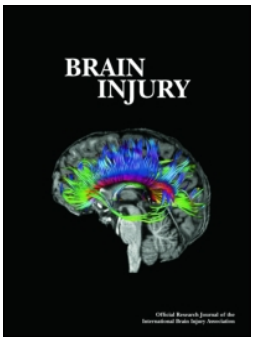


Taylor & Francis
Taylor & Francis Group

Brain Injury

ISSN: 0269-9052 (Print) 1362-301X (Online) Journal homepage: https://www.tandfonline.com/loi/ibij20

# A scoping review of interventions for adults with dysarthria following traumatic brain injury

**Pooja Gandhi, Shilagh Tobin, Monrada Vongphakdi, Anna Copley & Kerrin Watter**

**To cite this article:** Pooja Gandhi, Shilagh Tobin, Monrada Vongphakdi, Anna Copley & Kerrin Watter (2020): A scoping review of interventions for adults with dysarthria following traumatic brain injury, Brain Injury, DOI: 10.1080/02699052.2020.1725844

**To link to this article:** https://doi.org/10.1080/02699052.2020.1725844

Published online: 17 Feb 2020.

BRAIN INJURY
https://doi.org/10.1080/02699052.2020.1725844



# A scoping review of interventions for adults with dysarthria following traumatic brain injury

Pooja Gandhi[a], Shilagh Tobin[a], Monrada Vongphakdi[a], Anna Copley[a], and Kerrin Watter[b]

[a]School of Health and Rehabilitation Sciences, The University of Queensland, St Lucia, Queensland, Australia; [b]Acquired Brain Injury Transitional Rehabilitation Service, Division of Rehabilitation, Metro South Health, Brisbane, Australia

**ABSTRACT**

**Primary objective**: To review the current literature on interventions for dysarthria following traumatic brain injury (TBI) for their effectiveness and methodological quality, and identify future directions for research in developing guidelines for treating dysarthria in this population.

**Research design**: Scoping review.

**Methods and procedures**: Electronic databases were searched up until July 2018 to find intervention trials for treating dysarthria following TBI. Articles were assessed by three reviewers to meet the following criteria: (1) population (adults with dysarthria following TBI only) and (2) intervention studies. Of the 1481 articles initially identified, 17 were selected based on inclusion criteria. 16 articles were single case designs (SCD) and one was a cohort study. Methodological qualities of eligible articles were examined using the single-case experimental design (SCED) rating scale; the cohort study was qualitatively described.

**Main outcomes and results**: The interventions described fell into six broad categories - behavioral, prosthetic, instrumental, pharmacological, augmentative and alternative communication (AAC), and mixed intervention. Behavioral interventions received the most focus in the literature. The articles rated using the SCED received an average score of 6.8, indicating moderate methodological quality.

**Conclusions**: This field currently lacks high-quality research. Further research is required to determine the best clinical practice.

**ARTICLE HISTORY**
Received 5 April 2019
Accepted 1 February 2020

**KEYWORDS**
Traumatic brain injury; dysarthria; rehabilitation; intervention

## Introduction

Traumatic Brain Injury (TBI) is defined as brain pathology, or other alteration in the functioning of the brain, as a result of an external force (1). The estimates of TBI global incidence rates range from 10 million (2) to 69 million cases per year (3). The World Health Organization predicts that by 2020, TBI will become the third leading cause of death and disability across the lifespan (4). It is suggested that this is largely due to the increasing numbers of motor vehicles and associated vehicular trauma in developing countries (2). Incidence of TBI peaks in adolescence and early adulthood (5), with injury to males being twice as common as females (6,7).

Advances in technology and acute management of TBI have led to reductions in mortality rates (5). This, in conjunction with a higher prevalence of youth sustaining TBI (5), has resulted in the growth of the number of survivors in this population, leading to a greater likelihood of a lifetime of disability (8,9). Consequently, TBI is the greatest contributor to disability in adults during their most economically productive years, with considerable lost earning potential and costs related to long-term care (10). Although similar to several other injury types, the proportion of injury-related productivity loss attributed to TBI (15.7%) is 14 times that associated with spinal cord injury, another significantly disabling condition (10). In 2008, it was estimated that TBI cost Australians $8.6 billion per year, with a lifetime cost of $4.8 million per case of severe TBI (11).

Moscato, Trevisan, and Willer describe some estimates of the prevalence of long-term handicap: 66% of their sample TBI population required ongoing assistance with activities of daily living; 75% were not working, and 90% reported dissatisfaction or some limitations with social integration (12). Even among young patients with mild injuries and an unremarkable pre-injury status, one-third failed to achieve a good recovery (13).

Dysarthria is a common consequence of TBI, occurring in approximately 10-65% of this population (14–17). Dysarthria is a collective name for a group of motor speech disorders resulting from disturbances in control over the speech musculature due to damage of the central or peripheral nervous system (18). There are five systems that may be affected in dysarthria: respiration, phonation, resonance, articulation, and prosody (18). Individuals with dysarthria often produce speech with abnormal characteristics, which decreases intelligibility to varying degrees. These speech characteristics can be due to paralysis, spasticity, or incoordination in the speech musculature (18,19).

The presence of dysarthria has significant implications for the long-term quality of life for individuals with TBI (20). Dysarthria in TBI is often chronic in nature; it has been reported to be one of the most persistent of communication

**CONTACT** Anna Copley a.ocallaghan2@uq.edu.au School of Health and Rehabilitation Sciences, Faculty of Health and Behavioural Sciences, The University of Queensland, Building 84A, St Lucia, Brisbane, QLD 4072 Australia

**PROSPERO registration number**: CRD42018109055

impairments in this population and is associated with loss of vocational standing and social isolation (21). Thus, individuals with dysarthria are often vulnerable to social isolation (19) and many experience difficulties with employment and education (22). The considerably negative effects of dysarthria in the presence of TBI mean that it needs to be treated in the most efficacious fashion; if not, it will likely have significantly detrimental effects on the patient's wellbeing (19).

Traditionally, treatment for dysarthria following TBI focuses on facilitating the efficiency, effectiveness, and naturalness of communication (23,24). Treatment selection depends on a number of factors, including severity, prognosis of the underlying neurological disorder, perceptual characteristics of the individual's speech, the communication needs of the individual, and the presence of co-occurring conditions (25). There is a wide variety of interventions for dysarthria in adults following TBI discussed in the literature. These include behavioral (e.g. Lee Silverman Voice Treatment (LSVT) (26)), prosthetic (e.g. Palatal Lift Prosthesis) (27), instrumental (e.g. Electropalatography (EPG)) (28), pharmacological (e.g. prescribing a dopamine agonist) (29), and the use of AAC devices (e.g. Alphabet supplementation (AS)) (30).

Due to the need to understand the efficacy of this diverse range of interventions, a limited number of systematic reviews have been conducted on treatment for dysarthria following non-progressive brain damage (17,31). These studies, however, view non-progressive brain damage as a broad category, which includes TBI, stroke, meningitis, encephalitis, post-surgical meningioma, and acoustic neuroma (31). This is problematic as it fails to address the major underlying differences in the mechanisms by which the damage occurs and the resulting pathologies. The mechanisms of injury vary substantially in TBI compared to other forms of non-progressive brain damage. These differences lead to unique pathophysiological factors that negatively affect the way in which the patient is able to engage in rehabilitation, and consequently, the resulting outcomes. These may include fatigue, sleep disturbances, and headaches (2,32), which may be transient or persist long term (2). Neuropsychiatric changes are also common sequelae of TBI and often include depression, cognitive impairments, and personality and behavioral changes (33–38).

Cognitive impairment following TBI is frequently reported as the most common and debilitating symptom experienced, with 65% of patients with moderate to severe level of TBI reporting long-term problems in this area (39). Cognitive deficits are additionally, a significant contributor to an individual's perception of personal disability (40). While some patients who experience other non-progressive causes of brain damage may also experience cognitive impairments, Zhang and colleagues (40) report that clinically, cognitive deficits as a result of TBI compared to stroke differ in mechanisms, clinical manifestations, prognosis, and outcomes (37,41). Specifically, individuals sustaining TBI may experience cognitive deficits in areas of attention, working memory, processing speed, and executive functions (40). These cognitive impairments can have a significant impact on an individual's capacity to adequately engage in interventions.

As a result of these numerous and highly prevalent physiological and neuropsychiatric disturbances, patients who have sustained TBI are likely to engage in intervention for dysarthria differently than patients with other forms of non-progressive brain damage. Despite this, it is clear that clinicians are, indeed, treating dysarthria in this clinical population. Data on Speech Language Pathology (SLP) treatment outcomes and patterns for adults with TBI demonstrate that SLPs are providing treatment to adults with TBI for dysarthria in both inpatient and outpatient settings, and this is a feature of current clinical practice (42,43). Further, SLP clinical practice guidelines endorse the management and treatment of dysarthria following TBI internationally by the American Speech-Language-Hearing Association, the Royal College of Speech Language Therapists and the New Zealand Guidelines Group (19,44,45). Providing treatment and management for dysarthria post-TBI (and ABI) was also a recommendation from a recent Cochrane review (17). It is therefore of critical importance to understand the effectiveness of dysarthria intervention in a TBI specific population.

