Full title

Visual system disorders and musculoskeletal neck complaints: A systematic review and meta-analysis

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Short title

Visual system and neck: A review

Keywords

eye-lens accommodation; vergence disorders; eye discomfort; neck pain; whiplash Injuries; trapezius muscle

Abstract

Accommodation disorders and non-strabismic binocular dysfunctions affect patients' binocular system and visual performance. These visual disorders could be associated with musculoskeletal discomfort in the neck and shoulder area. The purpose of this systematic review and meta-analysis was to ascertain the relationship between visual system disorders and the musculoskeletal system of the neck. The review protocol is available in PROSPERO (CRD42018112771). All articles selected examined the relationship between neck conditions (chronic neck pain and whiplash) and the visual system in adult populations. Studies with optometric or physiotherapeutic measurements were included. Bias risk was evaluated with the modified Cochrane Collaboration Tool and Study Quality Assessment Tool. To offer complete quality assessment evidence, the authors applied the GRADEpro Guideline Development Tool. The literature search was conducted in November 2018 and yielded 745 studies among all the databases. Finally, 21 studies were included. Most of the studies presented a moderate methodological quality. Only one high-quality trial was found. Based on a qualitative assessment, our systematic review and meta-analysis revealed that all included studies established a relationship between the visual system and musculoskeletal system of the neck. However, the measurement methods of the visual system lacked uniformity.

1. Introduction

Accommodation anomalies and non-strabismic binocular dysfunctions are vision disorders that affect a patient's binocular system and visual performance. These dysfunctions challenge near-activity demands. Symptoms may include blurred vision, reading problems, headache, diplopia, and in many cases, difficulty in maintaining comfortable vision for a long time. [1–3] Also, these visual disorders are associated with musculoskeletal discomfort in the neck and shoulder. [4–12] Although the two conditions are usually studied independently, there are indications that they can be physiologically related. [5–10,13] It is important to note that the computer vision syndrome (64% - 90% prevalence)[4] is a term that encompasses one or more symptoms of the visual system, neck, and shoulder. However, it does not necessarily imply the co-existence of these conditions.

In 1943, Eckardt et al.[14] established a relationship between the visual system and the trapezius muscle by using prisms. Roy (1961)[15] and Roca (1972)[16] demonstrated visual disorders in whiplash subjects. Recently, other authors (Treleaven et al.)[17,18] reported the presence of visual symptoms in subjects with cervical complaints and neck pain. Similarly, patients with cervical complaints also reported visual symptom disorders. Brown[19] described an eye-sympathetic innervation dysfunction in whiplash patients that led to a disturbance in accommodation. Some authors [13] examined the possibility of a visual disorder triggering a cervical problem. Domkin et al.[13] claimed that a sustained contraction of the ciliary muscles increased the activation level of the trapezius, and this condition contributed to musculoskeletal pain complaints in the neck area.

Additionally, a visual disorder may produce a postural adaptation to maintain binocularity and visual comfort. This adaptation could lead to problems in the patient's neck region. Zhang et al.[20] observed an anomalous head posture in a group of children with reduced horizontal fusion range in both directions (convergence and divergence). The narrow binocular viewing field was compensated for by a rotation of the head. Several variations were observed in the measurement techniques used in different studies. Some authors used questionnaires to record the subjects' symptoms with a self-report system. [4,21] Others analyzed neck musculature at the same time that the visual system was altered. [5–7] Some investigators specifically determined visual system variables and tried to establish a relationship between the presence of visual dysfunction and the nature of cervical ailments. [11]

The subject has caught the interest of the scientific community, optometrists, ophthalmologists, and physiotherapists. However, there is a lack of homogeneity in the research, possibly due to its multidisciplinary nature. We recognized the need to conduct a systematic review and meta-analysis to study the accumulating evidence.

The objective of the systematic review and meta-analysis was to establish the relationship between visual system disorders and musculoskeletal discomfort related complaints in the neck. Additionally, we analyzed the risk of bias assessment and publication certainty in all included studies.

2. Methods

This systematic review was carried out according to Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA).[22,23] The review protocol is available in PROSPERO with the CRD42018112771 registration code. The PRISMA checklist is available as a supplementary file (Fig 1).

2.1 Eligibility criteria

A record was made of all articles published in English that examined the relationship between the neck region (chronic neck pain, whiplash, and healthy subjects) and the visual system in adult study populations. Comparison of the studies included accommodation, binocular system, and neck muscle activity measurements. The inclusion criteria did not stipulate the number or type of groups in the study. All results and all types of studies from 1961 to 2019 were included, but a specific follow-up period was not established. Only published works were included, regardless of whether the publication was online or in paper format.

2.2 Study search and selection

The following databases were searched: Cumulative Index to Nursing and Allied Health Literature (CINAHL), Cochrane Central Register of Controlled Trials (Central), Cochrane Central Register of Controlled Trials CENTRAL Plus, EMBASE, PubMed, PsycINFO, Scopus SPORT Discus, Web of Science, Clinicaltrial.gov, International Standard Randomized Controlled Trials Number (ISRCTN), and OpenGrey. The search strategy was the same for all databases. Eligibility assessment was performed independently in an unblinded, standardized manner by two reviewers. Disagreements between reviewers were solved by consensus. Weighted kappa qualitative method [24,25] comparisons appear in Table 1. Weighted kappa methodology is described by McHugh, [25] and the study selection process is represented in a flow chart (Fig 2). We

2.5 Data analysis

Data analysis was conducted using Revman 5.3.[29] It included mean and standard deviation (SD) in variables with normal distribution and median with interquartile range in variables with non-normal distribution. The differences between groups with neck pain complaints and control groups were described, and the statistical significance was expressed in terms of P-value. Effect sizes were not included. When the articles had homogeneous methodologies, a meta-analysis was performed. Heterogeneity was studied by an I^2 statistics test. [30] In addition, the authors chose between fixed- and random-effects models. [31] Evidence of publication bias was studied, according to Begg and Egger test results.

3. Results

The literature search was conducted in January 2019 and yielded 745 studies among all the databases. Duplicate results were eliminated. The search strategy was reflected in the systematic review registration. The flow chart representing the selection process is shown in Fig 2. Subsequently, 42 articles were evaluated in the full-text stage, and 21 items were excluded for reasons stated in Fig 2. All the documents were located through the University of Seville documentary register.

3.1 Study characteristics

Of the twenty-one articles included, three groups were distinguished due to neck system classification. One study[32] was not included in any group described below as it did not detail the subject's inclusion criteria.

3.1.1 Chronic neck pain group (ten studies)

Three studies were case control studies. [5,6,9] One study was case series study. [8] Three studies were observational cohort and cross-sectional studies. [11,12,33] Two studies were controlled interventional studies. [7,10] One study was a controlled randomized trial. [34] The studies included 547 subjects and were published between 2010 and 2019.

3.1.2 Whiplash group (six studies)

Five studies were case series studies. [15,16,19,35,36] One study was an observational cohort study. [37] The studies included 171 subjects and were published between 1961 and 2018.

3.1.3 Healthy subjects' group (four studies)

Three studies were case series studies. [13,38,39] One study was a controlled interventional study. [40] The studies included 57 subjects and were published between 2012 and 2016.

3.2 Synthesis of results

The analysis of the results reported for the twenty-one included studies from a qualitative point of view. Analyses were made from the optometric viewpoint (Table 3) and the perspective of physiotherapy (Table 4).

