UTILITY OF SUPPRESSION HEAD IMPULSE PARADIGM IN IDENTIFYING VARIOUS PERIPHERAL VESTIBULAR DISORDERS: A SYSTEMATIC REVIEW

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A Dissertation Submitted in Part Fulfilment of the Degree of

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August 2022

CERTIFICATE

This is to certify that this dissertation entitled "**Utility of Suppression head Impulse Paradigm (SHIMP) in identifying various peripheral vestibular disorders: A systematic review**" is a bonafide work submitted in part fulfilment for the degree of Master of Science (Audiology) of the student with Registration Number 20AUD018. This has been carried out under the guidance of the faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru

August, 2022

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CERTIFICATE

This is to certify that this dissertation entitled "**Utility of Suppression head Impulse Paradigm (SHIMP) in identifying various peripheral vestibular disorders: A systematic review**" has been prepared under my supervision and guidance. It is also certified that this dissertation has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled "**Utility of Suppression head Impulse Paradigm (SHIMP) in identifying various peripheral vestibular disorders: A systematic review**" is the result of my own study under the guidance of Dr. Sujeet Kumar Sinha, Associate Professor, Department of Audiology, All India Institute of Speech and Hearing, Mysuru, and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru,
August, 2022

Registration No.
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Dedicated to

All my TEACHERS and PROFESSORS

for

enlightening knowledge

and guiding me through the right path

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"God cannot be present everywhere, so he created parents."
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"Better than a thousand days of diligent study is one day with a great teacher."
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ABSTRACT

Introduction: The vestibulo-ocular reflex (VOR) is a gaze stabilization reflex which ensures ocular stability by making fovea focus on the object of interest. The VOR is often affected in patients with various peripheral vestibular disorders. The video head impulse test (vHIT) is a widely used clinical tool for assessing the functional integrity of semicircular canals and their projections in various vestibular pathologies. vHIT has two paradigms: Head impulse paradigm (HIMP) and Suppression head impulse paradigm (SHIMP).

Aim: To systematically review the articles related to Suppression Head Impulse Paradigm (SHIMP) findings in patients with various peripheral vestibular pathologies.

Method: A review search was carried out initially in different databases. Searches across different databases resulted in 109 topic-related articles, of which 13 met the inclusion and exclusion criteria to meet the objectives of the study. The quality and potential risk associated with each article were evaluated using the QUADAS-2 risk of bias assessment tool.

Results: The results of all the studies indicate that the VOR gain is reduced on the side with the lesion. On the contra-lesional side (healthy side), the VOR gain is observed to be normal. This was consistent among peripheral pathologies such as vestibular neuritis, unilateral and bilateral hypofunction, and vestibular schwannoma. The VOR gain aids in ruling out the extent of vestibular damage, course of the disease, central compensation, recovery process, and prognosis of vestibular rehabilitation. Across studies, it was consistent that there is no or significantly limited occurrence of anti-compensatory saccades in patients with various peripheral vestibular pathologies. The aspects of anti-compensatory saccade measures such as frequency of occurrence, peak-saccadic

velocities, and the ratio of saccadic velocity to head velocity of the anti-compensatory saccades are demonstrated across various studies that have affirmed the utility of this measure in arriving at a clinical diagnosis in patients with peripheral vestibular disorders.

Conclusion: The Suppression Head Impulse Paradigm (SHIMP) is valuable in providing insight into various peripheral vestibular pathologies. When administered along with the HIMP and other significant test tools, SHIMP offers useful information that aids in arriving at a clinical diagnosis. It is always recommended to administer both SHIMP and HIMP as they complement each other. The SHIMP VOR gain and the anti-compensatory saccades are the most crucial parameters that help diagnose various peripheral vestibular pathologies.

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CHAPTER I

INTRODUCTION

Sense of equilibrium, spatial orientation, and/or kinesthetic awareness are mediated by our body's vestibular, visual and musculoskeletal systems. The vestibular system in the inner ear comprises the utricle and saccule, which senses linear acceleration, whereas the three semicircular canals perceive the angular acceleration. The vestibular system and various central neural projections have neural connections with the visual system. Thus, when head movements stimulate the vestibular end organs, it helps stabilize the image at the retina level, assisting in clear vision. The information sensed by these organs is carried to the central system, where the sensory inputs are processed by integrating the inputs and those from the visual and proprioceptive systems.

The vestibulo-ocular reflex (VOR), a gaze stabilizing reflex that converts sensory inputs encoding head movements into motor commands that cause compensatory conjugate eye movements in the opposing direction, preserving ocular stability. The VOR can be categorized into canal-mediated VOR (angualarVOR) and otolith-mediated VOR (translational VOR). To elicit the semicircular canal-induced VOR, brief, quick head movements are carried out in each canal's axis of rotation. This evokes an equal and opposite eye movement that makes the fovea focus on the object of interest. The impulse needs to be transient (≥100º/sec) to obtain pure VOR responses, thus eliminating the influence of the oculomotor in mediating the eye movement. The VOR is usually elicited 5-6 milli seconds after the onset of the head impulses (Angelaki & Cullen, 2008). This can be efficiently tested using the video-head impulse test (vHIT), also called the Halmagyi Curthoys test (MacDougall et al., 2009).

vHIT is a widely used clinical tool for assessing the functional integrity of semicircular canals and their projections. It provides clinically vital information and is one of the initial assessments done when a patient with a complaint of dizziness or vertigo arrives at the clinic. vHIT has two paradigms: Head impulse paradigm (HIMP) and Suppression head impulse paradigm (SHIMP).

The VOR is affected by peripheral vestibular damage and shows compensatory saccades when tested with HIMP (Pogson et al., 2020). Head impulse paradigm (HIMP) and Suppression head impulse paradigm (SHIMP) are good indicators of the presence of any peripheral vestibular damage (Curthoys & Manzari, 2017). VOR gain, VOR asymmetry, and presence/absence of refixation saccades are the measures that assist in concluding the diagnosis. HIMP uses an earth-fixed target, whereas the SHIMP uses a head-fixed target that moves in alignment with the head movement (Chen & Halmagyi, 2020). The stimuli (brief, unpredictable head impulses) and the response (eye movement recording) are the same for HIMP and SHIMP. The only variation apart from the fixation of the target (earth-fixed & head-fixed) is in the instructions given to the patient. In HIMP, the patient is instructed to look at the target fixed on the wall, whereas in SHIMP, they are asked to look at the target, which would be moving. In SHIMP, anti-compensatory saccades are generated in subjects with a normal well-functioning vestibular system.

On the other hand, patients with peripheral vestibular damage will not exhibit any saccadic eye movement (Macdougall et al., 2016). Compared to HIMP, SHIMP could be more efficient since it would be easier to calculate the VOR gain as the responses are not contaminated with catch-up saccades. The latency of the saccades generated using

SHIMP is slightly larger and longer than that measured using HIMP and thus facilitates efficient measurements of VOR gain (Macdougall et al., 2016).

The current study will systematically review the intended articles to illuminate the diagnostic accuracy of the Suppression head impulse paradigm (SHIMP) in evaluating various peripheral vestibular pathologies. The study will include research findings regarding the utility of the SHIMP test during the stages and recovery of peripheral vestibular disorders.

1.1 Need of the study

Since vHIT (Video Head Impulse Test) uses natural stimuli of the vestibular system-, it is advantageous in every other way compared to other vestibular tests such as VEMP, scleral search coil, caloric test, Etc. It is an effective and efficient tool with good sensitivity and specificity reported across various studies. Although sufficient studies have proved the good diagnostic accuracy of the HIMP paradigm, there is a lacuna of literature in the case of SHIMP (Macdougall et al., 2016). Compared with HIMP, there are many more noticeable advantages of SHIMP reported across various research articles. More reliable gain values could be obtained using SHIMP as the calculation of VOR gain values is not contaminated by the presence of covert saccades (Van De Berg et al., 2018). A wide range of VOR gain values was obtained using SHIMP reported across studies (Devantier et al., 2018).

Thus the need to systematically review the utility of the Suppression head impulse paradigm (SHIMP) arises considering various peripheral vestibular pathologies, which would help audiologists and significant others who work in this area. Instead of searching for each relevant research study under the subject matter, this systematic review would act as a quick reference guide that provides the readers with direct insight and relevant information regarding the utility of SHIMP in various vestibular disorders.

Many primary research pieces have been related to HIMP, establishing normative values in different populations, diagnosing patients who exhibit vestibular symptoms, comparing vHIT to other vestibular diagnostic tests, and so on. Thus, systematically reviewing and encapsulating the information about SHIMP would benefit those working in this research area. To our best knowledge, no studies have systematically reviewed this subject matter.

1.2 Aim of the study

The present study aims to systematically review the articles related to Suppression Head Impulse Paradigm (SHIMP) findings in patients with various peripheral vestibular pathologies.