We conducted a scoping review in order to summarize the profile of existing interventions for dysarthria in a TBI specific population and to identify gaps in the existing literature. The current study aims to answer the following questions in this scoping review:

(1) What interventions are present in the literature for treating adults with dysarthria following TBI?
(2) Which interventions for dysarthria following TBI are effective?
(3) What is the methodological quality of studies that have evaluated dysarthria interventions for adults following TBI?

## Method

A scoping review of the current literature was completed following the procedure outlined by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (46). According to the Joanna Briggs Institute's Reviewer's Manual, a scoping review is a type of review that aims to determine the size and scope of a body of literature on a particular topic. Our aims were quite broad in investigating this topic, so it was deemed more appropriate to classify the current study as a scoping review, rather than a systematic review.

### Eligibility criteria

#### Types of participants

Participants in the included studies were adults with TBI (onset at age >18 years), and a subsequent diagnosis of dysarthria. Studies with participants with non-traumatic brain injuries such as stroke, brain inflammation conditions (e.g. encephalitis), and progressive neurodegenerative disorders (e.g. dementia) were excluded from the scoping review. Studies that included children or mixed etiologies were also omitted from the review.

#### Types of interventions

Only studies which described a specific treatment that was delivered to patients with dysarthria following TBI were considered in the review. Interventions included behavioral, prosthetic, instrumental, pharmacological, and the use of AAC devices.

### Types of outcome measures

Studies measured the effectiveness of treatment by comparing pre and post-therapy performance using standardized perceptual assessments of intelligibility (e.g. Assessment of Intelligibility of Dysarthric Speech) (47) and speech functions (e.g. Frenchay Dysarthria Assessment) (48). Outcome measures also included physiological measures (e.g. respiratory airflow), acoustic measures (e.g. spectrogram computer programs), instrumental measures (e.g. flexible nasendocopy), and measures of impact on functional communication (e.g. Voice Handicap Index) (49).

### Types of studies

Studies meeting levels II–IV of the National Health and Medical Research Council (NHMRC) evidence hierarchy (50) were included in the present review, with the exception of systematic reviews. These were not classified as treatment studies as per the inclusion criteria. Additionally, reports, conference abstracts, book chapters, and theses were excluded from the review.

### Search strategy

Electronic databases included in the search process included general medicine and allied health databases such as CINAHL, EMBASE, PsycINFO, PubMed, and SCOPUS which were searched for articles until June 2018, and more specialized databases such as SpeechBITE and Cochrane Library for articles until July 2018. Search terms for the CINAHL, EMBASE, PsycINFO, PubMed, and SCOPUS databases included the following search strings: 'traumatic brain injury,' 'traumatic brain injuries,' 'acquired brain injury,' 'acquired brain injuries,' 'brain injury,' 'brain injuries,' 'head injury,' 'head injuries,' 'brain damage,' 'brain damaged,' 'TBI,' and 'ABI,' which were combined using the Boolean operator 'OR.' Search terms in the title/abstract included: 'trauma' OR 'traumatic' AND 'head' OR 'brain' and 'dysarthria.' MeSH terms included 'brain injuries,' 'brain injuries, traumatic' OR 'brain injury, chronic' OR 'brain injuries, diffuse' and 'dysarthria.' The search strategy entries and relevant key terms were adjusted to comply with the requirements of each particular database. The exact search strategies for PubMed and Cochrane Library are provided in detail in Appendix A. Only articles published in English in peer-reviewed journals were considered. A gray literature search was also conducted and no additional studies were identified.

The initial pool of search results yielded an overall total of 2655 articles. After the removal of duplicates, 1481 remained. From this pool, 72 were considered relevant for inclusion based on title and abstract. Two researchers independently reviewed random samples of 10% each of the total articles and achieved a consensus 96.8%. Any disagreements between the reviewers were discussed until a resolution was reached; in the case that a resolution could not be reached, a third party was consulted. The 72 articles considered relevant for inclusion based on title and abstract were divided between three independent researchers, who determined whether the articles met inclusion and exclusion criteria upon accessing the full text. A fourth independent researcher reviewed a random sample of 10% of the 72 articles and achieved a consensus of 100% regarding inclusion/exclusion. In total, 17 studies were determined to have met the eligibility criteria for their inclusion in the review. A summary of the search process is demonstrated in Figure 1.

### Quality review

The Single Case Experimental Design (SCED) rating scale (51) was used to evaluate the methodological quality of 16 of the 17 studies. The remaining study was a cohort study, which will be described in detail in the Results section. The SCED rating scale was chosen because it specifically appraises the methodological quality of Single Case Designs (SCDs) that are distinct to Randomized Control Trials and other group designs, by evaluating the study against set criteria (51). The SCED uses an 11-point scale, where a score between 0 and 10 was allocated, with higher scores indicating higher methodological quality (see Table 1). The 16 articles were scored across two rounds, with each study receiving two independent SCED ratings based on the set criteria. A consensus of 96.6% was reached, and any disagreements between the reviewers were discussed until a resolution was achieved.

The final SCED ratings for each SCD study are displayed in harvest plots in the Results section of this article. Harvest plots are ideal visual representations for systematic and scoping reviews as they allow readers to view information for multiple studies regarding study design suitability, methodological quality and outcome measures (52,53). Modified harvest plots (52) consist of stacked bars displaying multiple features, with bar height representing overall methodological quality. Due to the heterogeneity in the reviewed articles, a meta-analysis was not possible; therefore, data from the reviewed studies were summarized descriptively in a table in the Results section. Studies were ordered according to their methodological quality.

## Results

### Participants

The participant characteristics in each of the 17 articles evaluated are outlined in Table 2. The number of participants in each study ranged from one to 28, with 16 of the 17 articles as SCD. The age of participants ranged from 18 to 45 years. Eighty percent of the participants were male.

The type of dysarthria, according to conventional dysarthria classification guidelines (54) was mentioned in all but five studies. Of these five studies, three studies described their patients as presenting with "velopharyngeal incompetence," while the remaining two studies did not specify the dysarthria subtype. All dysarthria subtypes were present across the participants in the included studies, with the exception of hyperkinetic dysarthria. Mixed dysarthria constituted just over 30% of the sample, with spastic-ataxic dysarthria noted to be the most common form, followed by spastic-flaccid dysarthria. Velopharyngeal incompetence was the most frequently occurring characteristic of dysarthria.

TBI severity was reported via the Glasgow Coma Scale (GCS), period of Post-traumatic Amnesia (PTA), or by