A meta-analysis of the accommodation response with binocular lenses –3.50 D yielded a mean difference of 0.59 D between the neck pain group and the control group (95% CI: –0.07 to 1.24), representing a descriptive increased tendency in accommodation response in the neck pain group, but not a statistically significant difference. Heterogeneity was very low (I^2 = 0%). A meta-analysis of the accommodation response with a monocular lens –3.50 D yielded a mean difference of 0.49 D between the neck pain group and the control group (95% CI –0.11 to 1.10), representing a descriptive increased tendency, but not a statistically significant difference in accommodation response in the neck pain group. Heterogeneity was very low (I^2 = 0%). A meta-analysis of the accommodation response with a monocular lens 0.00 D yielded a mean difference of 0.03 D between both groups (95% CI: –0.21 to 0.26), representing a non-statistically significant difference for any group. Heterogeneity was very low (I^2 = 0%). The four meta-analyses of the accommodation response (with monocular lens +3.50 D) yielded –0.01 D between both groups (95% CI: –0.32 to 0.30), representing a non-statistically significant difference for any group. Heterogeneity was very low (I^2 = 0%). Finally, the last meta-analysis of the Convergence Insufficiency Symptom Survey (CISS CI) symptom score yielded a mean significance difference of 8.36 points between the neck pain and the control groups (95% CI: 5.48 to 11.23). All meta-analyses are shown in Fig 3.

3.3 Risk of bias

Quality assessment tools were used for all studies, barring Lundqvist et al.[34] The risk-of-bias summary of the controlled clinical trial showed low risk in six of seven points (Fig 4). After quality assessment analysis, we found the following items: (1) All case-control studies[5,6,9] achieved five of twelve positive items. None received negative item (they were not reported or could not be determined with the available information) (Table 5). (2) One case series study[36] obtained one of nine positive items, two case series studies[16,35] achieved three of nine positive items, two case series studies[15,38] attained four of nine positive items, three case series studies[8,19,39] scored six of nine positive items, and, finally, one case series study[13] got a very low risk of bias with eight of nine positive items (Table 6). (3) One observational cohort and cross-sectional study[37] achieved four of twelve positive items, and the other three studies[11,12,33] attained five of twelve positive items (Table 7). (4) Finally, two controlled interventional studies[32,40] achieved three of fourteen positive items; one controlled interventional study[7] got four of fourteen positive items; and the last controlled interventional study, [10] obtained five of fourteen positive items with the quality assessment tool (Table 8).

Table. 9 shows a general summary of the risk of bias. It also demonstrates the relationship between trapezius muscle activity, the neck region, and optometry variables. According to the results offered by the Begg and Egger tests (p >0.05), there was no statistical evidence of publication bias.(also apparent in the funnel plot (Fig 5)). In this figure, we included three studies from Figure 5A to 5D and two studies from Figure 5E. The validity of these results is limited due to low sample size. These were the only studies included in the meta-analysis due to a lack of uniformity in methodologies. Sensitivity analysis indicated that no study substantially modified the overall results when eliminating it.

4. Discussion

4.1 Main findings

All studies have shown a relationship between the visual and the musculoskeletal system of the neck. On the one hand, the authors have established a relationship between accommodation and the cervical region. However, most of the reviewed work did not determine whether ocular accommodation affects cervical conditions. The objective was to investigate whether an increase in the ciliary muscle contraction strength increases trapezius muscle activity. These studies measured accommodation by the insertion of positive, neutral, or negative lenses at the same time as the trapezius activity was measured. Therefore, these studies did not determine the initial patient accommodation state. [5–10,32,39,40] They created a visually demanding situation and claimed that a sustained ciliary muscle contraction could lead to complaints in the cervical region. [13]

Some other authors[11] determined an accommodative function state through a test that demonstrated high repeatability and established a relationship between accommodative dysfunctions and neck complaints.

Other investigators observed a relationship between binocular vision and the neck system. Sánchez-González et al.[12] evaluated a binocular vision status and confirmed relationship between non-strabismic binocular dysfunctions and musculoskeletal neck disorders. Giffard et al.[33] showed a relationship between convergence insufficiency and cervical pain. Matheron et al. [38] reported a rotation of the head in an attempt to compensate for the vertical deviation produced by a prism placed in front of the eye.

Finally, we found only one controlled randomized clinical trial that fit the inclusion criteria. [34] It described the Feldenkrais efficacy method in patients with chronic neck pain and visual dysfunction. The method was based on a learning process that develops the awareness and intelligence of the moving body.

In this systematic review and meta-analysis, we found authors who had included whiplash subjects in their studies. Brown[19] stated that whiplash subjects experienced sympathetic innervation eye effects. The study assumed a sympathetic–parasympathetic balance alteration, and implied an accommodation disorder. Roy[15] described and quantified the alignment of visual axes in whiplash subjects.

Other authors reported accommodative and vergence disorders in whiplash subjects. Roca[16] and Burke et al.[35] claimed that convergence and accommodation are reduced in whiplash subjects. Hughes et al.[36] suggested that the next point of convergence was regular and reported one accommodation spasm in the same subject with whiplash. Stiebel-Kalish et al [37] stated that whiplash subjects presented convergence insufficiency and accommodative disorder symptoms.

4.2 Strengths and limitations

To our knowledge, this systematic review and meta-analysis are the first to compare studies that establish a relationship between the visual and the musculoskeletal system of the neck. This systematic review and meta-analysis revealed the differences in opinion among the authors. A lack of consensus was found in the neck system inclusion criteria and visual system measurement method.

Of the 11 articles that established a relationship between accommodation and the neck system, four meta-analyses were performed using three of them[5,6,10]. The first and second analyses showed that the introduction of binocular and monocular negative lenses of –3.50 D increased the accommodation response by 0.59 D [–0.07 to 1.24] and 0.49 D [–0.11 to 1.10], respectively. The third and fourth meta-analyses indicated that the accommodation response was unaffected when monocular neutral lenses were introduced. The accommodation response did not vary while introducing monocular positive +3.50 D lenses, –0.01 D [–0.32 to 0.30] and the change was 0.03 D [–0.21 to 0.26].

The overall evidence strength assessment made with GRADEpro showed low-quality evidence of accommodative response with monocular and binocular –3.50 D lenses inserted. In addition, evidence of moderate quality between neck complaints and accommodative response with +3.50 D and neutral monocular lenses was observed (Fig 6).

A fifth meta-analysis conducted between the two studies [33,37] showed that in patients with neck complaints, the convergence insufficiency symptom score increased by 8.36 points [5.48–11.23]. The overall assessment of evidence strength with GRADEpro showed high-quality evidence of visual symptoms in the convergence insufficiency symptom score (Fig 6).

Regarding the limitations of this systematic review, most of the studies demonstrated a moderate methodological quality. Only one high-quality trial was found. Only five meta-analyses could be performed, owing to heterogeneity in measurement methods. The inclusion of five articles in the meta-analysis is a major limitation of this systematic review. The meta-analyses confirm a relationship between systems, visual and the musculoskeletal system of the neck. As the results are based on the evaluation of five studies, they should be interpreted with caution.

4.3 Conclusions and implications

Based on the qualitative assessment performed, the systematic review and meta-analysis revealed that all included studies confirmed a relationship between the visual and the musculoskeletal system of the necks, but demonstrated a lack of uniformity in the measurement methods of the visual system.

There is some evidence to use the accommodation response to diagnose the accommodative system. The accommodative response allows establishing the plane of focus of the subject for the accommodative stimulus. This allows us to determine if there is an over-accommodation or under-accommodation. [41] However, studies that accurately assessed the accommodative and vergence systems were missing.

Further research is needed with suitably designed studies that allow a comprehensive evaluation of the accommodative and vergence systems. This implies the application of tests with high repeatability to prove the relationship between accommodative and vergence dysfunction and the musculoskeletal system of the neck.