1.3 Objectives of the study

The study's objective was to systematically review and rule out the clinical utility of the suppression head impulse paradigm (SHIMP) of video head impulse test in detecting various peripheral vestibular disorders. The objectives are defined according to the following parameters:

1. Vestibulo-ocular reflex gain values obtained using SHIMP
2. Vestibulo-ocular reflex gain asymmetry values obtained using SIMP
3. Presence or absence of anticompensatory saccades in SHIMP
4. Correlating HIMP parameters with that of SHIMP

CHAPTER II

METHOD

2.1 Searches

Searches were conducted using the following electronic bibliographic database: Google Scholar, Web of Science, Pubmed Central, Ovid Medline, and Cochrane Library. The search strategy included terms relating to Suppression Head Impulse Test (SHIMP) findings in various peripheral vestibular pathologies.

Compared with other clinical tests, all articles that define SHIMP in various peripheral vestibular pathologies studied the power of SHIMP as a diagnostic tool for various vestibular disorders and were considered for the preliminary search. No limits were placed on the date of publication. The searches were restricted to studies with available full-text, published in English, and including human subjects. The search was carried out until just before the final analysis to identify more studies to be included. Search words such as "video head impulse test, vestibular ocular reflex, suppression head impulse test, peripheral vestibular pathologies such as labyrinthitis, vestibular neuritis, Meniere's disease, Etc." were entered into different databases in different combinations with the use of Boolean operators such as AND, OR, NOT.

2.2 Study types included

A range of study designs was included: cross-sectional studies, retrospective, prospective studies, case series, randomized clinical trials, and other original research data. The present study has excluded other systematic reviews, case studies with <5 cases, and studies that do not report direct or indirect observations or original data and review articles.

2.3 Condition or Domain being studied

The predominant domain studied was the utility of the Suppression Head Impulse Test (SHIMP) in any peripheral vestibular pathologies with the following parameters:

1. VOR gain obtained using SHIMP in various peripheral vestibular pathologies
2. VOR gain asymmetry obtained using SHIMP in various peripheral vestibular pathologies
3. Presence or absence of anticompensatory saccades
4. Correlating HIMP versus SHIMP in various vestibular pathologies

2.4 Population/participants

Inclusion criteria: Studies involving patients under any age with peripheral vestibular pathologies.

Exclusion criteria: Patients being evaluated primarily for stroke evaluation or a specific neurologic disease, patients with any other comorbid disorders along with the peripheral vestibular pathologies, studies including less than 5 participants, or non-human participants were excluded from the study.

2.5 Analysis

2.5.1 Data Extraction (Selection & Coding)

The articles mentioned in the searches were extracted. In order to identify studies that potentially met the inclusion criteria, two review experts independently examined the titles and abstracts gathered from the electronic database sources. Research studies that fulfilled the inclusion criteria were only included. Two review authors retrieved the complete texts of these possibly eligible research, assessed their eligibility, and came to an agreement on any discrepancies. Missing data were gathered by requesting the respective research authors. Two independent reviewers screened all titles and abstracts using the previously articulated inclusion and exclusion criteria. All discrepancies between the reviewers' findings were reconciled through discussion. The risk of bias was independently assessed, and two independent researchers extracted all data.

Reasons for exclusion were documented and reported at this phase, following PRISMA standards (Page et al., 2021). The risk of bias was considered, and the two reviewers independently carried out the same assessment. VOR gain values, VOR gain asymmetry values, and presence or absence of anticompensatory saccades were taken as the data elements of interest.

2.5.2 Risk of bias (quality) assessment

At each screening stage, two reviewers were involved in overcoming the reviewer bias where disagreements were dealt with through discussions. In 2011, Quality Assessment of Diagnostic Accuracy Studies (QUADAS-2) was developed. A recent version of the tool was used in this study to evaluate the risk of bias and applicability of each diagnostic study for the systematic review. QUADAS-2 comprises four domains, including patient selection, index test(s), reference standards, and flow & timing (Whiting et al., 2011). There is a total of 11 questions that covers a set of signaling questions under each domain. It was categorized as having a low risk of bias if the domain has more 'yes' responses, and if it has maximum 'no' responses, it was considered to have a high risk of bias. Applicability concerns of the primary diagnostic accuracy studies were evaluated as low/high/unclear concerns. The domains and the set of signaling questions under each are listed below.

Domain 1: Patient selection

Was a consecutive or random sample of patients enrolled?

Was a case-control design avoided?

Did the study avoid inappropriate exclusions?

Domain 2: Index test(s)

Were the index test results interpreted without knowledge of the results of the reference standard?

If a threshold was used, was it pre-specified?

Domain 3: Reference standard

Is there a reference standard likely to correctly classify the target condition?

Were the reference standard results interpreted without knowledge of the results of the index test?

Domain 4: Flow and Timing

Was there an appropriate interval between index test(s) and reference standard?

Did all the patients receive a reference standard?

Were all patients included in the analysis?

Out of the 11 questions, the percentage of 'yes' were calculated for each study once the rating or each question was obtained. Risk of bias assessment guidelines given by The Joanna Briggs Institute (Moola et al., 2015) was utilized to categorize the percentage of positive answers to the questions. According to their guidelines, when only upto 49% of the answers were 'yes,' it is considered a high risk of bias; moderate risk of bias when 50% - 69% of the answers were 'yes'; and low risk of bias when more than 70% of the answers were 'yes.'

2.5.3 Strategy for data synthesis

The data synthesis was carried out by analyzing the homogeneity of the data, and different analysis parameters such as VOR Gain, VOR gain asymmetry ratio & presence and absence of anticompensatory saccades.

2.5.4 Analysis of subgroups or subsets

The correlation between the v-HIT paradigms, i.e., HIMP and SHIMP in all peripheral vestibular disorders, were analyzed and investigated.

CHAPTER III

RESULTS

The present study systematically reviewed the articles related to Suppression Head Impulse Paradigm (SHIMP) findings in patients with peripheral vestibular pathologies. The objectives were to define the following parameters:

1. Vestibulo-ocular reflex gain values obtained using SHIMP
2. Vestibulo-ocular reflex gain asymmetry values obtained using SHIMP
3. Presence or absence of anticompensatory saccades in SHIMP
4. Correlating HIMP parameters with that of SHIMP

3.1 Studies selection

Searches across databases, including Gooogle scholar, Web of Science, and Pubmed central, resulted in 109 topic-related records. After duplicate removal of 72 records, 37 were identified and screened. Considering the exclusion criteria, including studies in languages other than English, unavailability of complete texts, case series with less than 5 participants, and single case studies, 24 articles were excluded. The reasons for exclusions are listed below:

- Three papers had no full-text access
- Four studies were in other languages
- 12 studies included only normative subjects
- 1 study included only patients with central pathologies
- 1 case series paper
- Two single case studies
- One review paper

The full-text screening was carried out, which did not result in excluding any research articles. Thus, a total of 13 articles were included in this systematic review. The screening process and the reasons for the article exclusions are depicted in the PRISMA flow chart (Figure 3.1)