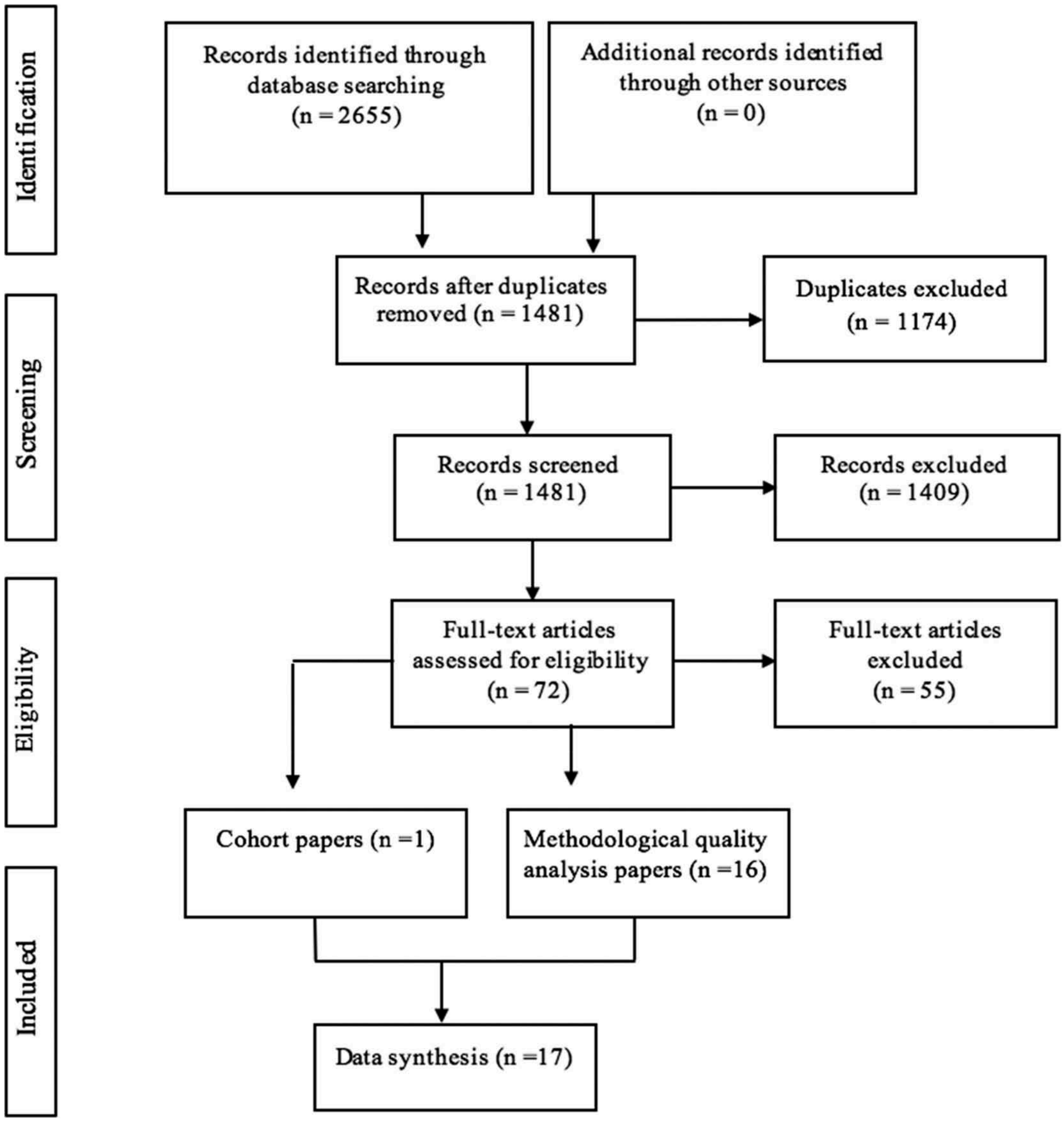


Figure 1. PRISMA flow chart outlining the search procedure used to identify the studies included in the final review.

Table 1. Single-case experimental design ratings.

| Condensed Category | SCED Item |
|---|---|
| Target behavior | 2. Target behaviors defined |
| Design | 3. A-B-A or multiple baseline design used |
| | 4. Sufficient baseline sampling conducted |
| | 5. Sufficient sampling conducted in the treatment phase |
| | 6. Raw data points reported |
| Bias | 7. Interrater reliability established for 1 target behavior |
| | 8. Independent assessors |
| Statistics | 9. Statistical analysis |
| Transferability | 10. Replication |
| | 11. Generalization |

a descriptor term (e.g. 'severe') in 13 of the 17 articles. Two studies reported a TBI severity rating of 'severe,' while six studies reported the patient's GCS score at the time of injury instead. These scores ranged from 3 to 4, indicative of a severe head injury. PTA duration was reported in only 5 studies, ranging from 30 days to 159 days, again, indicating severe head injury. Dysarthria severity was reported in 9 of the 17 articles, ranging from 'mild' to 'severe.' Time since onset of injury in which the intervention was initiated was reported in 13 articles. This ranged from approximately 2 months to 4 years, with an average of 18 months post-injury.

In the 10 articles which did address the cognitive ability of the participants, various approaches were used. Some studies simply reported the presence or absence of cognitive impairment, e.g.McMicken et al. (55), while others reported the results of a battery of cognitive assessments, e.g.Solomon et al. (56). The three most commonly reported cognitive impairments in the articles reviewed were memory deficits (26,28,57–59) as well as the decreased speed of information processing and attention deficits (58,59).

### *Methodological quality*

The overall SCED ratings from the 16 SCDs ranged from 0 to 10 (maximum possible rating, 10), with an average of 6.8, as seen in Figure 2. The article which received the highest score of 10 was Cahill and colleagues (60), which used an instrumental approach

**Table 2.** Participant Characteristics.

| Study | N | Age (Years)) | Sex | Severity and/or Type of Dysarthria | Severity of TBI/ GCS | PTA Duration | Cognitive Impairments | Time Post-onset |
|---|---|---|---|---|---|---|---|---|
| Cahill et al. (60) | 3 | 29<br>24<br>30 | F<br>M<br>M | Moderate-severe flaccid dysarthria<br>Severe flaccid dysarthria<br>Severe flaccid dysarthria | GCS 3<br>Not Specified<br>GCS 6 | Not specified | Adequate cognitive function for participation in intervention | 30 months<br>8 months<br>7 months |
| Solomon et al. (26) | 1 | 58 | M | Moderate hypokinetic dysarthria | Not specified | 8 weeks | Impaired memory<br>Impaired visual auditory learning | 10 months |
| Solomon et al. (56) | 1 | 25 | M | Hypokinetic-spastic dysarthria | GSC 4 | 1 month | Impaired cognition | 24 months |
| Nordness et al. (30) | 10 | 19 – 44 | 8M<br>2F | 4 Mixed spastic-ataxic dysarthria<br>5 Mixed spastic-flaccid dysarthria<br>1 Mixed spastic-ataxic-flaccid dysarthria | Not specified | Not specified | Not specified | Not specified |
| Pilon et al. (65) | 3 | 23<br>23<br>44 | M<br>M<br>M | Severe mixed spastic-ataxic dysarthria<br>Mild-moderate mixed spastic-ataxic dysarthria<br>Moderate-severe mixed Spastic-ataxic dysarthria | Not specified | Not specified | Impaired cognition<br>Not specified<br>Not specified | 24 months<br>18 months<br>12 months |
| Goldstein et al. (58) | 1 | 18 | M | Severe dysarthria | Not specified | Not specified | Impaired short-term memory<br>Impaired procedural learning<br>Impaired speed of cognitive processing<br>Impaired divided attention | 10 months |
| Hartelius et al. (28) | 1 | 30 | M | Moderate Spastic-Ataxic dysarthria | Not specified | Not specified | Impaired higher-level cogitation<br>Impaired memory | 7 months |
| McGhee et al. (59) | 2 | 45<br>33 | M<br>M | Moderate flaccid-ataxic dysarthria<br>Mild flaccid ataxic dysarth;ria | GCS 3<br>GCS 4 | 95 days<br>54 days | P1:<br>Impaired orientation<br>Impaired concentration<br>Impaired memory<br>P2:<br>Impaired orientation<br>Impaired concentration<br>Impaired memory<br>Impaired attention<br>Impaired speed of cognitive processing | 95 days post onset; 54 days post onset |
| Honda et al. (66) | 1 | 31 | M | Velopharyngeal Incompetence | Not specified | Not specified | Not Specified | Not Specified |
| McHenry et al. (67) | 1 | 39 | F | Spastic dysarthria | Severe | Not specified | Not specified | 36 months |
| McHenry (29) | 1 | 24 | M | Severe hypokinetic dysarthria | GCS 4 | Not specified | Not specified | 12 months |
| McMicken et al. (55) | 1 | 36 | M | Ataxic dysarthria | Not specified | Not specified | No cognitive impairment | Not specified |
| Nemec & Cohen (68) | 1 | 24 | M | Severe hypertonic spastic dysarthria | Not specified | Not specified | Not specified | Not specified |
| Brand et al. (57) | 1 | 20 | F | Moderate-severe dysarthria | Not specified | Not specified | Impaired higher-level cognition<br>Impaired long-term memory | 48 months |
| Rilo et al. (27) | 1 | 20 | M | Velopharyngeal incompetence | Severe | Not specified | Not specified | |
| Aten (61) | 1 | 23 | M | Spastic dysarthria | Not specified | 3 months | Not specified | 24 months |
| McHenry (64) | 28 | Avg: M: 26.2<br>F: 25.6 | 22M<br>6F | Velopharyngeal Incompetence | Not specified | Not specified | Not specified | Avg:<br>M: 39.7 months<br>F: 10.8 months |

Note. Abbreviations: TBI, Traumatic Brain Injury; GCS, Glasgow Coma Scale; PTA, Post-traumatic Amnesia; M, male; F, female

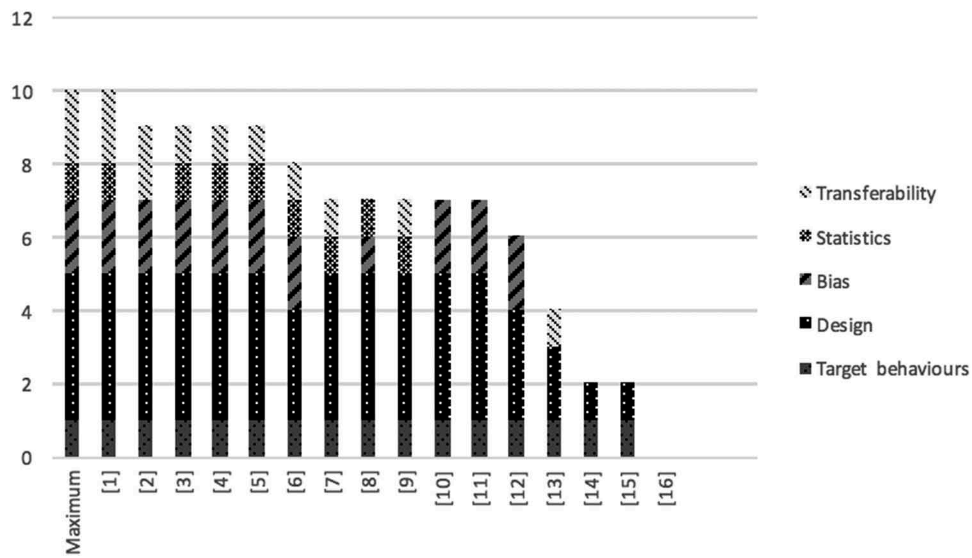


**Figure 2.** Single-case experimental design data harvest plot.

Maximum indicates the highest possible score that a study could receive in each category. Study identification numbers are: [1], Cahill et al.; [2], Solomon et al. (56); [3], Solomon et al. (26); [4], Nordness et al.; [5], Pilon et al.; [6], McGhee et al.; [7], Goldstein et al.; [8], Hartelius et al.; [9], Honda et al.; [10], McHenry (2002); [11], McHenry (29); [12], McMicken et al.; [13], Nemec & Cohen; [14], Rilo et al.; [15], Brand et al.; [16], Aten.

to treating dysarthria. This was followed by three studies that received a score of 9: an AAC intervention by Nordness et al. (30), and two behavioral management approaches by Solomon et al. (56) and Solomon et al. (26). All four studies provided adequate detail regarding study design, target behaviors, and bias, though Nordness et al. (30) lacked evidence regarding generalizability; Solomon et al. (56) lacked detail about statistical analysis; and Solomon et al. (26) had no evidence of replication. Three studies received a score of 2 or below, indicating poor methodological quality. Of these, a behavioral study by Aten received the lowest score of 0 (61), while the remaining two studies which evaluated a prosthetic approach to treatment achieved a score of 2.