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Competing interest

The authors whose names are listed immediately below certify that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements) or nonfinancial interest (such as personal or professional relationships, affiliations, knowledge, or beliefs) in the subject matter or materials discussed in this manuscript.

María Carmen Sánchez-González, Estanislao Gutiérrez-Sánchez, José-María Sánchez-González, Manuel Rebollo-Salas, Carmen Ruiz-Molinero, José Jesús Jiménez-Rejano and Verónica Pérez-Cabezas

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Figure Legends

Figure 1 (supplementary): PRISMA Checklist.

Figure 2: Flow chart.

Figure 3: Forest plots of the comparison of the difference between the neck pain group and control group in; (A) Accommodation Response with binocular lenses of -3.50 D, (B) Accommodation Response with monocular lens of -3.50 D, (C) Accommodation Response with monocular lens of 0.00 D, (D) Accommodation Response with monocular lens of +3.50 D. (E) Convergence Insufficiency Symptoms Survey symptom score (/60).

Figure 4 (supplementary): Risk-of-bias assessment of controlled randomized controlled trials assessed with the modified Cochrane tool.

Figure 5: Funnel plots; (A) Accommodation Response with binocular lenses of -3.50 D, (B) Accommodation Response with monocular lens of -3.50 D, (C) Accommodation Response with monocular lens of 0.00 D, (D) Accommodation Response with monocular lens of +3.50 D. (E) Convergence Insufficiency Symptoms Survey symptom score (/60).

Figure 6: Quality evidence diagram with GRADEpro development tool .

Table 1 (supplementary): Reliability assessment of the eligibility criteria as assessed using the weighted Kappa statistic.

Table 2: Study characteristics and patient population.

Table 3: Optometric data extraction.

Table 4: Physiotherapy data extraction.

Table 5 (supplementary): Quality Assessment Tool for Case Control Studies.

Table 6 (supplementary): Quality Assessment Tool for Case Series Studies.

Table 7 (supplementary): Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies.

Table 8 (supplementary): Quality Assessment Tool for Controlled Interventional Studies.

Table 9: Methodological studies quality and results obtained on: (1) neck pain with accommodation. (2) neck pain with vergences and (3) neck pain with other visual disorders.

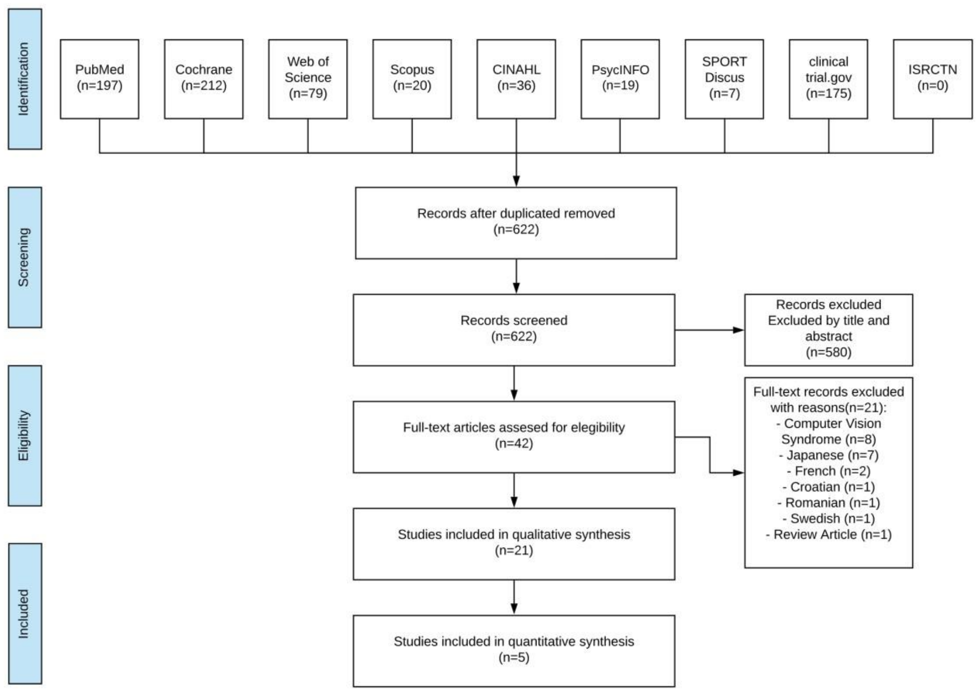

Figure 2: Flow chart.

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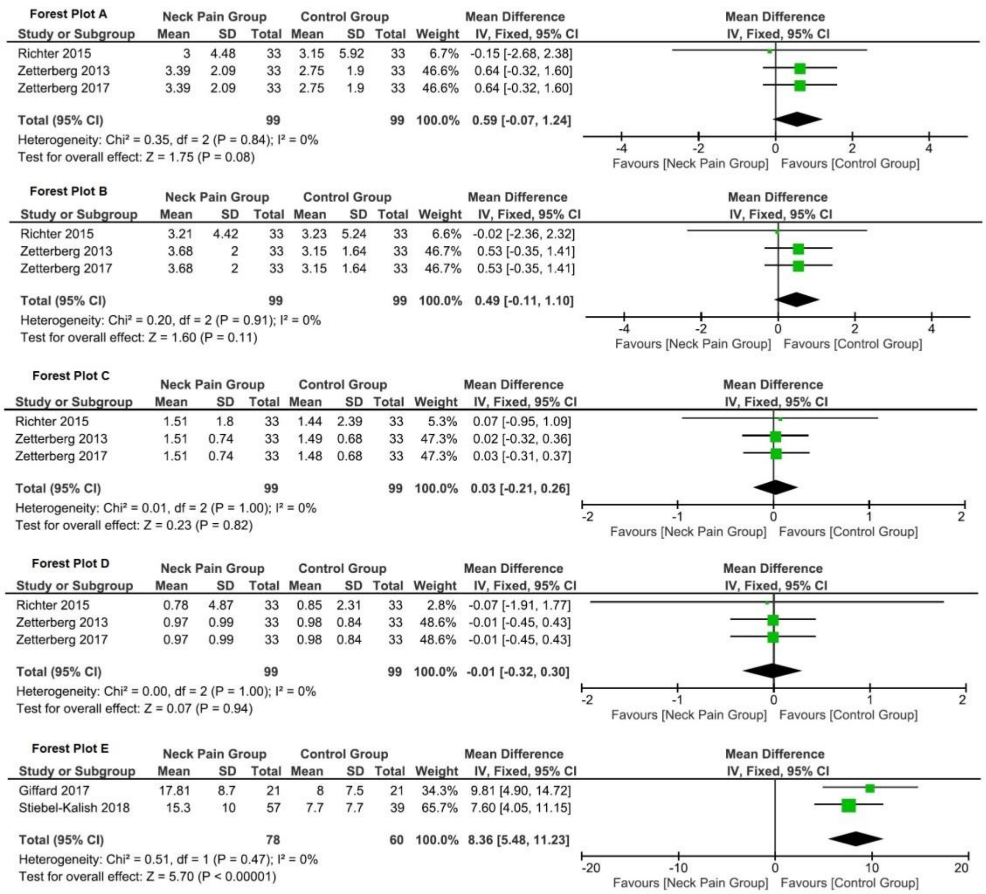