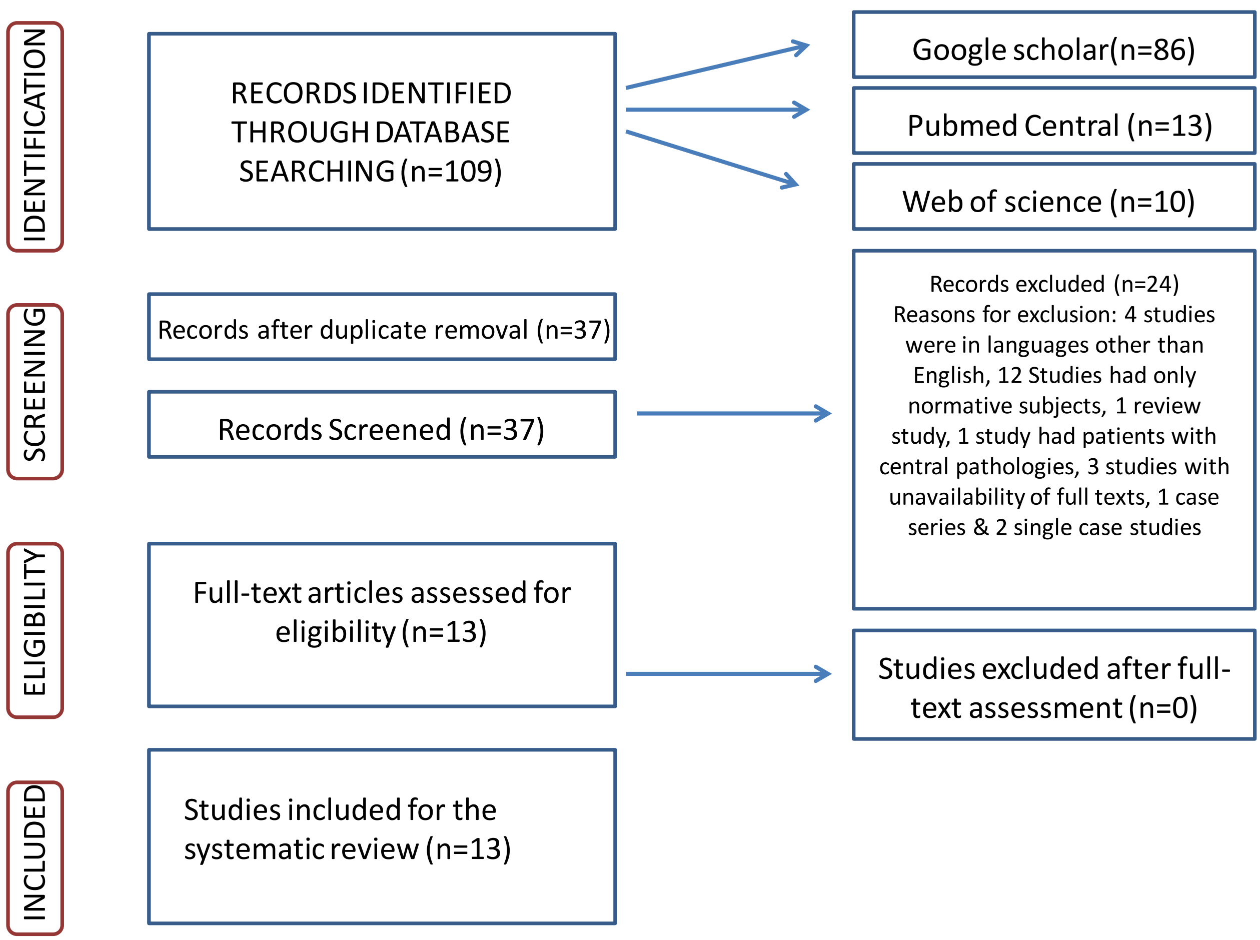

Figure 3.1 PRISMA chart for Systematic review and Meta-Analyses (PRISMA)

3.2 Risk of Bias

Administration of the QUADAS-2 tool for quality appraisal of the selected studies led to categorizing studies according to the domains, including patient selection, index test(s), reference standards, and flow & timing. The significant risk was observed only in the two domains: patient selection and index tests. Under risk of bias, two studies had high concerns in the 'patient selection domain', and around three had high concerns under the 'index test domain.'

The percentage of 'yes' was calculated from 11 questions for each study. All 13 studies included in the systematic review had a lower risk of bias, according to the Joanna Briggs Institute (JBI) guidelines. The Joanna Briggs Institute (JBI) is a membership-based international research and development organization established in the University of Adelaide's Faculty of Health Sciences. The Institute actively encourages evidence-based healthcare by providing resources for nurses, midwives, doctors, and other allied health professionals. The JBI guidelines have a unique perspective on what constitutes evidence and the methods used to combine various evidence. The Institute has established theories, methodologies, and systematic processes for critically evaluating and synthesizing these multiple forms of evidence to assist in clinical decision-making in health care. Table 3.1 shows the risk of bias in the included studies.

Table 3.1

Risk of bias assessment of 13 studies included for the systematic review

		RISK OF BIAS				APPLICABILITY CONCERN			
S. No.	**Study**	**Patient selection**	**Index test**	**Reference standard**	**Flow & Timing**	**Patient selection**	**Index test**	**Reference standard**	**Percentage of "YES"**
1	Casani et al. (2021)	✔	✔	✔	✔	✔	✔	✔	90.90%
2	Jensen & Hougaard (2022)	✔	✔	✔	✔	✔	✔	✔	72.72%
3	Manzari & Tramontano (2020b)	✘	✔	✔	✔	✘	✔	✔	81.81%
4	Kirazli et al. (2020)	✔	✘	✔	✔	✔	✔	✔	72.72%
5	Manzari et al. (2020a)	✔	✔	✔	✔	✔	✔	✔	81.81%
6	Park et al. (2019)	✘	✔	✔	✔	✘	✔	✔	72.72%
7	Ramos et al. (2019)	✔	✔	✔	✔	✔	✔	✔	90.90%

8	Roh et al. (2019)	✔	✘	✔	✔	✔	✔	✔	81.81%
9	Rey-Martinez (2017)	✔	✔	✔	✔	✔	✔	✔	90.90%
10	de Waele et al. (2017)	✔	✔	✔	✔	✔	✔	✔	90.90%
11	Macdougall et al. (2016)	✔	✘	✔	✔	✔	✔	✔	81.81%
12	Lee & Kim (2020)	✔	✔	✔	✔	✔	✔	✔	81.81%
13	Shen et al. (2016)	✔	✔	✔	✔	✔	✔	✔	81.81%

Icon illustration: ✔ indicates a low risk of bias & ✘indicates a high risk of bias

The proportion of studies with a low or high risk of bias and the proportion of studies with low or high concerns regarding applicability are depicted in figures 3.2 and 3.3, respectively.

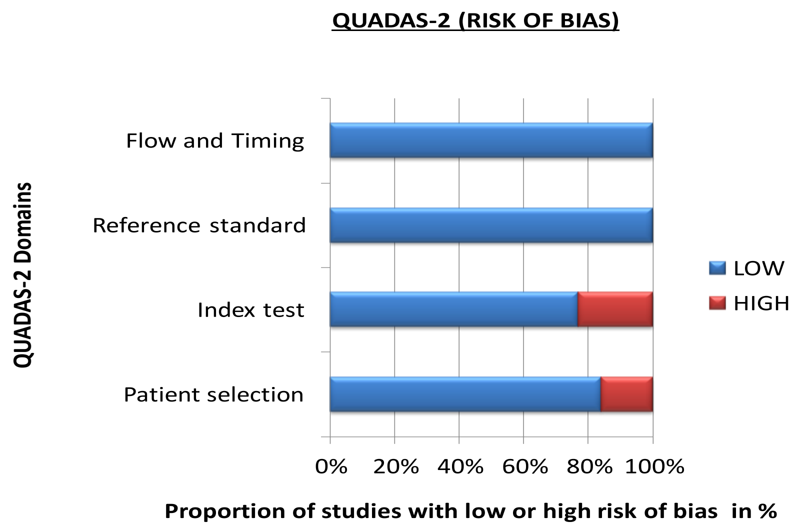

Figure 3.2

Proportion of studies with low or high risk of bias

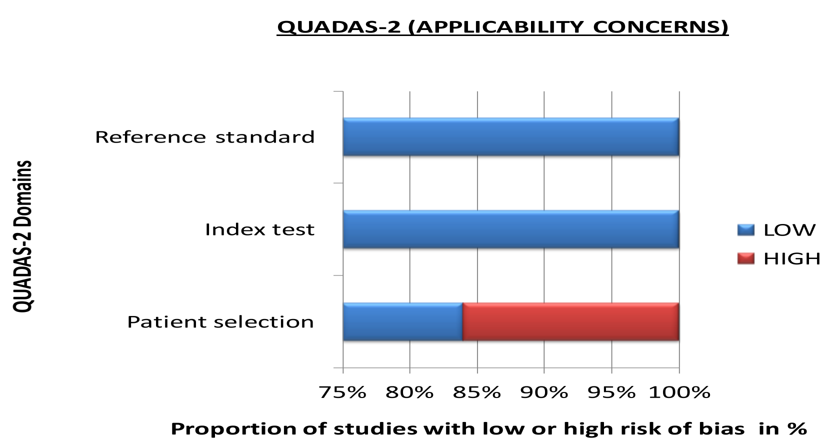

Figure 3.3

Proportion of studies with a low or high concerns regarding applicability

3.3 Characteristics of the selected studies

The studies included in the systematic review have compared the SHIMP paradigm in normals and subjects with peripheral vestibular pathologies. Studies that have compared SHIMP with HIMP and other significant vestibular tests are also incorporated in this systematic review. Among the included 13 studies, the number of patients incorporated ranged from 8 to 73. The studies have included the parameters such as VOR gain and VOR gain asymmetry values of SHIMP, percentage of anti-compensatory saccades in SHIMP, and anti-compensatory saccadic amplitude ratio (ASAR) among various peripheral vestibular pathologies. The studies incorporated in the systematic review have included subjects with-

1. Acute unilateral vestibulopathy/ vestibular syndrome
2. Sub-acute unilateral vestibulopathy
3. Chronic unilateral vestibulopathy
4. Bilateral peripheral vestibulopathy
5. Unilateral vestibular neuritis
6. Bilateral vestibular loss/hypofunction
7. Unilateral vestibular loss/hypofunction
8. Meniere's disease
9. BPPV
10. Migrainous vertigo
11. CPA tumor
12. VestibularSchwannoma

Table 3.2

Characteristics of the studies included in the systematic review

S.No	Authors and Year	Title of the study	Method used			Results		
			Participants & age range	**Pathology**	**Tests administered, and instruments used**	**Mean VOR gain obtained using SHIMP**	**Mean VOR gain asymmetry obtained using SHIMP**	**Anti-compensatory saccadic parameters**
1	Shen et al. (2016)	Saccadic Velocity in the New Suppression Head Impulse Test: A New Indicator of	23 acute UVL & 28 chronic UVL; 6 BVL; 35 normals (Age23–87 yrs)	PATIENTS WITH UVL AND BVL	HIMP, SHIMP, Caloric, DHI (OtosuiteV)	Nil	nil	**UVL- mean peak saccadic velocity** (deg/sec): 64(50) on the lesion side and 354(77) on the intact side;