Across the studies, one methodological feature that was frequently lacking was blinding. No studies included subject, therapist, and assessor blinding. Given that the majority of the interventions in this review were behavioral in nature, a lack of blinding for this intervention type was an inherent limitation. It is necessary to consider the implications of this, such as assessment and performance bias, which may affect the validity of the studies.

Evidence of maintenance of improvements was also limited across most studies. Eight of the 17 studies included some form of follow-up assessment, and one study also provided 'follow-up treatment.' This comprised of a 10-week period of treatment at decreased intensity directly following completion of the previous treatment phases. Follow-up assessments varied from 1 month to 1-year post-treatment, with only one study including multiple follow-ups, at 1 month and 2 months post-treatment.

Details regarding generalization of intervention outcomes were inconsistent across studies. Seven studies reported evidence that benefits from treatment occurred beyond the treatment setting. Replication was even less frequently evidenced, with only four studies reporting replication across participants. No studies reported replication across therapists or settings. A comprehensive summary of the intervention types is provided in Table 3.

## Intensity and duration

The interventions described above were provided individually, with only one study including group therapy as part of a follow-up measure. The intensity of the interventions varied greatly, from approximately 15 minutes per week to 4 hours per week, with six studies not reporting the intervention intensity at all. Of the eight studies that reported length of session, as well as the number of sessions per week, the average intensity was 136 minutes per week. However, no such intensity measures could be reported for prosthetic or pharmacological interventions given the nature of their administration. The time frames established varied across the studies. Of the 11 studies that reported intervention length, there was a range of 9 days to 12 months, with an average of 13 weeks. A summary of the intervention approaches and outcomes is provided below.

## Intervention and outcomes

The 17 articles reviewed included a diverse range of intervention approaches. These included seven behavioral, three prosthetic, three instrumental, two pharmacological, as well as one AAC, and one mixed intervention (see Table 3).

### Behavioral interventions

A number of different approaches were used across the seven behavioral interventions to treat a variety of dysarthria subtypes. These included the use of Lee Silverman Voice Treatment (LSVT) (62), Breathing-for-Speech Treatment (BST), and a modified Ryan Fluency Programme (RFP) (26,55,56,63). These intervention approaches aimed to improve the intelligibility of speech by targeting respiration and phonation

**Table 3.** Extracted data.

| Authors | Design | Intensity | Approach | Outcome Measures | Follow-up | Results | Consideration of Cognitive Impairments |
|---|---|---|---|---|---|---|---|
| Cahill et al. (60) | SCD: ABA | 4 × 10–24 minute sessions per week for 4 weeks | Instrumental:<br>1. Pt fitted with CPAP nasal mask and completed speech tasks | a) Perceptual evaluation – FDA, ASSIDS, speech sample analysis recorded<br>b) Instrumental evaluation – Nasometer | 1 month | Improvements described:<br>Sentence intelligibility immediately post-therapy:<br>P1: No improvement.<br>P2: 28.6% increase<br>P2: 0.7% decrease<br>Sentence intelligibility at follow-up:<br>P1: No improvement.<br>P2: 121.6% increase<br>P3: 16.8% increase<br>Improvements in nasalance scores were reported for all patients. | Not specified |
| Solomon et al. (26) | SCD: ABA | Treatment 1:<br>4 x 1 hour sessions per week for 4 weeks<br>Treatment 2:<br>4 x 1 hour sessions per week for 6 weeks<br>Treatment 3:<br>1 x 1 hour session per week for 10 weeks | Behavioral:<br>1. LSVT (goals: maximize loudness and duration during short phrases, paragraphs, reading and conversation)<br>2. Combination Therapy: incorporated direct respiration treatment by SLP and exercises in PT that targeted upper chest wall<br>3. Follow up Tx: combination treatment – plus speech and PT homework 3x per week | a) Flexible nasoendoscopy<br>b) Procedures in session included: oral motor examination, hearing screening, pulmonary function screening.<br>c) Session 1–5: chest wall kinematic data, lung volume subdivisions, acoustic analyses, auditory perceptual measures (sustained vowels), intelligibility, other perceptual measures (reading passage and a portion of a relatively fluid monologue) | 10 weeks of "Follow up Treatment" after completion of Combination Therapy and 3 months | Improvements described:<br>LSVT did not reliably improve lung volume levels or sentence intelligibility.<br>Combination therapy resulted in improvements in sentence intelligibility: from 71% to 89%. Higher lung volume levels for speech were also reported.<br>Vital capacity increased by almost 1 Liter over the course of intervention, implicating increased expiratory muscle strength.<br>Gains maintained to varying degrees at 3 months follow-up. Informal observations 2 years after discharge also suggest maintenance of post-treatment intelligibility. | Cognitive testing administered pre-treatment.<br>SLP addressed patient's cognitive-linguistic skills- specific goals were to increase use of an activity planner and task completion.<br>Authors mention patient's memory impairments may have contributed to limited improvement after LSVT. |
| Solomon et al. (56) | SCD: ABA | Treatment 1:<br>11 x 1 hour session across 6 weeks<br>Treatment 2:<br>4 x 1 hour sessions per week for 4 weeks | Behavioral:<br>1.Treatment phase 1: BST – Targets slow-to-moderately paced abdominal and rib cage expansion during inspiration, and relaxed expiration.<br>2. Treatment phase 2: LSVT (goals: maximize loudness and duration of sustained vowels, pitch range, and loudness during short phrases, paragraphs, reading and conversation | a) VHI<br>b) Sentence intelligibility- sentences read selected randomly from SIT inventory<br>c) Speech Breathing- chest wall kinematic signals, using respiratory inductive plethysmogaphy-<br>d) Perceptual ratings of speech: sentences (~30 seconds) | 1 month and 4 months | Improvements described:<br>Patient expressed extreme satisfaction with treatment- reduction in VHI score.<br>Speech breathing improved post-treatment; no increase in intelligibility post BST, but there was after LSVT (percentage of words understood improved from 87.7% to 95.5%).<br>Gains were generally maintained at follow-up but were limited (reduction from 95.5% to 91.4%). | Mention of VHI scores returning to severe range post-therapy- authors suggest that patient had continuing awareness of deficits, frustration from new seizure activity and perhaps reflecting cognitive difficulties responding to a graded rating scale. |
| Nordness et al. (30) | SCD: Multiple baseline | NA | AAC device:<br>1) Alphabet Supplementation | a) SPA used to determine: participant's speaking rate, total speaking time, percent pause time, total pause time, percent speech time, and total speech time in both habitual and AS conditions | NA | Improvements described: average increase in sentence intelligibility of the 10 participants was 32%.<br>There was also an average speaking rate decrease of 44.9% across the participants, and a pause duration increase of 331%. | Not Specified |

(*Continued*)