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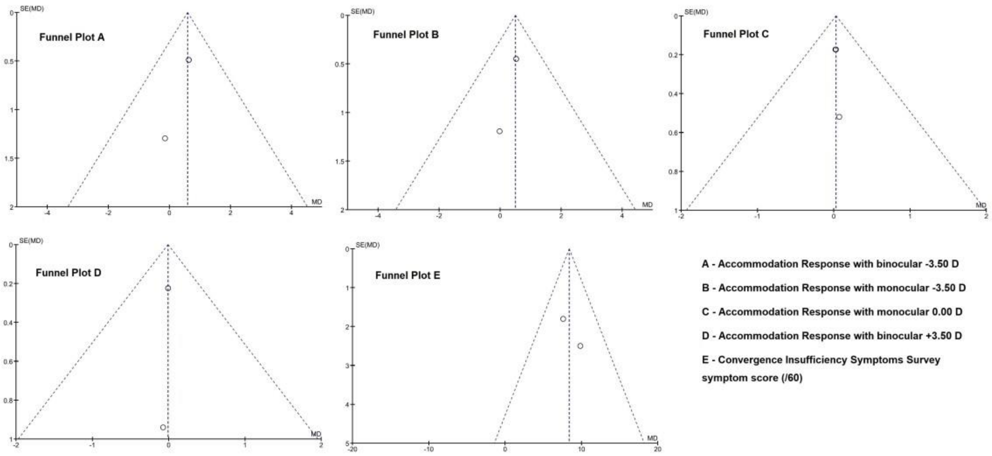

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Certainty assessment							№ of patients		Effect		Certainty
№ of studies	Study design	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	Neck Pain Group	Control Group	Relative (95% CI)	Absolute (95% CI)	
Accommodation Response with binocular lenses -3.50 D (assessed with: Autorefractometer)											
3	Prospective Experimental and Case Control Study	serious [a]	serious [b]	not serious	not serious	none	99	99	-	MD **0.59 D higher** (0.07 lower to 1.24 higher)	⊕⊕◯◯ LOW
Accommodation Response with monocular lens -3.50 D (assessed with: Autorefractometer)											
3	Prospective Experimental and Case Control Study	serious [a]	serious [b]	not serious	not serious	none	99	99	-	MD **0.49 D higher** (0.11 lower to 1.1 higher)	⊕⊕◯◯ LOW
Accommodation Response with monocular lens 0.00 D (assessed with: Autorefractometer)											
3	Prospective Experimental and Case Control Study	serious [a]	not serious	not serious	not serious	none	99	99	-	MD **0.03 D higher** (0.21 lower to 0.26 higher)	⊕⊕⊕◯ MODERATE
Accommodation Response with monocular lens +3.50 D (assessed with: Autorefractometer)											
3	Prospective Experimental and Case Control Study	serious [a]	not serious	not serious	not serious	none	99	99	-	MD **0.01 D lower** (0.32 lower to 0.3 higher)	⊕⊕⊕◯ MODERATE
Convergence Insufficiency Symptoms (assessed with: Survey Symptom Score (/60))											
2	Comparative cross-sectional observational and Prospective cohort study	not serious	not serious	not serious	not serious	none	78	60	-	MD **8.36 Points higher** (5.48 higher to 11.23 higher)	⊕⊕⊕⊕ HIGH

CI: Confidence interval; **MD:** Mean difference

Explanations

a. Most studies demonstrated a high risk of bias in more than one area of methodology

b. Significant heterogeneity but the direction of control group is consistent

Figure 6: Quality evidence diagram with GRADEpro development tool

279x215mm (200 x 200 DPI)

Table 2: Study characteristics and patient population

Chronic neck pain group									
Author	Study design	Conflict of interest	Inclusion criteria	Exclusion criteria	Follow-up	Subjects (% Male)	N (Patients)	Age (years)	Groups (n)†
Richter et al[8] (2010)	Retrospective Case Series	No competing interest	Chronic work-related myalgia and/or professional oculomotor near-work problems	gaze position exceeded 25° from the pupillary axis	2-3 months	35,7	28	29	1 – Symptoms free (15) 2- vision disorders and neck pain (13)
Richter at al[7] (2011)	Prospective Experimental Study	Not described	Symptom of strain, weakness or fatigue from the eyes and non-specific neck disorders	Not described	None	35,7	28	29	1 – Symptoms free (10) 2- vision disorders and neck pain (18)
Zetterberg et al[10] (2013)	Prospective Experimental Study	No competing interest	Experience of neck/shoulder pain during the last 12 weeks, and 10–68 points on the Neck Disability Index	Eye diseases	7 min	18.18%	66	38	1 – Neck pain (33) 2 – Control (33)
Lundqvist et al[34] (2014)	Randomized controlled trial	Not described	neck/scapular complaints	Traumatic origin or comorbidity of musculoskeletal- related disorders	12 months	16,3	61	53,3	1 – Treatment (30) 2 – Control untreated (31)
Richter et al[6] (2015)	Case Control Study	No competing interest	Corrected distance visual acuity > 1.0 decimal	Eye diseases	None	18,8	66	38	1 – neck pain (33) 2 – healthy control (33)
Zetterberg et al [9] (2015)	Case Control Study	No competing interest	normal vision, normal near point of accommodation and convergence, and no history of eye disease	The exclusion was due to noisy data from the auto refractor	None	34,6	26	29	1 – asthenopia and neck disorders (12) 2 – healthy control (14)
Giffard et al[33] (2017)	Comparative cross-sectional observational study	No competing interest	aged 18 to 65	Previous head injury or cervical dislocation/fracture, having diagnosed eye movement disorders or disease	15 weeks	24	42	31,6	1 – Neck Pain (21) 2 – Control (21)
Zetterberg et al[5] (2017)	Case Control Study	No competing interest	normal vision, normal near point of accommodation and convergence, and no history of eye disease	The exclusion was due to noisy data from the auto refractor	None	18,1	66	39	1 – neck pain (33) 2 – control group (33)
Sánchez-González et al [11] (2018)	Descriptive, cross-sectional, correlational study	No competing interest	All subjects had at least 20/20 visual acuity with their best correction and the absence of ocular motility defects,	History of head trauma, cervical fracture or surgery in this area, persons with intellectual disabilities or any problems that prevented	None	44.2	52	26	1 – Insufficiency (24) 2 – Normal (3) 3 – Excess (25)

			strabismus, nystagmus or amblyopia	them from completing the Neck Disability Index (NDI), or who suffered any type of degenerative disease or neurological alteration					
Sánchez-González et al [12] (2019)	Descriptive, cross-sectional, correlational study	No competing interest	All subjects had at least 20/20 visual acuity with their best correction and the absence of ocular motility defects, strabismus, nystagmus or amblyopia	History of head trauma, cervical fracture or surgery in this area, persons with intellectual disabilities or any problems that prevented them from completing the Neck Disability Index (NDI), or who suffered any type of degenerative disease or neurological alteration	None	45.5	112	39.8	1 – Inside the norm 2 – Outside the norm
Whiplash group									
Author	Study design	Conflict of interest	Inclusion criteria	Exclusion criteria	Follow-up	Subjects (% Male)	N (Patients)	Age (years)	Groups (n)†
Roy [15] (1961)	One Case Report	Not described	Whiplash car collision	None	8 months	0	1	26	None
Roca [16] (1972)	Case Report	Not described	Whiplash car collision	None	6 years	66,6	15	34.2	None
Burke et al[35] (1992)	Retrospective Longitudinal Case Series	Not described	Whiplash car collision	Non-contact injuries and head trauma	4 months	43,5	39	29.9	Cervical movements 1 – No loss 2 – Obvious reduction 3 – High reduced range
Brown [19] (2003)	Retrospective Case Series	Not described	Whiplash diagnosis 6/6 or better corrected distance visual acuity	Not described	From <1 to >6 years	31,5	19	38	1 – Whiplash 2 – Control (43)
Hughes et al[36] (2017)	One Case Report	No competing interest	Whiplash car collision	None	12 months	100	1	34	None
Stiebel-Kalish et al [37] (2018)	Prospective cohort study	No competing interest	Whiplash car collision	neurologic injuries or pre-existing lack of binocular vision (amblyopia, history or findings of strabismus, or ophthalmic disease precluding binocular vision)	None	43.9	96	37,2	1 – whiplash group (57) 2 – control group (39)
Healthy subjects' group									
Author	Study design	Conflict of interest	Inclusion criteria	Exclusion criteria	Follow-up	Subjects (% Male)	N (Patients)	Age (years)	Groups (n)†
Lodin et al[40] (2012)	Laboratory Study	Not described	No episodes of neck pain during the preceding three months	Not described	None	18,1	33	37	None