		Horizontal Vestibular Canal Paresis and of Vestibular Compensation							**% of ACS:** 34(25) on the lesion side and 100(0) on the intact side. **mean latency of ACS:** 241(40) **BVL- mean peak saccadic velocity (deg/sec):** 104(81) on the left side and 60(35) on the right side; **% of ACS:**36(27) on the left side and (25(14) on the right side;

								mean latency of ACS: 269(24) **NORMALS- mean peak saccadic velocity (deg/sec):** 347(66) on the left side and 346(61) on the right side; **% of ACS:** 100(0) on left side and 100(0) on right side; **mean latency of ACS:** 201(32)
2	MacDougall et al.	A new saccadic	5BVL and 5 UVL	BVL (2 gentamycin	HIMP, SHIMP	BVL: <0.66	nil	**BVL:**No saccades

	(2016)	indicator of peripheral vestibular function based on the video head impulse test	(BVL age37-73 yrs) (UVL age 28-68 yrs)	vestibulotoxicity & 3 idiopathic) & UVL (Operated Vestibular schwannoma)		UVL: Ipsilesion:<0.66		observed in SHIMP **UVL:** SHIMP= ACS observed during impulses towards the healthy side
3	Rey-Martinez (2017)	Validity of wavelet transforms for analysis of video head impulse test (vHIT) results	19 patients (Age:25-86 years)	Acute, Subacute and Chronic u/l vestibular loss	HIMP, SHIMP (ICS Impulse)	VOR Gain obtained using the AUC method : 0.41 ± 0.22 VOR gain obtained using wavelet method: 0.41 ± 0.22	nil	Nil
4	de Waele et al.	A novel saccadic	8 BVL (Age=34-77 yrs)	Bilateral vestibular	HIMP, SHIMP	nil	nil	**% of ACS in SHIMP:**

	(2017)	strategy revealed by suppression head impulse Testing of Patients with Bilateral Vestibular loss		loss	(OtosuiteV)			Right:18.8 Left:40.25 **Mean latency of ACS (in milliseconds):** 270(20); **Peak saccadic velocity of ACS (deg/sec):** right:43.67 Left:104.89
5	Roh et al. (2019)	Comparison of Suppression Head Impulse and Conventional Head Impulse Test Protocols	73 patients Mean (age=55.64±16.8 years)	5-acute VN 6-MD, 11-BPPV 2-migrainous vertigo 13-CPA tumor 13-SSNHL	HIMP, SHIMP (ICS Impulse)	Mean VOR Gain of all 140 ears= 0.88±0.17	nil	**% of ACS**: 42.5 **Amplitude of ACS (deg/sec):**298(61.20)

				4-CSOM 19-idiopathic dizziness				
6	Ramos et al. (2019)	Corrective Saccades in Unilateral and Bilateral Vestibular Hypofunction During Slow Rotation Expressed by Visually Enhanced VOR and VOR Suppression: Role of the Cerebellum	12UVH and 3BVH (Age:20-75 yrs)	Unilateral and bilateral vestibular hypofunction cases	HIMP, SHIMP, VVOR, VORS (Otometrics ICS)	nil	nil	**UVH:** SHIMP- No ACS on ipsilesional side impulse ACS present on contralesional side impulses **BVH:** SHIMP-No ACS observed

7	Park et al. (2019)	Comparing the suppression head impulse paradigm and the head impulse paradigm in vestibular neuritis	21patients (Age:24-84 years)	Acute vestibular neuritis	HIMP, SHIMP, Caloric (ICS Impulse)	Ipsilesion: 0.42(0.21) Contralesion: 0.96(0.15)	nil	Nil
8	Manzari & Tramontano (2020b)	Suppression Head Impulse Paradigm (SHIMP) in evaluating the vestibulo-saccadic interaction in patients with vestibular	15 patients (Age-58.73 ± 10.73)	Unilateral vestibular neuritis	DHI, bedside HIT, HIMP, SHIMP, OVEMP, CVEMP (OtosuiteV)	Acute stage of VN= Ipsilesion:0.30 Contralesion: 0.79 78days (mean) after acute stage of VN= Ipsilesion:0.3	nil	11/15 Patients did not show anti-compensatory saccades

		neuritis				9 Contralesion: 0.81		
9	Kirazli et al. (2020)	Evaluation of high-frequency horizontal VOR parameters in patients with chronic bilateral and unilateral peripheral vestibulopathy : a preliminary study	6BPV and 10UPV (BPV Age: 47-65 yrs) (UPV age:34-65 yrs)	Bilateral peripheral vestibulopathy And unilateral peripheral vestibulopathy-7MD and 3VN	VDI questionnaire, HIMP, SHIMP, fHIT (Eyeseecam interacoustics)	BPV: R=0.57 ± 0.31 L=0.59 ± 0.36 UPV: R=0.86 ± 0.12 L=0.73 ± 0.32 (70% of UPV had left ear paresis)	nil	**BPV:** SHIMP=No ACS **UPV:** SHIMP=60% Pts. ACS on the healthy side
10	Lee & Kim (2020)	Importance of Video Head Impulse Test	27 patients (Age:38-84 yrs)	Acute VN (GroupF-symptoms-	DHI, VAS, VNG,	SHIMP: Group F: 0.99 Group R:0.37	nil	**Occurrence of ACS:** Group F: 100%

		Parameters for Recovery of Symptoms in Acute Vestibular Neuritis		free group) (GroupR-Symptoms residual group)	HIMP, SHIMP, Caloric (ICS Impulse)			Group R:7% **Peak velocity of ACS (deg/sec):** Group F:414 Group R:81
11	Manzari et al. (2020a)	The Different Stages of Vestibular Neuritis from the Point of View of the Video Head Impulse Test	15AVS and 13PAVS [Age= 55(16.5)Yrs:AVS group and 53.9(18.2yrs):PAVS group]	Acute vestibular syndrome and post acte vestibular syndrome: VN	DHI, HIMP, SHIMP (OtosuiteV)	AVS: Ipsilesional= 0.39 (0.17) Contalesional = 0.91(0.11) PVS: Ipsilesional= 0.54 (0.09) Contalesional = 0.94(0.25)	nil	**% of SHIMP ACS** in contralesional side AVS: 15(100) PAVS: 10(73)
12	Jensen & Hougaard	Suppression head impulse	55 patients AGE:62.74	Unilateral vestibular	HIMP, SHIMP, DHI,	Mean gain cutoff values	**SHIMP ASAR=**	**Mean SHIMP saccadic**

	(2022)	testing is recommended for vestibular testing of patients with untreated unilateral vestibular schwannoma		schwannoma	Audiometry	obtained : 0.80, 0.75 and 0.70	93.43±25.92	**amplitude**=295.85 deg/sec on VS side and 314.91 deg/sec on non-VS side. **Mean SHIMP saccadic latency**=222.33 ms on VS side and 218.49ms on the non-VS side
13	Casani et al. (2021)	Prognosis after acute unilateral vestibulopathy : Usefulness of the suppression head impulse paradigm	30 patients (Age:27-83 yrs)	Acute unilateral vestibulopathy	DHI, HIMP, SHIMP (ICS Impulse system)	**Asymmetry index (%):** Group 1(pts. With worse recovery)= 0.28 (0.17) Group2(pts. With spontaneous	Group 1(pts. With worse recovery) = 67.93(16.48) Group2(pt	**Mean % of ACS** in Group1=(18.23(29.43) **Mean % of ACS** in Group2= 61.06(39.45)

		(SHIMP)				recovery)= 0.58 (0.18)	s. With spontaneous recovery) = 26.44 (21.60)	

vHIT*- Video Head Impulse Test,* ***HIMP****- Head Impulse Paradigm,* ***SHIMP****- Suppression Head Impulse Paradigm,* ***VOR****- Vestibulo-Ocular Reflex,* ***UVL****- Unilateral Vestibular Loss,* ***BVL****- Bilateral Vestibular Loss*, ***UVH-*** *Unilateral Vestibular Hypofunction,* ***BVH****- Bilateral Vestibular Hypofunction,* ***UPV****- Unilateral Peripheral Vestibulopathy,* ***BPV****- Bilateral Peripheral Vestibulopathy,* ***DHI****- Dizziness Handicap Inventory,* ***ACS****- Anti-Compensatory Saccades,* ***CS-*** *Compensatory Saccades,* ***AUC****- Area Under Curve,* ***MD****- Meniere's Disease,* ***BPPV****- Benign Paroxysmal Positional Vertigo,* ***SSNHL-*** *Sudden Sensorineural Hearing Loss,* ***CSOM****- Chronic Suppurative Otitis Media,* ***VVOR****- Visually enhanced Vestibulo-Ocular Reflex,* ***VORS-*** *Vestibulo-Ocular Reflex Suppression,* ***oVEMP****- Ocular Vestibular Evoked Myogenic Potential,* ***cVEMP-*** *Cervical Vestibular Evoked Myogenic Potential,* ***VN-*** *Vestibular Neuritis,* ***VDI-*** *Vertigo, Dizziness, Imbalance,* ***fHIT-*** *Functional Head Impulse Test,* ***VAS****- Visual Analog Scale,* ***VNG-*** *Video Nystagmography,*

AVS- *Acute Vestibular Syndrome*, ***PAVS***- *Post Acute Vestibular Syndrome*, ***VS***- *Vestibular Schwannoma*, ***ASAR***- *Anti-Compensatory Saccadic Amplitude Ratio*

3.4 SHIMP Vestibulo-ocular reflex gain

3.4.1 Vestibular Neuritis:

Manzari and Tramontano (2020b) retrospectively evaluated 15 patients with unilateral vestibular neuritis. SHIMP was done twice for all the patients with a mean inter-assessment interval of seventy-eight days. In the acute stage of vestibular neuritis, the VOR gain values of the ipsilesional and contralesional sides obtained using SHIMP were 0.30 and 0.79, respectively. During the post-acute phase of vestibular neuritis, the VOR gain values of ipsilesional and contralesional sides were 0.39 and 0.81, respectively. 13 out of 15 patients exhibited a slight improvement in the VOR gain with an increase in the percentage of anti-compensatory saccades in the affected side during the second assessment.