**Table 3.** (Continued).

| Authors | Design | Intensity | Approach | Outcome Measures | Follow-up | Results | Consideration of Cognitive Impairments |
|---|---|---|---|---|---|---|---|
| Pilon et al. (65) | SCD: ABACAD | 1 x session per week for 6 weeks | Behavioral:<br>1) Pacing technique under 4 conditions: no pacing, singing pacing, metronomic pacing, and board pacing | a) Verbal intelligibility and Speech rate using 30 sentence samples | Not specified | Improvements described: Metronome pacing yielded 21.2% increase in intelligibility over baseline, the pacing board resulted in a 13.6% increase over baseline, and singing resulted in a 12.2% increase over baseline | Author mentions cognitive impairments present in one participant. |
| Goldstein et al. (58) | SCD: ABA | 280 x 50 minute sessions across 12 months | Prosthetic/Instrumental/ Behavioral<br>1. Velar desensitization, pneumotachometer training for respiratory control, articulation – tactile and mirror feedback<br>2. PLP and articulation therapy<br>3. EPG feedback training – nonspeech movements<br>4. EPG feedback training- speech movements<br>5. Functional communication therapy – individual<br>6. Functional communication therapy- group | a) EPG- contact patterns for fricatives and alternation between velar and alveolar place of articulation recorded palatographically<br>b) Acoustic – using laboratory computer: sentence production, maximum sustained phonation, mean syllable duration, and minimum intensity during closure, number of within sentence inspirations<br>c) Perceptual data – MVP intelligibility profile, rating of overall speech impairment and articulatory precision | 6 months | Placement of a PLP resulted in a 20% improvement in intelligibility.<br>Improvements described: more advanced tongue positioning, closer constrictions, more appropriately timed articulations, and articulation precision.<br>While improvements were noted during the EPG treatment phase, overall severity scores remained high.<br>Gains maintained at follow-up. | Not specified |
| Hartelius et al. (28) | SCD: ABA | 3 x 45 minute sessions per week for 5 weeks. | Instrumental:<br>1. Desensitization<br>2. EPG use during articulation therapy | a) ASSIDS<br>b) MWIT<br>c) EPG- read a randomized word list of 50 words | Nil | Improvements described: speech intelligibility in sentences improved from 46% to 56% during treatment. | Author mentions attempt to make the therapy task 'less cognitively demanding'. |
| McGhee et al. (59) | SCD: ABA | 2x 15 minute sessions per day for 5 days per week for 64 days for patient 1 and 9 days for patient 2 | Behavioral:<br>1.Therapy occurred during PTA: Altering positioning and posture, improving respiratory capacity and efficiency, modification of muscle tone and strengthening exercises.<br>3. Once emerging from PTA, patients return to "traditional rehabilitation" | a) Westmead PTA Scale<br>b) Motor Speech Examination- informal tool<br>c) Perceptual Speech Analysis Scale | Nil | Intelligibility:<br>P1: improved by 28.1% for single words and 10% on phrases.<br>P2: improved by 6.3% for single words and 11% for phrases. | Author mentions multi-modality training utilized in order to overcome patient's potential deficits in areas of executive abilities and memory skills typical of TBI.<br>Author mentions closely monitoring patients for signs of difficulty.<br>Treating SP used a checklist of neurobehavioural consequences of TBI to document during sessions, combined with anecdotal evidence of patient's ability to participate in sessions. |
| Honda et al. (66) | SCD: ABA | NA | Prosthetic:<br>1.PLP fitted<br>2.Speech therapy (unspecified) | a) Nasometer<br>b) Perceived speech intelligibility | 2 months and 1 year | Improved from approximately 20% to 40% for single-word speech intelligibility with the PLP at 2 months post-treatment, and reached 75% after 1 year. Conversational speech intelligibility<br>improved from a score of 4 (poorly identified) to 2 (fairly well identified). | Not Specified |
| McHenry et al. (67) | SCD: ABA | Nil | Pharamcological<br>1.Botulin toxin type A injected percutaneously. | a) Aerodynamic Measures Analysis<br>b) Acoustic measures – analyzed using the Multi-Dimensional Voice Profile<br>c) Perceptual measures – Videotaped segments of conversational speech | 2 months | Significantly decreased perceived listener burden. Improvements noted: relaxed voice and pleasant voice.<br>No differences noted in intelligibility, intensity, estimated laryngeal airway resistance.<br>Variable maintenance of effects at follow-up. | Nil specific |

(*Continued*)

**Table 3.** (Continued).

| Authors | Design | Intensity | Approach | Outcome Measures | Follow-up | Results | Consideration of Cognitive Impairments |
|---|---|---|---|---|---|---|---|
| McHenry (29) | SCD: BABA | 3 x doses of 0.05 mg per day for 5 days | Pharmacological<br>1. Patient took Permax Monday-Friday, with washout occuring over a weekend. | a) Conversational speech sample rated by 2 groups of unfamiliar listeners for affect, intelligibility & listener burden on 5 point scale<br>b) Respiratory inductive plethysmograph bands<br>c) Electroglottographic electrodes<br>d) Nasometer<br>e) Head-mounted strain gauge transduction system | NA | There was no significant difference between conditions for intelligibility. One difference occurred in the velopharyngeal orifice area, where closure was within normal limits in the off condition, and abnormally large in the on condition. Another area of marked improvement in the off condition was the number of dysfluencies in the stimulus sentences. | Neuropsychological tests were scored and interpreted by a licensed neuropsychologist experienced in TBI. No differences in performance between the two conditions reported. |
| McMicken et al. (55) | SCD: ABA | 2x 50 minute sessions per week for 18 weeks | Behavioral:<br>1) LSVT and RFP treatment | a) Examination of oral mechanism and a motor speech assessment<br>b) AMRs and SMRs for perceptual speech and articulatory assessment<br>c) Modified Erickson Scale of Communication Abilities S-24 | Nil | Improvement in intelligibility increased from 3.7 (difficult to understand) to 5.3 (intelligible but noticeably in error). | Authors mentioned using portions of the Woodcock-Johnson Test of Cognitive Ability – Revised and the Mini Mental Status Examination to assess patient's cognition, including memory, judgment, reasoning and problem solving. |
| Nemec & Cohen (68) | SCD: ABA | 3 x 5 minute trials for 17 sessions across 20 weeks | Instrumental:<br>1) EMG Biofeedback was used to increase awareness of increased tension of facial muscles | a) Performance level defined as the average percentage of time during the three trials when he could sustain target microvolt reading (maintaining closure) | 16 weeks-20 weeks | Speech intelligibility of phrases improved from 40% to 50% in known contexts and 30% to 40% in unknown contexts.<br>Gains maintained at follow-up. | Not Specified |
| Brand et al. (57) | SCD: ABA | NA | Prosthetic:<br>1. Intraoral prosthesis<br>2. Topical anesthetic introduced | a) Vital Capacity<br>b) Tape and Video recording | Nil | Improvements described: patient immediately able to retain the device for approximately three to four hours per application. Intelligibility was rated at 50%. | Impact of memory problems minimized with the inclusion of topical anesthetic gel application in the daily routine. |
| Rilo et al. (27) | SCD: ABA | NA | Prosthetic:<br>1)PLP inserted | a) Perceptual judgment with a standardized speech passage<br>b) Nasoendoscopic examination | NA | Improvements described: Significant reduction in hypernasality noted, with 95% closure of velopharyngeal valve. | Nil |
| Aten (61) | SCD: Design not specified | NA | Behavioral:<br>1.Assisted exhalation (pushing on stomach)<br>2.Sensory stimulation of oral cavity<br>3. behavioral cues for increased inspiration<br>4.Oromotor exercises | Not specified | NA | Improvements described: voluntary phonation achieved; increased strength and range of motion of articulators; overall intelligibility. | Nil |
| McHenry (64) | Cohort | NA | Behavioral:<br>1) Data are reported for the subjects' habitual loudness and for increased vocal effort | a) Nasal cavity resistance, including three trials each of quiet and deep breathing, at various nasal airflow values. b) At a typical pitch and self-perceived habitual and loud levels, participants produced trains of seven/pi/ syllables at approximately 2–3 syllables. Three trials were obtained for each loudness condition. | NA | Improvements described: 89% of the subjects decreased velopharyngeal orifice area by increasing vocal effort. In several cases, the change would likely affect perceived hypernasality. | Not specified |

Note. Abbreviations: AMR, Alternating motion rate; ASSIDS, Assessment of Intelligibility of Dysarthric Speech; BST, Breathing-for-speech; EMG, Electromyography; EPG, Electropalatography; FDA, Frenchay Dysarthria Assessment; LSVT, Lee Silverman Voice Treatment; MVP, Munich Intelligibility Profile; MWIT, Multiple Word Intelligibility Test; NA, Not applicable; PLP, Palatal lift prosthesis; PT, Physical therapy; PTA, Posttraumatic amnesia; SCD, Single case design; SIT, Sentence Intelligibility Test; SLP, Speech-language pathologist; SPA, Speech Pause Analysis; SPL, Sound pressure level; VHI, Voice Handicap Index; TBI; Traumatic brain injury dysfunction. One study also investigated compensatory strategies to minimize resonance abnormalities on speech production, by establishing high phonatory effort (64). Aten investigated the effect of strengthening respiratory control in order to enhance phonation (61). Pilon and colleagues used external rate control techniques focused on the prosodic aspects of speech (65). Overall, while intelligibility appeared to improve across all behavioral studies, these gains were not consistently maintained at follow-up, and generalization was rarely evident. Strengths of these behaviorally based intervention studies included a sufficient description of target behaviors and design for replication, with weaknesses noted in ecological validity. Excluding one outlier study which received a score of 0, the average SCED score for behavioral interventions was 8, indicating overall moderate to high methodological quality.

### Prosthetic interventions

Three studies investigated the effect of prosthetic devices on the resonatory characteristics of dysarthric speech, as a result of velopharyngeal incompetence. Honda et al. (66) and Rilo et al. (27) both investigated the effect of fitting a Palatal Lift Prosthesis (PLP); however, Honda and colleagues (66) also incorporated an unknown period of unspecified speech therapy into their intervention program. Brand et al. (57) also investigated the effects of a PLP but focused more on solving the problem of limited retention of the device. All three studies suggested that fitting a PLP device was beneficial in decreasing hypernasality, though there was limited evidence of generalizability of treatment. The SCED ratings of these prosthetic studies ranged from 2 to 7, with an average of 3.6, suggesting overall poor methodological quality. Two of the three prosthetic studies were limited in their description of data collection, variables addressing bias, statistical analysis, and transferability.