Domkin et al[13] (2016)	Case Series	No competing interest	Corrected to normal vision	Musculoskeletal complaints in neck, shoulders, arms or hands	None	41,6	12	23	None
Matheron et al[38] (2016)	Case Series	No competing interest	Healthy young subjects	Neurological, ophthalmological, or musculoskeletal symptoms or troubles (problems)	None	62,5	8	24	None
Richter et al[39] (2016)	Case Series	No competing interest	Corrected distance visual acuity > 1.0 decimal	Not described	None	50	4	46	None
Non-defined criteria study group									
Richter et al[32] (2012)	Prospective Experimental Study	Not described	Not described	Subjects with eye disease	None	Not described	66	36	None
† number of subjects in the group									

Table 3: Optometric data extraction

Author et al (year) — Chronic neck pain group - Optometric Measures

Author et al (year)	Measure	Binocular with -3.5 D	Binocular with 0.0 D	Binocular with +3.50 D	Binocular 1-2Δ BO
Richter et al[8] (2010)	**Amplitude of eye-lens accommodation (D)**	-3.04±1.64	-0.57±0.91	4.00±.094	-0.53±1.03

Author et al (year)	Measure	Binocular with -3.5 D	Binocular with 0.0 D	Measure	Binocular with -3.5 D	Binocular with 0.0 D
Richter et al[7] (2011)	**Response diopters (D)/ EMG (% RVE)**	r^2 = 0.25 p = 0.013	r^2 = 0.016 p = 0.563	**Accommodative error (D)/ EMG (% RVE)**	r^2 = 0.3686 p = 0.001	r^2 = 0.0018 p = 0.845

Author et al (year)	**Accommodation response (D)**	Binocular with -3.5 D	Monocular with -3.5 D	Monocular with 0.0 D	Monocular with +3.5 D
Zetterberg et al[10] (2013)	Neck pain	3.39 ± 2.09	3.68 ± 2.00	1.51 ± 0.74	0.97 ± 0.99
	Control	2.75 ± 1.90	3.15 ± 1.64	1.49 ± 0.68	0.98 ± 0.84

Author et al (year)	Measure	Total	Treatment Group	Control group
Lundqvist et al[34] (2014)	**Reading distance (cm) (at baseline) ΔP = 0.08**	28.9 ± 12.4	27.2 ± 11.5	30.8 ± 13.2
	VFQ-NAS (at baseline) ΔP = 0.18 (0-100)	54.3 ± 23.9	52.9 ± 22.5	55.6 ± 25.4

Author et al (year)	**Accommodation response (D)**	Binocular with -3.5 D	Monocular with -3.5 D	Monocular with 0.0 D	Monocular with +3.5 D
Richter et al[6] (2015)	Neck pain	3.00 (0.47 – 4.59)	3.21 (0.66 – 4.78)	1.51 (0.51 – 2.15)	0.78 (-0.34 – 2.51)
	Control	3.15 (0.38 – 5.25)	3.23 (0.29 – 5.09)	1.44 (0.21 – 2.29)	0.85 (0 – 1.67)

Author et al (year)	**Accommodation response (D)**	Binocular with 0.0 D		Binocular with -3.5 D		Binocular with +3.5 D	
		Near	Far	Near	Far	Near	Far
Zetterberg et al [9] (2015)	**Patients**	≈ 3 D	≈ 1.0 D	≈ 3.5 D	≈ 1.0 D	≈ 2.5 D	≈ 0.5 D
	Control	≈ 5 D	≈ 0.5 D	≈ 6 D	≈ 0.5 D	≈ 4.5 D	≈ 0.5 D

Author et al (year)	**Near Point Convergence (NPC) Break(cm)**	Neutral (p=0.73)	Left torsion (p=0.18)	Right torsion (p=0.11)	Average torsion (p= 0.13)	Left torsion difference (p=0.01)	Right torsion difference (p=0.02)	Torsion difference (p=0.01)
Giffard et al[33] (2017)	**Neck pain**	8.7 ± 2.2	9.8 ± 2.8	10.1 ± 3.4	9.9 ± 3.0	1.1 ± 1,1	1.4 ± 2.1	1.3 ± 1.6
	Control	8.4 ± 2.3	8.7 ± 2.4	8.6 ± 2.2	8.7 ± 2.3	0.3 ± 1.0	0.2 ± 0.8	0.3 ± 0.8
		VSS score (/168) (p<0.01)				**CISS score (/60) (p<0.01)**		
	Neck pain	21.05 ± 17.3				17.81 ± 8.7		
	Control	6.63 ± 6.1				8 ± 7.5		

Author et al (year)			Binocular with -3.5 D		Monocular with -3.5 D		Monocular with 0.0 D		Monocular with +3.5 D	
Zetterberg et al[5] (2017)	**Accommodation response (D)**	Neck	3.39 ± 2.09	(p=0.53)	3.68 ± 2.00	(p=0.53)	1.51 ± 0.74	(p=0.90)	0.97 ± 0.99	(p=0.72)
		Control	2.75 ± 1.90		3.15 ± 1.64		1.49 ± 0.68		0.98 ±	

						0.84
	BOR´s Scale internal eye discomfort (0-10)	Neck	3.0 (0 – 9.0)	2.0 (0 – 6.0)	2.0 (0 – 7.0)	3.0 (0 – 9.0)
		Control	2.0 (0 – 9.0)	2.0 (0 – 6.0)	1.5 (0 – 7.0)	2.0 (0 – 9.0)
	BOR´s Scale external eye discomfort (0-10)	Neck	3.0 (0 – 7.0)	2.5 (0.3 – 7.0)	2.0 (0. – 7.0)	2.5 (0 – 7.0)
		Control	0.5 (0 – 7.0)	1.0 (0 – 5.0)	1.0 (0 – 3.0)	1.0 (0 – 5.0)

	Characteristics of the variables that define accommodation		Classification of subjects according to normative values n (%)		
			Insufficiency	Normal	Excess
Sánchez-González et al [11] (2018)	AA RE	8.3 ± 2.7	28 (53.8)	22 (42.3)	2 (3.8)
	AA LE	8.5 ± 2.6	27 (51.9)	23 (44.2)	2 (3.8)
	AA BE	8.2 ± 2.6	28 (53.8)	23 (44.2)	1 (1.9)
	NRA	2.4 ± 0.8	21 (40.4)	23 (44.2)	8 (15.4)
	PRA	--2.3 ± 1.8	26 (50.0)	11 (21.2)	15 (28.8)
	AF RE	10.2 ± 4.4	6 (11.8)	39 (76.4)	6 (11.8)
	AF LE	9.9 ± 4.8	10 (19.6)	34 (66.7)	7 (13.7)
	AF BE	10.18 ± 4.57	2 (4.3)	35 (76.1)	9 (19.6)
	AR	0.1 ± 0.5	3 (5.8)	12 (23.1)	37 (71.2)