Park et al. (2019) conducted retrospective evaluations of twenty-one individuals with unilateral acute vestibular neuritis. The average number of days between the beginning of vestibular neuritis and the testing day was 1.2. The SHIMP VOR gain measurements were calculated based on the AUC (area under the ROC curve). The mean SHIMP VOR gain values were 0.42(0.21) on the ipsilesional side and 0.96(0.15) on the contra-lesional side. In the case of unilateral vestibular neuritis, the SHIMP VOR gain values obtained using the head impulses on the lesion side are comparatively lower than that obtained using head impulses towards the healthy or contra-lesion side.

Lee and Kim (2020) assessed semicircular canal function using SHIMP in 27 patients with acute vestibular neuritis. They divided them into 19 patients in Group F (symptoms-free), and eight belonged to Group R (residual symptoms). The groups were divided based on Dizziness Handicap Inventory (DHI) and Visual Analog Scale (VAS). SHIMP results suggested significantly higher VOR gain among the patients with acute vestibular neuritis with no vestibular symptoms than in the symptoms residual group.

Casani et al. (2021) categorized 30 acute unilateral vestibulopathy patients into group1(patients with worse recovery) and group2 (patients with spontaneous recovery). The groups were categorized by observing the patients until 4-8 weeks after the onset of AUV. Patients in group 1 had no spontaneous nystagmus, and their symptoms gradually disappeared within 4-8 weeks from the onset. In contrast, patients in group 2 showed no improvement in the symptoms, and spontaneous nystagmus did not seem to disappear. SHIMP was administered to both groups, wherein the VOR Gain values were found to be 0.28±0.17 and 0.58±0.18 for group 1 and group 2respectively. They also demonstrated that VOR gain values of SHIMP effectively assist in identifying the extent of vestibular damage and the course of disease in patients with acute unilateral vestibulopathy than HIMP.

Manzari et al. (2020a) administered SHIMP on 15 patients with acute vestibular syndrome (AVS)and 13 with post-acute vestibular syndrome (PAVS). The AVS group had patients who were assessed within seventy-two hours since the onset, whereas the post-Acute Vestibular Syndrome group (PAVSg) included patients who were evaluated from 4 days to 6 weeks after AVS. The mean SHIMP VOR gain values of the AVS group were 0.39±0.17 (ipsilesional) and 0.91±0.11 (contralesional), whereas it was 0.54±0.09 (ipsilesional) and 0.94±0.25 (contralesional) in case of the PAVS group.

3.4.2 Vestibular Schwannoma:

Jensen and Hougaard (2022) evaluated 55 patients with vestibular schwannoma using SHIMP and HIMP. They compared how the sensitivity and specificity of SHIMP vary across three different mean gain cutoff values, i.e., 0.80, 0.75, and 0.70. They found that the gain value threshold of 0.7 demonstrated high sensitivity (25.5%) and specificity (90.9%) compared to the other two gain cutoff values. Their results have shown that SHIMP VOR gain values provide important information regarding the pathology even in cases where patients were deemed healthy by the HIMP test.

3.4.3 Unilateral and Bilateral Vestibular Hypofunction:

Kirazli et al. (2020) included ten patients with unilateral peripheral vestibulopathy (UPV) and six patients with bilateral peripheral vestibulopathy (BPV) in their study. SHIMP was administered on all the patients. They observed the mean VOR gain values of right and left ears in patients with BPV to be 0.57±0.31 and 0.59±0.36, respectively. Around 70% of UPV patients were observed to have left ear paresis; thus, ear-specific mean VOR gain was calculated in them. In patients with UPV, the right and the left ear VOR gain values were 0.86±0.12 and 0.73±0.72, respectively. Decreased SHIMP VOR Gain values in both ears were observed in patients with bilateral vestibular hypofunction. Whereas, patients with unilateral vestibular hypofunction exhibited normal SHIMP VOR gain values when head impulses were given at the contralesional side

Rey-Martinez (2017) included two groups of subjects in their experiment: Group 1 had 10 subjects with normal angular VOR gain values, and group 2 had 19 subjects with altered angular VOR gain values. The second group included subjects with acute or subacute and chronic vestibular loss. The acute vestibular loss group included patients with peripheral vestibular conditions such as vestibular neuritis (N=8) and Meniere's disease after intratympanic gentamycin chemical labyrinthectomy (N=4). The chronic vestibular loss group contained patients who underwent surgical neurectomy due to vestibular schwannoma (N=5) and patients with post-traumatic vestibular dysfunction (N=2). They calculated the mean VOR gain values for both the groups using two methods: AUC and wvelet methods. Group 1 showed mean Area Under Curve (AUC) VOR gain and mean wavelet VOR gain to be 0.84±0.06 and 0.82±0.06, respectively. The mean Area Under Curve (AUC) VOR gain and mean wavelet VOR gain for group 2 were found to be 0.41±0.22. From the observed resuts, it was concluded that the VOR gain values obtained using discrete wavelet transforms valid and concordant than gain values obtained using standard AUC method.

McDougall et al. (2016) studied how the SHIMP VOR gain values vary in patients with unilateral and bilateral vestibular loss (UVL and BVL). He included five patients with BVL (2 with gentamycin vestibulotoxicity and 3 with idiopathic cause) and 5 with UVL, including patients who underwent surgery for vestibular schwannoma. SHIMP was administered in order to evaluate the semicircular canal function in all the patients.They found that the bilateral VOR gain values in BVL patients and ipsilesional VOR gain values in UVL patients were less than 0.66.

Roh et al. (2019) studied 73 patients with various peripheral vestibular pathologies. They included five patients with acute vestibular neuritis, six with Meniere’s disease, 2 with migrainous vertigo, 13 CP angle tumor patients, 13 SSNHL, 4CSOM, and 19 with idiopathic dizziness. They administered SHIMP in all the patients. They calculated the SHIMP mean VOR gain value as a whole by including all the 73 patients (140 ears with the pathology) and it was found to be 0.88±0.17.

3.6 SHIMP VOR gain Asymmetry ratio

3.6.1 Acute unilateral vestibulopathy:

Casani et al. (2021) categorized the patients into group1 (patients with worse recovery) and group2 (patients with spontaneous recovery). The results have shown that patients in Group 1 (pts. With worse recovery) had 67.93(16.48)% of asymmetry index, whereas patients in Group2 (pts. With spontaneous recovery) had 26.44 (21.60)% of asymmetry index on SHIMP testing. The asymmetry index for group1 patients ranged from 30% to 90%; for the group2, it ranged from 1% to 69%.

3.6.2 Vestibular schwannoma:

Mean Anti-compensatory saccadic amplitude ratio (ASAR) was studied among 55 patients with unilateral vestibular schwannoma by Jensen and Hougaard (2022). They observed the mean ASAR to be 93.43(25.92).

3.7 SHIMP Anti-compensatory saccades

Predominant studies have shown the absence of anti-compensatory saccades in patients with peripheral vestibular disorders, whereas controls exhibit such anti-compensatory saccades.

3.7.1 Vestibular Neuritis:

Manzari et al. (2020a) evaluated the proportion of covert saccades in patients with vestibular neuritis during their acute and post-acute stages. In the acute stage of vestibular neuritis, 11 out of 15 patients did not exhibit saccades on the ipsilesional side, whereas 100% of the head impulses had covert saccades on the contra-lesional side. With the recovery, they observed a significant increase in the proportion of anti-compensatory saccades on the ipsilesional side.

Using the SHIMP, Park et al. (2019) ruled out the significant inter-aural difference in the mean peak saccadic velocity among patients with unilateral acute vestibular neuritis. They found that the mean peak saccade velocities of ipsilesional and contra-lesional ears were 120.62(116.61) degrees/s and 356.29(66.28) degrees/s, respectively.