### Instrumental interventions

Three studies investigated the effect of an instrumental intervention approach on patients with flaccid and spastic dysarthria. The devices used, as well as the time frame and approach to therapy tasks, differed across the studies. These included the use of electropalatography (EPG) (28) and electromyographic (EMG) neuromuscular biofeedback (68) to target imprecise articulation, and Continuous Positive Airway Pressure (CPAP) (60) therapy to target resonance and reduce hypernasality. EPG and EMG appeared to have an overall positive effect on increasing intelligibility, while CPAP had varying degrees of improvement at follow-up. Across all studies, there was inconsistent evidence of generalization of gains. The devices used, as well as the time frame and approach to therapy tasks, differed across the studies. The overall methodological quality of the instrumental studies ranged from 4 to 10 on the SCED scale, with an average of 7, suggesting moderate quality. While one study received a maximum score (60), the two other studies had weaknesses in the areas of addressing bias, and transferability. All three instrumental studies had strengths in describing target behaviors, as well as study design.

### Pharmacological interventions

Two studies evaluated the effectiveness of pharmacological treatments on dysarthria. One study investigated the effects of Permax (a dopamine agonist) on hypokinetic dysarthric speech, while the second study examined the impact of Botulinum Toxin A injection into the thyroarytenoid muscles on spastic dysarthric speech. While results in both pharmacological studies demonstrated little evidence of objective improvement, participants in both studies reported satisfaction with the treatments and perceived gains. No evidence of follow-up or generalization beyond the therapy setting was noted. According to the SCED, both pharmacological studies received scores of 7 indicating moderate methodological quality. These studies lacked sufficient detail with regard to statistical analysis and transferability. Strengths lay in describing target behaviors, study design and addressing risk of bias.

### AAC interventions

One study described the use of an AAC device to accompany speech in patients with mixed spastic subtypes of dysarthria. They found that the AS intervention resulted in increased speech intelligibility and decreased speaking rate due to increased pause frequency and duration. This study received a SCED rating of 9 indicating strong methodological quality. The only weakness noted was the lack of generalizability of treatment outcomes.

### Mixed intervention

While the previously discussed studies focused on one approach to treating dysarthria, Goldstein and colleagues (58) presented a unique mixed approach. This intervention combined prosthetic and instrumental approaches in the treatment of a patient with severe dysarthria and velopharyngeal incompetence. Results indicated improvements in speech breathing, intelligibility, and improved articulation. Performance at 6-month follow-up was maintained with the PLP in place. This study received a SCED rating of 7 indicating moderate methodological quality. While the study provided evidence of generalization, it did not adequately address the risk of bias.

## Discussion

Dysarthria is highly prevalent in the TBI population (14,15). It can often have unrelenting and detrimental effects on an individual's capacity to effectively communicate, increasing the likelihood of long-term disability (20,33). Cognitive impairments also commonly accompany traumatic injuries to the brain and may affect the outcomes of intervention for dysarthria in this population (39). The identification of effective interventions for dysarthria in this complex and vastly heterogeneous population is therefore required. This scoping review aimed to answer three pertinent research questions regarding dysarthria following TBI in an adult population; 1) what interventions are present in the literature, 2) which interventions are effective, and 3) what is the methodological quality of studies?

The results of this review found a number of intervention types in the literature. These included behavioral, prosthetic, instrumental, pharmacological, AAC, and mixed approaches to treating dysarthria. Of the studies in this review, behavioral approaches were the most prevalent. Specific interventions included standardized programs such as LSVT, BST, and a modified RFP, as well as the use of external rate control strategies. Instrumental interventions included EPG, EMG, and CPAP, while all of the prosthetic interventions utilized application of a PLP. Two studies investigated the use of pharmacological interventions in treating dysarthria. One of these investigated the effect of prescribing a dopamine agonist whereas the other study evaluated the effect of injecting botulinum toxin into the thyroarytenoid muscles. A single study implemented an AAC approach by using AS, while another study used a combination of prosthetic and instrumental techniques in the treatment of dysarthria following TBI.

The effectiveness of treatment varied across and within intervention types. Behavioral approaches were implemented across the most diverse dysarthria subtype presentations and reported improvements for the particular skills they addressed. While the methodological quality of these approaches was moderate to high, not all studies demonstrated maintenance at follow-up, reflecting limited evidence of functional speech improvements in everyday life.

The few instrumental approaches present in the literature were used with patients with flaccid and spastic dysarthria, with consistently positive outcomes, and moderate methodological quality. There was preliminary evidence that using a prosthetic approach to treating velopharyngeal incompetence was beneficial; however, the overall methodological quality of these prosthetic studies was low. Therefore, it is difficult to draw conclusions regarding the effectiveness and maintenance of this intervention type beyond the treatment setting.

Other types of interventions have received comparatively little formal investigation.

For the few studies which investigated an AAC and pharmacological approach, benefits were reported in treating mixed-spastic and hypokinetic dysarthria types. Although the methodological quality of these studies was consistently moderate to high, given the small number of studies, paired with inconsistent treatment findings, limited conclusions can be drawn about the effectiveness of these interventions.

The one study that used an eclectic approach to treat a patient with deficits across multiple subsystems appeared to substantially mitigate the patient's severe communication problem, with improvements across all areas of impairment. This was reflected post-treatment and maintained at 6-month follow-up. Functional speech was also addressed through individual and group therapy, which appeared beneficial. Despite only one study investigating this combination approach to treating dysarthria, a score indicating moderate methodological quality suggests that such an approach has the potential to yield positive results with further investigation.

The overall methodological strength of the SCDs as rated by the SCED ranged from a score of 0 to 10, with an average of 6.8, indicative of moderate quality (see Figure 1). As described above, the current literature of treatment for dysarthria following TBI is clearly limited in quantity and favors single case studies. The lack of large scale clinically controlled trials is potentially related to the extreme heterogeneity and complexity of the TBI population, and consequent presentation of dysarthria. The methodological quality of many of the SCD articles reviewed suggested there is potential for improvement in the design of investigations of specific treatments.

## Study limitations

While this review aimed to provide a summary of the current evidence both in terms of methodological rigor and treatment content and outcomes in the area of dysarthria treatment following TBI, there were some limitations to the review. Every effort was made to conduct a comprehensive search of available evidence; however, it is possible that studies may have been missed (e.g. those not published in English), and hence not included in the scoping review. In addition, the lack of a uniform rating scale for evaluating methodological quality across all study designs reviewed limited the ability to fully synthesize the study in terms of methodological rigor. In particular, one cohort study was unable to be rated as thoroughly. It was also not possible to conduct a meta-analysis of the data from the studies reviewed, due to the vast differences in research methods and outcome measures provided in each study.

## Clinical implications

This review emphasized the heterogeneity of intervention approaches when providing management of cases of dysarthria following TBI. The findings of this review have highlighted how little is understood about best practice for treating this complex and diverse population. The presence of dysarthria following TBI evidently has implications for long-term quality of life, and as such, SLP clinical practice guidelines endorse the management and treatment of dysarthria following TBI internationally. It is clearly apparent that clinicians are abiding by this in everyday practice. The presence of dysarthria following TBI evidently has implications for long-term quality of life, and as such, SLP clinical practice guidelines endorse the management and treatment of dysarthria following TBI internationally. It is clearly apparent that clinicians are abiding by this in everyday practice.

While the majority of studies reported improved intelligibility following intervention, measures of functional improvement were rarely undertaken. Only two studies used a measure to determine the psychosocial consequences of the patient's speech disorder pre- and post-treatment. Therefore, due to this lack of evidence of improvement in functional speech or perceived communication abilities and their impact on the quality of life, it is difficult to draw conclusions about the true effectiveness of these interventions. Further research in this area with a focus on functional outcomes is warranted.

While seven out of 17 articles reported that their participants presented with a cognitive impairment post-TBI, only four reported addressing these cognitive impairments in their therapy approach. Previous literature has reported that cognitive impairments may impact on an individual's capacity to engage in, and consequently benefit from therapy. Therefore, it would seem crucial for clinicians to modify their treatment approach to account for these impairments. Interestingly, the few studies in our review that accounted for these impairments did not yield notably different outcomes compared to the studies that did not. It is important to note that the degree to which the cognitive impairment was addressed in these four studies varied greatly. For instance, while one study used compensatory strategies to account for memory deficits, another increased therapy duration to address the same. An additional study altered the way in which therapy was delivered by providing multimodal cueing to overcome potential impairments in executive function and memory, while another simplified therapy tasks altogether. Because of the varied nature in which cognitive impairments were addressed in these studies, it is difficult to draw conclusions about the added benefit of modifying treatment to account for these deficits.