Sánchez-González et al [12] (2019)	Lateral Phoria (distance / near), Δ	-0.52 ± 2.18 / -5.52 ± 6.88
	NFV Distance (Break and Recovery), Δ	8.51 ± 2.28 / 4.50 ± 1.85
	NFV Near (Blur, Break and Recovery) , Δ	10.95 ± 4.56 / 17.11 ± 5.13 / 11.59 ± 4.66
	PFV Distance (Blur, Break and Recovery) , Δ	9.97 ± 4.51 / 17.29 ± 6.72 / 8.10 ± 4.58
	PFV Near (Blur, Break and Recovery) , Δ	11.00 ± 6.00 / 17.17 ± 7.46 / 9.74 ± 6.12
	Vergence Facility , cpm	9.49 ± 4.60
	Vertical Vergence Distance (Break and Recovery), Δ	3.18 ± 0.95 / 0.93 ± 0.78
	Vertical Vergence Near (Break and Recovery), Δ	3.54 ± 1.17 / 1.16 ± 0.85

Author et al (year)	Whiplash group - Optometric Measures				
Roy et al[15] (1961)	Distance phoria = 8Δ exophoria, near phoria = 3Δ exophoria, vertical phoria = 2Δ hyperphoria LE				
Roca et al[16] (1972)	Decreased accommodation and convergence (10), diplopia (7), vitreous detachment (1), hyperphoria (6), exotropia (7), ptosis (1) and tearing (3)†				
Burke et al[35] (1992)	Reduced accommodation (9), reduced convergence (9), abnormal eye movements (5), reduced stereoacuity (3), superior oblique paresis (2)†				
Brown [19] (2003)	**Accommodation BE media (D)**	<29 years (RE / LE)	30-39 years (RE / LE)	40-49Years (RE / LE)	>50 years (RE / LE)
	Whiplash	5.96 ± 2.85* / 5.50 ± 3.34	4.20 ± 2.45 / 4.55 ± 2.81	1.05 ± 0.41 / 1.05 ± 0.54	1.25 ± 0.50 / 0.83 ± 0.14
	Control	8.11 ± 3.16 / 8.09 ± 3.66	5.44 ± 1.13 / 5.96 ± 1.32	3.44 ± 1.33 / 3.28 ± 1.25	1.17 ± 0.49 / 1.21 ± 0.56
Hughes et al[36] (2017)	Accommodative amplitude (D)	RE → 10 LE → 8 and BE → 8			

<table>
<tr><td></td><td>Near point of convergence (cm)</td><td colspan="4">Near point of convergence → 6 cm</td></tr>
<tr><td rowspan="9">Stiebel-Kalish et al [37] (2018)</td><td></td><td colspan="2">Whiplash group</td><td colspan="2">Control group</td></tr>
<tr><td>Accommodative Amplitude (D) (p=0.41)</td><td colspan="2">9.15 ± 3.50</td><td colspan="2">8.75 ± 2.89</td></tr>
<tr><td>Distance heterophoria (Δ) (p=0.41)</td><td colspan="2">0.19 ± 2.32 EP</td><td colspan="2">0.31 ± 2.32 XP</td></tr>
<tr><td>Near heterophoria (Δ) (p=0.03)</td><td colspan="2">1.21 ± 3.70 XP</td><td colspan="2">3.21 ± 4.67 XP</td></tr>
<tr><td>Near point of convergence break (cm) (p=0.38)</td><td colspan="2">3.84 ± 4.49</td><td colspan="2">4.85 ± 5.16</td></tr>
<tr><td>Near point of convergence recovery (cm) (p=0.72)</td><td colspan="2">4.24 ± 6.53</td><td colspan="2">7.38 ± 8.01</td></tr>
<tr><td>Stereopsis (arc sec) (p=0.21)</td><td colspan="2">66 ± 71</td><td colspan="2">80 ± 112</td></tr>
<tr><td>CISS CI symptom score (/60) (p<0.001)</td><td colspan="2">15.3 ± 10.0</td><td colspan="2">7.7 ± 7.7</td></tr>
<tr><td>Meeting criteria for CI findings, % (p=0.90)</td><td colspan="2">7.0</td><td colspan="2">7.7</td></tr>
<tr><th>Author et al (year)</th><th colspan="5">Healthy subjects' group - Optometric Measures</th></tr>
<tr><td rowspan="4">Lodin et al[40] (2012)</td><td rowspan="2">Amplitude of eye-lens accommodation (D)</td><td>Binocular with -3.5 D</td><td>Monocular with -3.5 D</td><td>Monocular with 0.0 D</td><td>Monocular with +3.5 D</td></tr>
<tr><td>3.0 ± 2.0</td><td>3.3 ±1.8</td><td>1.4 ± 0.5</td><td>1.0 ± 0.8</td></tr>
<tr><td rowspan="2">Eye discomfort
Borg's CR-10 scale (0-10)</td><td>Binocular with -3.5 D</td><td>Monocular with -3.5 D</td><td>Monocular with 0.0 D</td><td>Monocular with +3.5 D</td></tr>
<tr><td>1.48 ± 1.69</td><td>1.31 ±1.09</td><td>1.69 ± 1.50</td><td>2.04 ± 1.79</td></tr>
<tr><td>Domkin et al[13] (2016)</td><td colspan="5">Visual task distance was constant at 40 cm (2.5 D)</td></tr>
<tr><td>Matheron et al[38] (2016)</td><td colspan="5">Simulated vertical heterophoria by a 2 D vertical prism</td></tr>
<tr><td rowspan="3">Richter et al[39] (2016)</td><td>Lens introduced</td><td>Binocular with 0.0 D</td><td colspan="2">Binocular with -1.5 D</td><td>Binocular with -3.5 D</td></tr>
<tr><td>Accommodation response (D)</td><td>No change</td><td colspan="2">No change</td><td>Decreased</td></tr>
<tr><td>Contrast Sensitivity (C)</td><td>No change</td><td colspan="2">No change</td><td>First increased, after decreased</td></tr>
<tr><th>Author et al (year)</th><th colspan="5">Non-defined criteria study group</th></tr>
<tr><td rowspan="2">Richter et al[32] (2012)</td><td rowspan="2">Amplitude of eye-lens accommodation (D)</td><td colspan="2">Binocular with -3.5 D</td><td colspan="2">Monocular with ± 0.0D</td></tr>
<tr><td colspan="2">0.98 ± 0.61</td><td colspan="2">1.46 ± 0.60</td></tr>
<tr><td colspan="6">Δ: prism diopter; LE: left eye; BE: both eyes; D: diopters; RE: right eye; BO: Base-out; EMG: electromyography; RVE: reference voluntary electrical activity; CR-10: category ratio-10; cm: centimeter; VFQ-NAS: The Visual Functioning Questionnaire - Near Activities Subscale; C: Contrast Sensitivity; NPC: near point convergence; VSS: Vancouver Scar Scale; CISS: Convergence Insufficiency Symptoms Survey; arc sec: arcsecond; CI: convergence insufficiency; AA: accommodative amplitude o accommodation amplitude; NRA: negative relative accommodation; PRA: positive relative accommodation; AF: accommodative facility; AR: accommodative response; NFV: negative fusional vergences; PFV: positive fusional response; cpm: cycles per minute</td></tr>
<tr><td colspan="6">†number of cases with the pathology *Mean ± SD</td></tr>
</table>

Table 4: Physiotherapy data extraction

Author et al (year)	Chronic neck pain group - Neck Measures				
Richter et al[8] (2010)	**Trapezius muscle activity (in %RVE)**	Binocular with -3.5 D	Binocular with 0.0 D	Binocular with +3.50 D	Binocular 1-2Δ BO
		9.143 RS y 5.143 LS	11.571 RS and 9.143 LS	7.00 BS	5.143 RS and 2.286 LS