Lee and Kim (2020) compared the peak velocity and occurrence of anti-compensatory saccades among the symptoms-free group and symptoms residual group of patients with acute vestibular neuritis. The results showed that patients in the symptoms-free group showed higher occurrence and higher peak velocity of the anti-compensatory saccades than those with residual symptoms.

Unilateral and Bilateral peripheral vestibulopathy:

Kiralzi et al. (2020) studied the occurrence of anti-compensatory saccades in patients with UPV and BPV. Patients with bilateral peripheral vestibulopathy did not show any ACS on SHIMP testing in both ears. In contrast, those with unilateral peripheral vestibulopathy exhibited 60% of ACS on the healthy side and no ACS on the ipsilesional side.

MacDougall et al. (2016) observed large anti-compensatory saccades in the controls, whereas patients with BVL did not show any ACS in SHIMP. Patients with UVL did not exhibit any ACS when the impulses were given towards the contralesional side, whereas ACS was seen in all the impulses given towards the ipsilesional side.

Results of a study by Casani et al. (2021) showed that Group 1(patients with worse recovery) had 18.23(29.43) % of overt ACS, whereas Group2(patients With spontaneous recovery) had 61.06(39.45)% of overt ACS among patients with acute unilateral vestibulopathy. The mean saccadic amplitude of group1 and 2 were 204.33(97.12) and 240.54(81.37), respectively.

Ramos et al. (2019) studied the trend of ACS in 12 UVH and 3 BVH patients. They found that subjects with unilateral vestibular hypofunction did not exhibit any ACS on the ipsilesional side, whereas ACS was present when head impulses were given on the contralesional side. They also observed that patients with bilateral vestibular hypofunction did not exhibit ACS on both sides.

This study's findings were in agreement with a study by Shen et al. (2016) wherein they showed that patients with unilateral vestibular hypofunction had 50% of ACS on the ipsilesional side and 100% of ACS on the contralesional side. They included 23 acute unilateral vestibular loss (UVL) patients, 28 chronic UVL patients, and 6 patients with bilateral vestibular loss (BVL). They demonstrated that ACS generated during head impulse towards the lesion side had lower velocity than those generated during head impulse towards the non-lesion side or when compared with normals. They also found that there were no or significantly smaller ACS generated in patients with BVL {14% of ACS on the right side and 27% of ACS on the left side}.

de Waele et al. (2017) studied the trend of ACS among 8 BVL patients. SHIMP was administered in all the patients and found that the patients had only 18.8% of ACS on their right side and 40.25% of ACS on their left side. This was in agreement with many studies that had demonstrated no or significantly lower ACS in patients with BVL.

Manzari et al. (2020a) categorized the patients based on the stages of VN. The acute vestibular syndrome group (AVSg) included patients assessed within 72 hours since AVS. The post-Acute Vestibular Syndrome group (PAVSg) included patients who were evaluated from 4 days to 6 weeks after AVS.On administering the SHIMP test, they found that percentage of ACS on the contralesional side for the acute vestibular syndrome (AVSg) was 100%. At the same time, the ACS percentage for post-acute vestibular syndrome(PAVSg) was 73% on the contralesional side.

Roh et al. (2019) demonstrated the total percentage of ACS among patients with various peripheral vestibular disorders. The mean ACS% among the 140 ears with various peripheral vestibular disorders was 9.22%. Around 42.5% of the patients showed the presence of overt saccades only, whereas none of them demonstrated covert saccades during SHIMP testing. 53.4% exhibited the presence of both overt and covert saccades.

3.7.2 Vestibular schwannoma:

Jensen and Hougaard (2022) studied the SHIMP saccadic latency and amplitude in 55 patients with unilateral vestibular schwannoma. They found that the mean saccadic latencies (in milliseconds) on the ipsilesional and contralesional sides were 222.33(69.37) and 218.49(36.64), respectively. The mean saccadic amplitude of the ipsilesional and contralesional sides were 295.85(86.87) and 314.91(50.18), respectively.

3.8 SHIMP versus HIMP

3.8.1 VOR Gain

MacDougall et al. (2016) found that in patients with UVL and BVL, SHIMP VOR gain was significantly lower than that of the HIMP VOR Gain, with a difference of 0.06(0.05). They proved that both HIMP and SHIMP had high sensitivity and specificity. The trend of lower VOR gain obtained with SHIMP compared to that of HIMP has been consistently observed in many studies (Roh et al.,2019; Casani et al.,2021).

Roh et al. (2019) showed a significant correlation and substantial agreement between VOR gain of HIMP and SHIMP. This was supported by a study by Park et al. (2019) as well, which proposed a significant correlation between the VOR gain values of HIMP and SHIMP. It was shown that the mean difference between the VOR gain values of HIMP and SHIMP was 0.07±0.09. Additionally, they reported that the difference in HIMP and SHIMP VOR gain increased on the affected side (0.10±0.09) which was more significant than that on the healthy side (0.03±0.09). Casani et al. 2021 demonstrated that in patients with Acute unilateral vestibulopathy, SHIMP VOR gain values positively correlated with HIMP VOR gain.

3.8.2 Saccades

de Waele et al. (2017) demonstrated that patients with BVL exhibited similar latencies of covert saccades in both HIMP and SHIMP. Roh et al.,2019 demonstrated no correlation in both percentage and amplitude of saccades between HIMP and SHIMP in patients with vestibular neuritis.

Jensen and Hougaard (2022) showed that the optimal gain threshold was 0.7 during SHIMP testing among patients with vestibular schwannoma for achieving high sensitivity and specificity in relation to HIMP. Casani et al., 2021 demonstrated that in patients with Acute unilateral vestibulopathy, SHIMP VOR gains positively correlated with the percentage of SHIMP overt saccades. They also showed that patients with worse recovery demonstrated that the prevalence of overt saccades was high during HIMP testing and low during SHIMP testing.

Table 3.2

Summary Table of all the studies incorporated for the Systematic Review

S.No	Authors and Year of the study	Findings
1	Shen et al. (2016)	• Zero or few ani-compensatory saccades were observed in patients with acute UVL during head impulse towards the lesion side. • Anti-compensatory saccades generated during head impulse towards the lesion side had lower velocity than those generated during head impulses towards the non-lesion side and compared with saccades measured in normals • At the chronic stage of UVL, patients recovered the ability to perform SHIMP saccades but were of lower velocity • In BVL patients, no anti-compensatory saccades were detected on both sides
2	MacDougall et al. (2016)	• Lower SHIMP VOR gain than HIMP VOR Gain • HIMP- Compensatory saccades present in patients • SHIMP-Large anti-compensatory saccades present in controls • BVL- SHIMP: No saccades present • UVL(Impulses towards lesion side)- HIMP: covert saccades; SHIMP: Smaller saccades present • HIMP and SHIMP has high sensitivity and specificity
3	Rey-Martinez (2017)	• HIMP: significant difference observed between the gain calculation methods (AUC and waaavelet

		methods) and also between controls and patient groups. • Gain values obtained using discrete wavelet transforms were valid and in concordance than the gain values obtained using standard methods.
4	de Waele et al. (2017)	• In SHIMP, some BVL patients exhibited inappropriate covert compensatory saccades, whereas other BVL patients did not show such inappropriate covert saccades and also did not show any anti-compensatory saccades too. • BVL patients exhibited similar latencies of covert saccades in both HIMP and SHIMP.
5	Roh et al. (2019)	• VOR Gain of SHIMP was smaller than that of HIMP. • VOR gain of HIMP and SHIMP showed significant correlation and substantial agreement • No correlation was present in both the percentage and amplitude of saccades between HIMP and SHIMP.
6	Ramos et al. (2019)	• UVL: VVOR- patients exhibited corrective saccades when head impulses were given towards the lesion side. VORS-They exhibited larger anti-compensatory saccades when head impulses were given towards the healthy side. • BVL-In VVOR, Patients exhibited corrective saccades to the opposite side of the head movements. In VORS- They did not reveal any corrective saccades during the head movements to either side.

7	Park et al. (2019)	• A significant correlation is present between SHIMP and HIMP • Lower VOR gain in SHIMP than that of HIMP • The difference in the SHIMP and HIMP VOR gains was more significant on the affected side than on the healthy side. • Significant correlation of peak saccadic velocity of SHIMP obtained with HIMP gain and canal paresis. • 100% of the patients exhibited ipsilesional caloric canal paresis, and 50% showed no anti-compensatory saccades in SHIMP. • Variable VOR gain values observed in SHIMP
8	Manzari and Tramontano (2020b)	• Significant differences were observed in within-subject analysis after 1 month in DHI scores, VOR Gain, and percentage of saccades in SHIMP for patients with vestibular neuritis.
9	Kirazli et al. (2020)	• BPV and UPV: low percentage of correct answers using fHIT and lower VOR Gains obtained. • HIMP: Compensatory saccades present in all patients • SHIMP: Anti-compensatory saccades seen in controls and during head impulses towards healthy sides of the patients; No saccades in BVP.
10	Lee and Kim (2020)	• One-month period (HIMP): Symptom-free group exhibited higher VOR gain, high occurrence of covert saccades, and low occurrence of overt saccades than the symptoms residual group.