It is also important to note the lack of recent contributions to this area of research. The vast majority of studies in this review were published over 10 years ago. This has implications for clinical practice, given advances in medical technology, improved understanding of brain localization and neuroplasticity, as well as changes in treatment approaches and guidelines. It is imperative that research in this area be updated in order to determine best practice in treating this population.

## Conclusion

The research in the area of dysarthria treatment following TBI has explored a diverse range of interventions. Behavioral interventions have received the most focus in the literature, and appear to be consistently effective, with some demonstrating maintenance at follow-up. Instrumental and prosthetic approaches were comparatively less prevalent in the literature, but demonstrated some promising results; other approaches were limited. It is evident that this field requires high-quality research to inform the best clinical practice.

## Acknowledgments

We thank Christine Dalais from the University of Queensland library for assistance with database searching.

## Disclosure of interest

The authors report no conflict of interest.

## References

1. Menon DK, Schwab K, Wright DW, Maas AI. Position statement: definition of traumatic brain injury. Arch Phys Med Rehabil. 2010;91(11):1637–40.doi:10.1016/j.apmr.2010.05.017.
2. Hyder A, Wunderlich C, Puvanachandra P, Gururaj G, Kobusingye O. The impact of traumatic brain injuries: a global perspective. NeuroRehabilitation. 2007;22:341–53.doi:10.3233/NRE-2007-22502.
3. Dewan MC, Rattani A, Gupta S, Baticulon RE, Hung Y-C, Punchak M, Agrawal A, Adeleye AO, Shrime MG, Rubiano AM, et al. Estimating the global incidence of traumatic brain injury. J Neurosurg. 2018; 1–18.
4. World Health Organisation. World report on disability. Geneva, Switzerland: WHO Press; 2011.
5. Bruns J Jr., Hauser WA. The epidemiology of traumatic brain injury: a review. Epilepsia. 2003;44(s10):2–10.doi:10.1046/j.1528-1157.44.s10.3.x.
6. Kelly MDDF, Becker MDDP. Advances in Management of Neurosurgical Trauma: USA and Canada. World J Surg. 2001;25 (9):1179–85.doi:10.1007/s00268-001-0080-x.
7. Fakhry S, Trask A, Waller M, Watts D. Management of brain-injured patients by an evidence-based medicine protocol improves outcomes and decreases hospital charges. J Trauma. 2004;56(3):492–500.doi:10.1097/01.TA.0000115650.07193.66.
8. Colantonio A, Ratcliff G, Chase S, Kelsey S, Escobar M, Vernich L. Long-term outcomes after moderate to severe traumatic brain injury. Disabil Rehabil. 2004;26(5):253–61. doi:10.1080/0963828031000 1639722.
9. Gerber LM, Chiu Y-L, Carney N, Härtl R, Ghajar J. Marked reduction in mortality in patients with severe traumatic brain injury. J Neurosurg. 2013;119(6):1583–90.doi:10.3171/2013.8.JNS13276.
10. Langlois J, Rutland-Brown W, Wald M. The epidemiology and impact of traumatic brain injury: A brief overview. J Head Trauma Rehabil. 2006;21(5):375–78.doi:10.1097/00001199-200609000-00001.
11. Access Economics Pty Ltd. The economic cost of spinal cord injury and traumatic brain injury in Australia. Melbourne, Vic: The Victorian Neurotrauma Initiative; 2009.
12. Moscato H, Trevisan M, Willer BS. The prevalence of traumatic brain injury and cooccurring disabilities in a national survey of adults. Neuropsychiatry Clin Neurosci. 1994;6:134–42.
13. Thornhill S, Teasdale GM, Murray GD, McEwen J, Roy CW, Penny KI. Disability in young people and adults one year after head injury: prospective cohort study. BMJ. 2000;320 (7250):1631–35.doi:10.1136/bmj.320.7250.1631.
14. Sarno MT, Buonaguro A, Levita E. Characteristics of verbal impairment in closed head injured patients. Arch Phys Med Rehabil. 1986;67(6):400–05.
15. Yorkston KM, Honsinger MJ, Mitsuda PM, Hammen V. The relationship between speech and swallowing disorders in head-injured patients. J Head Trauma Rehabil. 1989;4(4):1–16. doi:10.1097/00001199-198912000-00005.
16. Safaz I, Alaca R, Yasar E, Tok F, Yilmaz B. Medical complications, physical function and communication skills in patients with traumatic brain injury: a single centre 5-year experience. Brain Inj. 2008;22(10):733–39.doi:10.1080/02699050802304714.
17. Mitchell C, Bowen A, Tyson S, Butterfint Z, Conroy P. Interventions for dysarthria due to stroke and other adult-acquired, non-progressive brain injury. Cochrane Database Syst Rev. 2017; Jan 25:1.
18. Darley FL, Aronson AE, Brown JR. Motor speech disorders. Philadelphia, PA: Saunders; 1975.
19. Enderby P, Pickstone C, John A, Fryer K, Cantrell A, Papaioannou D. Resource manual for commissioning and planning services for SLCN. London, UK: Royal College of Speech Language Therapists; 2009.
20. Guo YE, Togher L. The impact of dysarthria on everyday communication after traumatic brain injury: a pilot study. Brain Inj. 2008;22(1):83–98.doi:10.1080/02699050701824150.
21. McDonald S, Togher L, Code C. Social and communication disorders following traumatic brain injury. 2nd ed. McDonald S, Togher L, Code C, editor. Great Britain: Psychology Press; 2013.
22. Enderby P, Emerson J. Speech and language therapy: does it work? BMJ. 1996;312(7047):1655–58.doi:10.1136/bmj.312.7047.1655.
23. Rosenbeck J, Netsell R. Treating the dysarthrias: speech and language evaluation in neurology: adult disorders. New York: Grune & Stratton; 1985.
24. Yorkston KM, Beukelman DR, Strand E, Hakel M. Management of motor speech disorders in children and adults. Austin, Texas: Pro-Ed; 2010.
25. Duffy JR. Motor speech disorders: substrates, differential diagnosis, and management. St Louis, MO: Elsevier; 2013.
26. Solomon NP, McKee AS, Garcia-Barry S. Intensive voice treatment and respiration treatment for hypokinetic-spastic dysarthria after traumatic brain injury. Am J Speech Lang Pathol. 2001;10 (1):51–64.doi:10.1044/1058-0360(2001/008).