Author et al (year)						
Richter et al[7] (2011)	**Response diopters (D)/ EMG (% RVE)**	Binocular with -3.5 D	Binocular with 0.0 D	**Accommodative error (D)/ EMG (% RVE)**	Binocular with -3.5 D	Binocular with 0.0 D
		$r^2 = 0.25$ p = 0.013	$r^2 = 0.016$ p = 0.563		$r^2 = 0.3686$ p = 0.001	$r^2 = 0.0018$ p = 0.845

Author et al (year)	**10th percentile EMG RMS values (in %RVE)**	Binocular with -3.5 D (vision task / rest)	Monocular with -3.5 D (vision task / rest)	Monocular with 0.0 D (vision task / rest)	Monocular with +3.5 D (vision task / rest)
Zetterberg et al[10] (2013)	Neck group	0.76 ± 0.55 / 0.56 ± 0.37	0.90 ± 1.37 / 0.66 ± 0.55	0.74 ± 0.93 / 0.63 ± 0.51	0.66 ± 0.44 / 0.66 ± 0.58
	Control	0.66 ± 0.67 / 0.49 ± 0.31	0.70 ± 0.58 / 0.45 ± 0.28	0.67 ± 0.79 / 0.41 ± 0.19	0.90 ± 0.95 / 0.37 ± 0.18

Author et al (year)	**Feldenkrais Method VAS (0-10cm) * P < 0.001**	Occipital left			Occipital right			Trapezius left		
		Baseline	Post treatment	1 year	Baseline	Post treatment	1 year	Baseline	Post treatment	1 year
Lundqvist et al[34] (2014)	Treatment	32.2 ± 23.4	33.0 ± 23.3	50.0 ± 28.3	30.8 ± 25.7	33.3 ± 27.3	32.2 ± 22.3	39.6 ± 29.4	40.1 ± 28.1	37.6 ± 27.3
	Control	25.8 ± 21.3	40.5 ± 23.9*	39.4 ± 22.3*	34.8 ± 23.7	44.2 ± 26.1*	47.2 ± 25.0*	27.5 ± 21.5	46.5 ± 26.0*	43.3 ± 23.8*
	Feldenkrais Method VAS (0-10cm) * P < 0.001	Trapezius right			Elevator scapulae left			Elevator scapulae right		
		Baseline	Post treatment	1 year	Baseline	Post treatment	1 year	Baseline	Post treatment	1 year
	Treatment	53.2 ± 28.5	52.5 ± 28.4	43.4 ± 28.2	42.1 ± 29.6	39.3 ± 29.3	54.9 ± 24.5	49.8 ± 28.0	50.0 ± 28.3	35.5 ± 26.1
	Control	39.7 ± 23.7	58.7 ± 22.6*	59.2 ± 23.1*	35.8 ± 26.4	41.8 ±19.6	42.7 ± 23.0	49.1 ± 23.8	55.3 ± 23.2	55.4 ± 24.5

Author et al (year)	**VMB-M (0-10)**	Baseline	Post treatment	1 year	**SF-36-BPS (0-100)**	Baseline	Post treatment	1 year
Lundqvist et al[34] (2014)	Treatment	6.8 ± 1.6	5.6 ± 1.7*	5.8 ± 1.7*	Treatment	46.9 ± 21.1	48.9 ± 22.7	47.6 ± 22.0
	Control	6.2 ± 1.6	5.8 ± 2.1	5.6 ± 2.2	Control	51.4 ± 28.5	52.9 ± 22.6	47.2 ± 23.0

Author et al (year)	**Trapezius muscle activity (in %RVE)**	Binocular with -3.5 D P < 0.001	Monocular with -3.5 D P < 0.001	Monocular with 0.0D P = 0.001	Monocular with +3.5 D P < 0.001
Richter et al[6] (2015)	Log EMG rest full 3 min	0.579 (0.271 – 0.887)	0.615 (0.410 – 0.819)	0.733 (0.408 – 1.057)	0.620 (0.297 – 0.944)

Author et al (year)	Variables	Neck disability index (NDI) (0-50)	Trapezius muscle activity (in %RVE)		
			0.0 lenses	-3.5 lenses	+3.5 lenses
Zetterberg et al [9] (2015)	**Patients**	9.3 ± 4.5 (3–20)	1.82 (0.79 - 2.86)	2.36 (0.72 - 3.99)	1.74 (0.28 - 3.21)
	Control	-	2.50 (0.84 - 4.16)	2.71 (1.08 - 4.35)	2.53 (0.98 - 4.09)

<table>
<tr><td rowspan="3">Giffard et al[33] (2017)</td><td>Variables</td><td colspan="2">Neck Pain VAS(0-10cm)
P < 0.01</td><td>NDI (%) (0-50)
P < 0.01</td><td colspan="2">NDI Reading item score (0-5)
P < 0.01</td><td>DHIsf (0-13)
P = 0.01</td><td colspan="2">Dizziness VAS(0-10cm)
P = 0.02</td></tr>
<tr><td>Neck pain</td><td colspan="2">34.81 ± 19.5</td><td>19.43 ± 7.0</td><td colspan="2">2.29 ± 1.7</td><td>11 ± 2.5</td><td colspan="2">8.91 ± 18.8</td></tr>
<tr><td>Control</td><td colspan="2">1.24 ± 4.0</td><td>1.33 ± 2.3</td><td colspan="2">0.1 ± 0.4</td><td>12.81 ± 0.5</td><td colspan="2">0.67 ± 3.1</td></tr>
<tr><td rowspan="9">Zetterberg et al[5] (2017)</td><td>Trapezius muscle activity (in %RVE)</td><td colspan="2">Binocular with -3.5 D</td><td colspan="2">Monocular with -3.5 D</td><td colspan="2">Monocular with 0.0 D</td><td colspan="2">Monocular with +3.5 D</td></tr>
<tr><td>Neck</td><td>0.21 ± 0.43</td><td rowspan="2">(p = 0.29)</td><td>0.24 ± 1.37</td><td rowspan="2">(p=0.11)</td><td>0.12 ± 0.96</td><td rowspan="2">(p= 0.13)</td><td>0.00 ± 0.59</td><td rowspan="2">(p= 0.02)</td></tr>
<tr><td>Control</td><td>0.17 ± 0.64</td><td>0.26 ± 0.55</td><td>0.27 ± 0.79</td><td>0.53 ± 0.89</td></tr>
<tr><td>Borg´s Scale Neck/shoulder discomfort (0-10)</td><td colspan="2">Binocular with -3.5 D</td><td colspan="2">Monocular with -3.5 D</td><td colspan="2">Monocular with 0.0 D</td><td colspan="2">Monocular with +3.5 D</td></tr>
<tr><td>Neck</td><td colspan="2">3.0 (1.0–9.0)</td><td colspan="2">3.0 (0.5–10.0)</td><td colspan="2">3.0 (1.0–10.0)</td><td colspan="2">3.0 (0.5–9.0)</td></tr>
<tr><td>Control</td><td colspan="2">1.0 (0–6.0)</td><td colspan="2">1.5 (0–5.0)</td><td colspan="2">1.5 (0–7.0)</td><td colspan="2">2.0 (0–5.0)</td></tr>
<tr><td>Heart rate variability</td><td colspan="2">Binocular with -3.5 D</td><td colspan="2">Monocular with -3.5 D</td><td colspan="2">Monocular with 0.0 D</td><td colspan="2">Monocular with +3.5 D</td></tr>
<tr><td>Neck</td><td>41.2 ± 29.7</td><td rowspan="2">(p = 0.07)</td><td>39.4 ± 28.1</td><td rowspan="2">(p = 0.03)</td><td>41.4 ± 29.5</td><td rowspan="2">(p = 0.20)</td><td>40.9 ± 29.3</td><td rowspan="2">(p = 0.11)</td></tr>
<tr><td>Control</td><td>44.4 ± 14.8</td><td>43.7 ± 13.6</td><td>42.7 ± 13.9</td><td>42.5 ± 13.8</td></tr>
<tr><td rowspan="10">Sánchez-González et al [11](2018)</td><td colspan="4">NDI, 0-50</td><td colspan="5">5.7 ± 5.8</td></tr>
<tr><td colspan="4">AS</td><td colspan="5">5.1 ± 3.1</td></tr>
<tr><td colspan="4">PI</td><td colspan="5">14.1 ± 15.6</td></tr>
<tr><td colspan="4">VAS, 0–10 cm</td><td colspan="5">2.7 ± 2.7</td></tr>
<tr><td colspan="4">Flexion, degrees</td><td colspan="5">52.4 ± 10.9</td></tr>
<tr><td colspan="4">Extension, degrees</td><td colspan="5">65.9 ± 14.2</td></tr>
<tr><td colspan="4">RSB, degrees</td><td colspan="5">41.6 ± 8.5</td></tr>
<tr><td colspan="4">LSB, degrees</td><td colspan="5">46.2 ± 10.2</td></tr>
<tr><td colspan="4">RR, degrees</td><td colspan="5">66.7 ± 10.3</td></tr>
<tr><td colspan="4">LR, degrees</td><td colspan="5">70.9 ± 11.1</td></tr>
<tr><td rowspan="11">Sánchez-González et al [12] (2019)</td><td colspan="4">Cervicalgia (Yes / No), n (%)</td><td colspan="5">67 (60.4%) / 44 (39.6%)</td></tr>
<tr><td colspan="4">NDI, 0-50</td><td colspan="5">6.37 ± 6.32</td></tr>
<tr><td colspan="4">AS</td><td colspan="5">4.43 ± 3.06</td></tr>
<tr><td colspan="4">PI</td><td colspan="5">10.84 ± 12.71</td></tr>
<tr><td colspan="4">VAS, 0–10 cm</td><td colspan="5">2.67 ± 2.78</td></tr>
<tr><td colspan="4">Flexion, degrees</td><td colspan="5">50.48 ± 10.78</td></tr>
<tr><td colspan="4">Extension, degrees</td><td colspan="5">60.79 ± 14.60</td></tr>
<tr><td colspan="4">RSB, degrees</td><td colspan="5">38.59 ± 8.98</td></tr>
<tr><td colspan="4">LSB, degrees</td><td colspan="5">42.94 ± 10.38</td></tr>
<tr><td colspan="4">RR, degrees</td><td colspan="5">63.49 ± 10.77</td></tr>
<tr><td colspan="4">LR, degrees</td><td colspan="5">67.15 ± 12.08</td></tr>
</table>