		• 1month period (SHIMP): Symptom-free group exhibited high VOR gain, high occurrence of anti-compensatory saccades, and high peak velocity of ACS than the symptoms residual group.
11	Manzari et al. (2020a)	• AVS patients evaluated within 72 hours showed ACS during head impulses towards the contralesional side • ACS on the contralesional side is a sign of acute phase in patients with unilateral Superior vestibular neuritis
12	Jensen and Hougaard (2022)	• For patients with vestibular schwannoma: The optimal gain threshold was 0.7 in SHIMP testing for achieving high sensitivity and specificity in relation to HIMP. • A significant correlation was present between the Anticompensatory saccadic amplitude ratio (ASAR) and a high degree of vestibular pathology.
13	Casani et al. (2021)	• AVS: SHIMP VOR gain is significantly lower than HIMP VOR gain. • SHIMP VOR gain negatively correlated with DHI • SHIMP VOR gain positively correlated with HIMP VOR gain, and the percentage of SHIMP overt saccades • Patients with worse recovery had higher DHI, Lower SHIMP nad HIMP VOR gain, lower prevalence of SHIMP overt saccades, and higher prevalence of HIMP overt saccades.

All 13 records included in the study described the SHIMP findings in various peripheral vestibular pathologies. The researchers have studied SHIMP parameters, including Vestibulo-ocular reflex gain, Vestibulo-ocular reflex gain asymmetry, presence or absence of anti-compensatory saccades, percentage of anti-compensatory saccade responses, Peak saccadic velocity, the latency of the anti-compensatory saccades and Anti-compensatory saccadic amplitude ratio. Out of 13 studies, SHIMP VOR gain values have been calculated in 12 of the included records for different peripheral vestibular pathologies. In contrast, only two studies had mentioned the SHIMP VOR gain asymmetry.

Predominant records have shown that the VOR gain calculated for patients with peripheral vestibular pathologies using SHIMP has always been significantly lower than that of healthy subjects. Thus VOR gain is considered an essential parameter for arriving at a provisional diagnosis of any peripheral vestibular pathologies. Asymmetry ratio has been demonstrated to have a large variability among patients with peripheral vestibular pathologies. Thus, it is usually considered less significant in arriving at a clinical diagnosis than VOR gain and anti-compensatory saccades.

Chapter IV

DISCUSSION

McDougall et al. (2016) developed a relatively new test protocol for the video head impulse test called the Suppression Head Impulse Paradigm (SHIMP). This test has been proposed to be of more excellent utility for evaluating peripheral vestibular disorders compared to the conventional head impulse paradigm. The current study aimed to systematically review the articles related to Suppression Head Impulse Paradigm (SHIMP) findings in patients with various peripheral vestibular pathologies. For this purpose, nineteen studies were evaluated under the following parameters:

1. Vestibulo-ocular reflex gain and gain asymmetry
2. Anti-compensatory saccades
3. SHIMP versus HIMP

4.1 Vestibular Neuritis

Most of the studies have reported reduced VOR gain in all the patients with vestibular neuritis. In these patients, the VOR gain recovery can be total or partial but does not reach the normative values (Manzari et al., 2020a; Jacobson et al., 1991; Halmagyi et al., 2004).

Reduced VOR gain in patients with vestibular neuritis indicates damage to the vestibular nerve. It has been reported that the vestibular neuritis affects the superior vestibular nerve more than the inferior vestibular nerve; hence, the canals innervated by the superior vestibular nerves will be affected more than the inferior vestibular nerve (Taylor et al., 2015).

It has been hypothesized that a recovery pattern in patients with vestibular neuritis could be due to both central compensation and functional recovery of the peripheral system (de Waele et al., 2017; Manzari et al., 2020a; Jacobson et al., 1991; Halmagyi et al., 2004). Interestingly, it was observed that two out of fifteen patients with vestibular neuritis did not show any improvement in VOR gain values even though they presented an increasing percentage of anti-compensatory saccades with recovery. It was proposed that this could be due to the involvement of somatosensory inputs as a compensatory strategy during the recovery process (Manzari et al., 2020a).

Casani et al. (2021) assessed all the patients under group 1 (those with reduced VOR gain) within four weeks since the onset of AUV. Such a time duration of four weeks was considered based on the research findings by Palla et al. (2008), where they had described that the improvement of high-velocity VOR gain occurs spontaneously within the first four weeks since the onset of AUV. Contradictively, the study findings of Casani et al. (2021) revealed that a better prognosis or recovery of VOR gain could happen even after four weeks after the onset. The study has also demonstrated the importance of SHIMP in categorizing AUV patients who can show complete disappearance of symptoms during their chronic stages from those who cannot.

This would provide valuable information on the required intensity of vestibular rehabilitation based on the time taken for the neuronal plasticity, reorganization in the associated vestibular neural networks, and also the information regarding the evolution of the lesion affecting the dynamic function of semicircular canals (Lacour et al., 2016; Lacour et al.,2020; Manzari et al. 2020b).

The majority of the studies have ruled out that there is a no or significantly limited occurence of anti-compensatory saccades in patients with vestibular neuritis. Studies have also observed that both the occurrence and peak saccadic velocities of the anti-compensatory saccades were higher in the symptoms-free group than in the symptoms residual group. Therefore SHIMP efficiently helps track the prognosis during vestibular rehabilitation that triggers early anti-compensatory saccades in patients with AVN.

Casani et al. (2016) demonstrated that the prevalence of anti-compensatory saccades of SHIMP in patients with AUV could provide information regarding the symptoms as they exhibited a positive correlation between DHI scores and prevalence of anti-compensatory saccades. Manzari et al. (2020a) reported that apart from the increment in VOR gain, the reappearance of anti-compensatory saccades and the evolution of saccadic patterns (from overt to covert) are also indicators that there is a recovery happening efficiently in patients with vestibular neuritis. Shen et al. (2016) demonstrated an exciting finding in patients with unilateral vestibular loss. They ruled out a correlation between the patients' complaints and the generation of anti-compensatory saccades. They found that patients with relatively more complaints had less frequency of saccadic occurrence and vice versa.

4.2 Vestibular Schwannoma

Among the thirteen, only one study has reported the SHIMP findings in 55 patients with vestibular schwannoma. They reported reduced VOR gain values in the ear with vestibular schwannoma. The study has highlighted mainly the anti-compensatory saccadic amplitude ratio (ASAR).

Jensen and Hougaard (2022) demonstrated increased mean Anti-compensatory saccadic amplitude ratio (ASAR) in patients with vestibular schwannoma.

Jensen and Hougaard (2022) reported the importance of demonstrating an anti-compensatory saccadic amplitude ratio (ASAR), also referred to as the asymmetry ratio in patients with unilateral vestibular schwannoma. An essential prerequisite is that the patient needs to have a healthy, well-functioning vestibular system on the contralesional side for efficient calculation of ASAR. This measure helps standardize the amplitude and aids in comparing the subjects. They reported a strong correlation between ASAR and vestibular pathology. ASAR could serve as an efficient and faster measurement when used solely compared to other SHIMP measures such as VOR gain and the percentage of anti-compensatory saccades. The ASAR measure has been mentioned to provide various helpful information regarding the vestibular function over time, such as monitoring the residual vestibular function, how the degrees of vestibular impairment vary with the subsequent follow-ups and the prognosis of vestibular rehabilitation.

4.3 Unilateral and bilateral vestibular hypofunction

The studies consistently reported a significant reduction in VOR gain values in the ipsi-lesional ear with the hypofunction. In contrast, both ears demonstrated reduced VOR gain in the case of bilateral hypofunction.

Kiralzi et al. (2020) reported a significant correlation between the VOR gain values of SHIMP and HIMP in all the patients with unilateral vestibular hypofunction. Unfortunately, the correlation was lacking among patients with bilateral hypofunction. The authors reported that this might be due to ow number of participants in the BVH group. They also reported that the SHIMP VOR gain values were consistently lower than that of HIMP. This trend could be due to the utility of desaccadic algorithm in SHIMP for eliminating the catch-up saccades, thus causing reduced VOR gain than that of HIMP (MacDougall et al., 2016).

Majority of the studies have demonstrated that the anti-compensatory saccadic parameters such as frequency of saccadic responses, the ratio of saccade velocity to head velocity, and peak saccadic velocity provide a valuable information such as efficiently discriminates between the ipsilesional and contralesional sides of patients with acute unilateral vestibulopathy (Park et al., 2019) and also information regarding the compensation processes.

Shen et al. (2016) observed that the results of peak saccadic velocity of the healthy side (contralesional side) in patients with AUV were similar to that observed in normal subjects. There are chances of false-negative results due to slow head velocities; thus, such factors can be eliminated by implementing the ratio of peak saccade velocity to peak head velocity measure.