27. Rilo B, Fernandez-Formoso N, da Silva L, Pinho J. A simplified palatal lift prosthesis for neurogenic velopharyngeal incompetence. J Prosthodont. 2013;22(6):506–08.doi:10.1111/jopr.12024.
28. Hartelius L, Theodoros D, Murdoch B. Use of electropalatography in the treatment of disordered articulation following traumatic brain injury: a case study. J Med Speech Lang Pathol. 2005;13 (3):189–204.
29. McHenry M. The effect of a dopamine agonist on dysarthric speech production: a case study. J Commun Disord. 2001;34(5):397–414.
30. Nordness AS, Beukelman DR, Ullman C. Impact of alphabet supplementation on speech and pause durations of dysarthric speakers with traumatic brain injury: a research note. J Med Speech Lang Pathol. 2010;18(2):8p–p.
31. Sellars C, Hughes T, Langhorne P. Speech and language therapy for dysarthria due to nonprogressive brain damage: a systematic Cochrane review. Clin Rehabil. 2002;16(1):61–68.doi:10.1191/0269215502cr468oa.
32. Maas A, Stocchetti N, Bullock R. Moderate and severe traumatic brain injury in adults. Lancet Neurol. 2008;7(8):728–41. doi:10.1016/S1474-4422(08)70164-9.
33. Olver JH, Ponsford JL, Curran CA. Outcome following traumatic brain injury: a comparison between 2 and 5 years after injury. Brain Inj. 1996;10(11):841–48.doi:10.1080/026990596123945.
34. Coelho CA, DeRuyter F, Stein M. Treatment efficacy: cognitive-communicative disorders resulting from traumatic brain injury in adults. J Speech Hear Res. 1996;39(5):S5–17. doi:10.1044/jshr.3905.s5.
35. Forducey PG, Ruwe WD, Dawson SJ, Scheideman-Miller C, McDonald NB, Hantla MR. Using telerehabilitation to promote TBI recovery and transfer of knowledge. NeuroRehabilitation. 2003;18(2):103–11.doi:10.3233/NRE-2003-18203.
36. Isaki E, Turkstra L. Communication abilities and work re-entry following traumatic brain injury. Brain Inj. 2000;14(5):441–53. doi:10.1080/026990500120547.
37. Jagnoor J, Cameron I. Traumatic brain injury – support for injured people and their carers. Aust Fam Physician. 2014;43:758–63.
38. Stewart-Scott AM, Douglas JM. Educational outcome for secondary and postsecondary students following traumatic brain injury. Brain Inj. 1998;12(4):317–31.doi:10.1080/026990598122629.
39. Rabinowitz A, Levin H. Cognitive sequelae of traumatic brain injury. Psychiatr Clin North Am. 2014;37(1):1–11.doi:10.1016/j.psc.2013.11.004.
40. Lezak MD, Howieson DB, Bigler ED, Tranel D. Neuropsychological assessment. 5th ed. New York, NY: Oxford University Press; 2012.
41. Zhang H, Zhang X-N, Zhang H-L, Huang L, Chi -Q-Q, Zhang X, Yun X-P. Differences in cognitive profiles between traumatic brain injury and stroke: a comparison of the montreal cognitive assessment and mini-mental state examination. Chin J Traumatology. 2016;19 (5):271–74.doi:10.1016/j.cjtee.2015.03.007.
42. National Outcomes Measurement System. Adults in healthcare - Inpatient rehab national data report. Rockville, MD: National Centre for Evidence Based Practice in Communication Disorders: American-Speech-Language-Hearing Association; 2019.
43. National Outcomes Measurement System. Adults in healthcare - Outpatient national data report. Rockville, MD: National Centre for Evidence Based Practice in Communication Disorders: American-Speech-Language-Hearing Association; 2019.
44. Traumatic Brain Injury in Adults. American Speech-Language-Hearing association; 2019. https://www.asha.org/PRPSpecificTopic.aspx?folderid=8589935337§ion=Overview.
45. New Zealand Guidelines Group. Traumatic brain injury: diagnosis, acute management and rehabilitation. Wellington, NZ: ACC; 2006.
46. Liberati A, Altman D, Tetzlaff J, Mulrow C, Gøtzsche P, Ioannidis J, Moher D. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. Ann Intern Med. 2009;151(4):W65–94. doi:10.7326/0003-4819-151-4-200908180-00136.
47. Yorkston K, Beukelman D. Assessment of intelligibility of dysarthric speech. Austin: Pro-Ed; 1981.
48. Enderby P. Frenchay dysarthria assessment. Br J Disord Commun. 1980;15(3):165–73.doi:10.3109/13682828009112541.
49. Jacobson B, Johnson A, Grywalski C, Silbergleit A, Jacobson G, Benninger M, Newman C. The voice handicap index (VHI). Am J Speech Lang Pathol. 1997;6:66–70.doi:10.1044/1058-0360.0603.66.
50. NHMRC additional levels of evidence and grades for recommendations for developers of guidelines. Canberra, Australia: National Health and Medical Research Council, Australian Government; 2009.
51. Tate R, Mcdonald S, Perdices M, Togher L, Schultz R, Savage S. Rating the methodological quality of single-subject designs and n -of-1 trials: introducing the single-case experimental design (SCED) scale. Neuropsychol Rehabil. 2008;18(4):385–401. doi:10.1080/09602010802009201.
52. Crowther M, Avenell A, MacLennan G, Mowatt G. A further use for the Harvest plot: a novel method for the presentation of data synthesis. Res Synth Methods. 2011;2(2):79–83.doi:10.1002/jrsm.v2.2.
53. Ogilvie D, Fayter D, Petticrew M, Sowden A, Thomas S, Whitehead M, Worthy G. The harvest plot: a method for synthesising evidence about the differential effects of interventions. BMC Med Res Methodol. 2008;8:8.doi:10.1186/1471-2288-8-8.
54. Yorkston K, Beukelman D. Motor speech disorders. Communication disorders following traumatic brain injury. Austin, Texas: Management of Cognitive, Language and Motor Impairments; 1991. p. 251–315.
55. McMicken BL, Ostergren JA, Vento-Wilson M. Therapeutic intervention in a case of ataxic dysarthria associated with a history of amateur boxing. Commun Disord Q. 2011;33(1):55–64. doi:10.1177/1525740110397829.
56. Solomon NP, Makashay MJ, Kessler LS, Sullivan KW. Speech-breathing treatment and LSVT for a patient with hypokinetic-spastic dysarthria after TBI. J Med Speech Lang Pathol. 2004;12(4):213–19.
57. Brand HA, Matsko TA, Avart HN. Speech prosthesis retention problems in dysarthria: case report. Arch Phys Med Rehabil. 1988;69(3 Pt 1):213–14.
58. Goldstein P, Ziegler W, Vogel M, Hoole P. Combined palatal-lift and EPG-feedback therapy in dysarthria: a case study. Clin. Ling. Phonetics. 1994;8(3):201–18.doi:10.3109/02699209408985307.
59. McGhee H, Cornwell P, Addis P, Jarman C. Treating dysarthria following traumatic brain injury: investigating the benefits of commencing treatment during post-traumatic amnesia in two participants. Brain Inj. 2006;20(12):1307–19.doi:10.1080/02699050601081851.
60. Cahill LM, Turner AB, Stabler PA, Addis PE, Theodoros DG, Murdoch BE. An evaluation of continuous positive airway pressure (CPAP) therapy in the treatment of hypernasality following traumatic brain injury: a report of 3 cases. J Head Trauma Rehabil. 2004;19(3):241–53.doi:10.1097/00001199-200405000-00005.
61. Aten JL. Spastic dysarthria: revising understanding of the disorder and speech treatment procedures. J Head Trauma Rehabil. 1988;3 (2):63–73.doi:10.1097/00001199-198806000-00008.
62. Ramig LO, Fox C, Sapir S, Countryman S. Changes in vocal loudness following intensive voice treatment (LSVT) in individuals with Parkinson's disease: A comparison with untreated patients and normal age-matched controls. Mov Disord. 2001;16:79–83.doi:10.1002/1531-8257(200101)16:1<79::AID-MDS1013>3.0.CO;2-H.
63. Ryan B. Programmed stuttering therapy for children and adults. Springfield, IL: Charles C Thomas; 2001.
64. McHenry MA. The effect of increased vocal effort on estimated velopharyngeal orifice area. Am J Speech Lang Pathol. 1997;6 (4):55–61.doi:10.1044/1058-0360.0604.55.
65. Pilon MA, McIntosh KW, Thaut MH. Auditory vs visual speech timing cues as external rate control to enhance verbal intelligibility in mixed spastic-ataxic dysarthric speakers: a pilot study. Brain Inj. 1998;12(9):793–803.doi:10.1080/026990598122188.

66. Honda K, Urade M, Kandori Y. Application of a specially designed palatal lift prosthesis to a patient with velopharyngeal incompetence due to severe brain injury. Quintessence Int. 2007;38(6):e316–20.
67. McHenry M, Whatman J, Pou A. The effect of Botulin Toxin A on the vocal symptoms of spastic dysarthria: A case study. Journal of Voice. 2002;16(1):124–131.
68. Nemec RE, Cohen K. EMG biofeedback in the modification of hypertonia in spastic dysarthria: case report. Arch Phys Med Rehabil. 1984;65(2):103–04.

## Appendix A.

### PubMed Search Strategy

(1) "traumatic brain injury" OR "traumatic brain injuries" OR "acquired brain injury" OR "acquired brain injuries" OR "brain injury" OR "brain injuries" OR "head injury" OR "head injuries" OR "brain damage" OR "brain damaged" OR TBI OR ABI
(2) (trauma[TIAB] OR traumatic[TIAB]) AND (head[TIAB] OR brain[TIAB])
(3) "Brain injuries, Traumatic"[Mesh]
(4) "Brain injuries"[Mesh] OR "Brain Injury, Chronic"[Mesh] OR "Brain Injuries, Diffuse"[Mesh]
(5) (((("traumatic brain injury" OR "traumatic brain injuries" OR "acquired brain injury" OR "acquired brain injuries" OR "brain injury" OR "brain injuries" OR "head injury" OR "head injuries" OR "brain damage" OR "brain damaged" OR TBI OR ABI)) OR ((trauma[TIAB] OR traumatic[TIAB]) AND (head[TIAB] or brain[TIAB]))) OR "Brain Injuries, Traumatic"[Mesh]) OR ("Brain Injuries"[Mesh] OR "Brain Injury, Chronic"[Mesh] OR "Brain Injuries, Diffuse"[Mesh])
(6) "Dysarthria"[Mesh]
(7) dysarthria
(8) dysarthria[TIAB]
(9) (dysarthria[TIAB]) OR "Dysarthria"[Mesh]
(10) (((dysarthria[TIAB]) OR "Dysarthria"[Mesh])) AND ((((("traumatic brain injury" OR "traumatic brain injuries" OR "acquired brain injury" OR "acquired brain injuries" OR "brain injury" OR "brain injuries" OR "head injury" OR "head injuries" OR "brain damage" OR "brain damaged" OR TBI OR ABI)) OR ((trauma[TIAB] OR traumatic[TIAB]) AND (head[TIAB] OR brain[TIAB]))) OR "Brain Injuries, Traumatic"[Mesh]) OR ("Brain Injuries"[Mesh] OR "Brain Injury, Chronic"[Mesh] OR "Brain Injuries, Diffuse"[Mesh]))

### Cochrane Library Search Strategy

(1) dysarthria:ti,ab,kw (Word variations have been searched)
(2) MeSH descriptor: [Brain Injuries, Traumatic] explode all trees
(3) tbi or "traumatic brain injur*" or "acquired brain injur*" or ABI
(4) "head injur*" or brain damage
(5) MeSH descriptor: [Brain Injury, Chronic] explode all trees
(6) MeSH descriptor: [Brain Injuries, Diffuse] explode all trees
(7) #2 or #3 or #4 or #5 or #6
(8) 8. #1 and #7