that when clients identify handwriting as a goal, they should allocate time and resources to addressing handwriting directly through practice. Similarly, if the client desires to learn VRS to augment traditional written expression, time and resources must also be allocated for direct practice.

Future Research Needs

Occupational therapy practitioners work with adult clients with a variety of diagnoses that potentially inhibit participation in tasks that demand fine motor coordination. Without supporting research, it cannot be assumed that practitioners regularly address handwriting as a motor coordination skill. Nor can best-practice standards for interventions be established to address deficits until focused research related to common clinical interventions are documented and assessed. It would be meaningful to systematically examine the extent of handwriting intervention done with adult populations in the United States. For example, researchers could explore volume and frequency of writing done among various ages, genders, education levels, occupations, and cultures. Survey research is needed to explore what, if any, handwriting training interventions are used with adult clients. Researchers may use this information to construct clinically relevant research to explore the value of one strategy over the next. Quality clinical trials could compare outcomes as a function of the three intervention options put forth in this review: remediation, cross-dominance training, and compensation.

Limitations

There are two recognizable limitations of this review. First, focusing solely on intervention literature limits this review by excluding potentially valuable basic science research. For example, research conducted in such disciplines as neurology, biology, and psychology may have offered a useful bridge to understanding the best application of therapeutic interventions. Basic science studies may help answer questions related to the process of learning a skill that was once proficient in the other limb. The second limitation was that analysis of results was limited by the heterogeneity of intervention programs and corresponding heterogeneity of subjects, including the obvious dichotomy of practice approaches between adult and pediatric populations. The ability to generalize the results of pediatric studies to the adult population is limited, specifically when comparing pediatric populations with minor neurological deficits (fine motor coordination and motor planning problems) with adult populations with major neurological and physical disabilities (Parkinson's disease, brain injury, and amputation).

Conclusion

The included studies provided a collection of recent literature related to interventions to address handwriting deficits in adult and pediatric populations. Seven of 10 experimental studies relating to pediatric population showed positive changes in handwriting skills with a positive effect from direct practice, regardless of selected intervention method. This review exposed a clinical question that currently remains unanswerable. The logical conclusion is therefore a call for research related to handwriting deficits and interventions in adult populations. Occupational therapy practitioners design highly specialized rehabilitation programs for clients with loss of hand function and this topic of handwriting interventions merits further scientific examination.

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