Author et al (year)	Whiplash group - Neck Measures					
Roy [15] (1961)	Patients had whiplash					
Roca [16] (1972)	Patients had whiplash					
Burke et al[35] (1992)	Patients had whiplash					
Brown [19] (2003)	Patients had whiplash					
Hughes et al[36] (2017)	Patients had whiplash					
Stiebel-Kalish et al [37] (2018)	Quebec Task Force Grading Scale Grade (0-4)	Grade 0	Grade 1	Grade 2	Grade 3	Grade 4
		7 (12.3) %	46 (80.7) %	4 (7.0) %	0 (0.0) %	0 (0,0) %
Author et al (year)	**Healthy subjects' group - Neck Measures**					
Lodin et al[40] (2012)	**Neck/shoulder discomfort Borg's CR-10 scale (0-10)**	Binocular with -3.5 D	Monocular with -3.5 D	Monocular with 0.0 D	Monocular with +3.5 D	
		1.05 ± 1.21	1.32 ± 1.06	2.01± 1.79	2.10 ± 1.32	
Domkin et al[13] (2016)	**Trapezius muscle EMG activity**	The trapezius muscle EMG activity on the right side was significantly higher than on the contralateral side (paired samples t-test, p < 0.01)				
Matheron et al[38] (2016)	**Head rotation**	Head left rotation (normal vision) > Head right rotation (normal vision) (p = 0.049) Head left rotation (2-diopter vertical dominant eye) < Head left rotation (normal vision) (p = 0.011) Head left rotation (2-diopter vertical non-dominant eye) < Head left rotation (normal vision) (p = 0.011)				
Richter et al[39] (2016)	Lens introduced	Binocular with 0.0 D	Binocular with -1.5 D	Binocular with -3.5 D		
	Baseline-subtracted DLPFC activity (ΔHbO2)	Increased	Increased	Increased		
Author et al (year)	**Non-defined criteria study group**					
Richter et al[32] (2012)	**Trapezius muscle activity (in %RVE)**	HOL-group binocular with -3.5 D (p=0.015)	HOL-group monocular with ± 0.0D (p=0.002)			
		0.929 + time (min) x 0.04	0.926 + time (min) x 0.088			
RVE: reference voluntary electrical activity; D: diopters; BO: Base-out; RS: right shoulder; LS: left shoulder; EMG: electromyography: CR-10: category ratio-10E; HOL: high-oculomotor-load; RMS: root-mean-square; VAS: visual analogue scale; VMB-M: visual, musculoskeletal and balance symptoms; SF-36-BPS: short form health survey; NDI: neck disability index; DLPFC: dorsolateral prefrontal cortex; ΔHbO2: oxy-hemoglobin predicted change; DHIsf: short form of the dizziness handicap inventory; cm: centimeter; AS: activation score; PI: performance index of deep cervical musculature; RSB: right-side bending; LSB: left-side bending; RR: right rotation; LR: left rotation.						
*Mean ± SD						

Table 9: Methodological studies quality and results obtained on: (1) neck area with accommodation. (2) neck area with vergences and (3) neck area with other visual disorders.

Study (Author et al.)	Quality Assessment Tool	Neck Area with accommodation	Neck Area with vergences	Neck Area with other visual disorder
Case Control Studies (/12)				
Richter et al [6] (2015)	5 / 12	X	O	O
Zetterberg et al [9] (2015)	5 / 12	X	O	O
Zetterberg et al [5] (2017)	6 / 12	X	O	O
Case Series Studies (/9)				
Roy [15] (1961)	4 / 9	O	X	O
Roca [16] (1972)	3 / 9	X	X	O
Burke et al [35] (1992)	3 / 9	X	X	O
Brown [19] (2003)	6 / 9	X	O	O
Richter et al [8] (2010)	6 / 9	X	O	O
Domkin et al [13] (2016)	8 / 9	X	O	O
Matheron et al [38] (2016)	4 / 9	O	X	O
Richter et al [39] (2016)	6 / 9	X	O	O
Hughes et al [36] (2017)	1 / 9	X	X	O
Observational Cohort and Cross-Sectional Studies (/12)				
Giffard et al [33] (2017)	5 / 12	O	X	O
Stiebel-Kalish et al [37] (2018)	4 / 12	X	X	O
Sánchez-González et al [11] (2018)	5 / 12	X	O	O
Sánchez-González et al [12] (2019)	5 / 12	O	X	O
Controlled Interventional Studies (/14)				
Richter et al [7] (2011)	4 / 14	X	O	O
Lodin et al [40] (2012)	3 / 14	X	O	O
Richter et al [32] (2012)	3 / 14	X	O	O
Zetterberg et al [10] (2013)	5 / 14	X	O	O
Controlled Clinical Trial				
Lundqvist et al [34] (2014)	6 / 7 [a]	O	O	X
[a] Risk of bias summary for Controlled Clinical Trial from Review Manager 5.3 (Cochrane)				

X: Authors found relationship between both systems.
O: Authors did not find relationship between both systems.