Shen et al., (2016) demonstrated an exciting finding in patients with unilateral vestibular loss. They ruled out a correlation between the patients' complaints and the generation of anti-compensatory saccades. They found that patients with relatively more complaints had less frequency of saccadic occurrence and vice versa. It is always recommended to provide head impulses with head velocities ranging from 150 to 250 degrees/second since peak head velocities below 150 degrees/second tend to produce errors during VOR gain calculation, mainly in patients with spontaneous nystagmus (Mantakoudis et al.,2014; Kim et al.,2018; MacDougall et al.,2016).

The frequency of anti-compensatory saccades observed in patients tends to show information regarding the compensation. This was ruled out when all the patients with acute unilateral vestibular loss and those with small anti-compensatory saccades complained of oscillopsia (Shen et al.,2016). Lee and Kim (2020) noted that in patients with vestibular neuritis, the residual vestibular function present during recovery directly impacts the chronic phase.

de Waele et al. (2017) observed the presence of inappropriate anti-compensatory saccades during the administration of SHIMP in patients with bilateral vestibular loss. They postulated that this could be due to various factors, such as eye-lid artefacts (Halmagyi et al., 2017). Such inappropriate anti-compensatory saccades can also arise when patients intend to falsify the head impulses or during instances where they do not understand the instructions. They observed that few patients with bilateral vestibular lesions (BVL) exhibited anti-compensatory saccades with larger amplitude on both sides, similar to healthy subjects. This mechanism can be explained as a retinal smear triggering such covert saccades due to the discrepancies between the head and the compensatory eye movements in patients with BVL. Even though these patients demonstrated lower VOR gain, the presence of such high amplitude anti-compensatory saccades might raise an issue in the clinical diagnosis. Interestingly, it was noted that these patients exhibited inappropriate covert compensatory saccades, which preceded the high amplitude anti-compensatory saccades during SHIMP testing. BVL Patients with a trend of such inappropriate anti-compensatory saccades reported fewer symptoms than the patients who showed no or significantly lesser anti-compensatory saccades.

4.4 SHIMP vs HIMP

SHIMP and HIMP tests complement each other, and it is usually recommended to administer both as one provides clinical information regarding the vestibular function and the other is sensitive to detecting vestibular loss.

Many studies have reported that SHIMP is comparatively more advantageous than HIMP. During each impulse, the saccades rarely appear before the cessation of the head movement, and thus the measurement error of VOR gain due to the presence of covert saccades can be reduced (Manzari et al., 2020a). Moreover, since the anti-compensatory saccades appear in the opposite direction of the spontaneous nystagmus, it is relatively efficient to differentiate the saccadic responses (Park et al., 2019). MacDougall et al. (2016) stated that the anti-compensatory saccades of the SHIMP are relatively easier to detect due to their increased amplitude compared with the HIMP corrective saccades.

A trend consistently observed across all studies that included both SHIMP and HIMP is the presence of reduced VOR gain followed in SHIMP compared to that of HIMP. This could be probably due to an early saccade mechanism, de-saccadic algorithm, or contamination by spontaneous nystagmus (McDougall et al.,2016). This explanation is not convincing since the trend has also been observed in normal across studies. It was suggested that VOR inhibition could be a cause for such gain difference observed in normal, and saccadic suppression is the mechanism that helps to bring back the fovea to the target (Rey-Martinez et al.,2018; Jacobson et al., 1991).

The frequency of anti-compensatory saccades in SHIMP tends to have a complementary role compared to HIMP in providing information regarding the occurrence of compensation and thus helps in tracking the efficacy of rehabilitation (Park et al., 2019). In patients with iatrogenic AUV, it was evident that the saccades generated during HIMP and SHIMP tests were results of variation in the processing of vestibular information (Shen et al., 2016). They observed that the corrective saccades were consistently present in all the patients on the administration of HIMP. In contrast, the SHIMP anti-compensatory saccades were observed to be more inconsistent. They hypothesize that this could be due to the evident involvement of cortical processing in generating anti-compensatory saccades during the SHIMP test compared to that of HIMP.

Casani et al. (2021) demonstrated that during the later course of the disease, SHIMP could be more beneficial than HIMP in arriving at a diagnosis. This was observed in three out of thirty patients who exhibited normal HIMP VOR gains and pathological SHIMP VOR gain values during a follow-up visit. Lehnen et al. (2013) observed that during the chronic stages of patients with bilateral vestibular loss, they exhibited small saccades in SHIMP, whereas the residual function was observed during the administration of HIMP. Shen et al. (2016) studied that around 15% of the patients included in their experiment had difficulty focusing gaze on the target or moving their trunk along with the head during the impulses. Thus, SHIMP appeared to be an easier task for them compared to HIMP, as they needed to fix their gaze on the moving target.

Roh et al. (2019) evaluated HIMP and SHIMP in 73 patients with peripheral vestibular pathologies. They did not find any significant correlation between HIMP and SHIMP in saccadic amplitudes and the presence of saccades. They hypothesized that the reduction in the correlation could be due to the interference of covert saccades, thus reducing the amplitude of overt saccades.

Even though studies have reported SHIMP as an efficient tool to rule out peripheral vestibular pathology, the paradigm also has a few disadvantages. SHIMP cannot entirely replace HIMP as it is incapable of evaluating the vertical canals. SHIMP testing is performed only for the lateral canals; thus, it does not provide information regarding the functional integrity of the anterior and the posterior semicircular canals.

Jensen and Hougaard (2022) found no statistically significant differences between the sensitivity and specificity measured using HIMP and SHIMP in patients with unilateral vestibular schwannoma. They reported that in such circumstances, SHIMP could be more advantageous than HIMP, as it aids in measuring the anti-compensatory saccadic amplitude ratio (ASAR) apart from VOR gain and percentage of anti-compensatory saccade measurements.

CHAPTER V

SUMMARY & CONCLUSIONS

The objective of this current study was to systematically review the utility of the Suppression Head Impulse Paradigm (SHIMP) in various peripheral vestibular disorders. The parameters evaluated include VOR gain, gain asymmetry, and the presence or absence of anti-compensatory saccades. The study also aimed to find the association between the paradigms of vHIT, i.e., the HIMP and the SHIMP in different vestibular pathologies. Different databases were utilized for the review search. Total 109 topic-related studies were extracted from these databases. A total of thirteen articles that met the inclusion and exclusion were included to meet the objectives of the current study. Potential risks and the quality of each article were assessed using the QUADAS-2 risk of the bias assessment tool.

A detailed review of all the articles revealed that the VOR gain is the most extensively studied parameter of the SHIMP. In contrast, the VOR gain asymmetry is the least studied among patients with peripheral vestibular pathologies. The results of all the studies reduction of VOR gain on the side with the lesion. In the contra-lesional side (healthy side), VOR gain is normal. This was consistent among peripheral pathologies such as vestibular neuritis, unilateral and bilateral hypofunction, and vestibular schwannoma. Few studies have also reported a trend where a gradual increment in the VOR gain values of the affected side occurs from the pathology's acute to post-acute phase, indicating the central compensation and recovery process. Thus, the VOR gain value aids in ruling out the extent of vestibular damage, course of the disease, and prognosis of vestibular rehabilitation.

The second parameter studied was the SHIMP VOR gain asymmetry ratio. Across various studies, the asymmetry index, also called the anti-compensatory saccadic amplitude ratio (ASAR) reveals that it does not provide much potential information as it shows a wide range of variability. Only two out of thirteen studies have reported the findings and the utility of asymmetry ratio in unilateral vestibular lesions.

The anti-compensatory saccadic measure is the third parameter considered .in this study. After the VOR gain measure, anti-compensatory saccadic measures are the second most extensively studied parameter among various researches on SHIMP findings in peripheral vestibular pathologies. Within the anti-compensatory saccade measure, researchers have studied various aspects such as frequency of occurrence, peak-saccadic velocities, and the ratio of saccade velocity to head velocity of the anti-compensatory saccades. The majority of studies have affirmed the utility of anti-compensatory saccadic measures as it provides adequate insight regarding the extent of lesion, compensation process, and prognosis of vestibular rehabilitation (Casani et al., 2016; Shen et al., 2016; Park et al., 2019; Lee and Kim, 2020)

Based on the above findings, it can be concluded that the SHIMP is a valuable paradigm in providing an insight into various peripheral vestibular pathologies. When administered along with the HIMP and other significant test tools, SHIMP offers useful information that aids in arriving at a clinical diagnosis. The SHIMP cannot replace HIMPas both complement each other, making the diagnosis more accurate. Since SHIMP does not assess the vertical canals, it is always recommended to administer SHIMP along with HIMP. The SHIMP VOR gain and the anti-compensatory saccades are the most crucial parameters that help diagnose various peripheral vestibular pathologies.

5.1 Implications of the study

- The systematic review provides insight regarding the utility or the diagnostic accuracy of the Suppression Head Impulse Paradigm (SHIMP) of the video head impulse test in individuals with various peripheral vestibular pathologies.
- The systematic review provides knowledge into the different parameters of SHIMP, such as the VOR gain, VOR gain asymmetry ratio, and frequency of occurrence of anti-compensatory saccades, peak saccadic velocity, and the ratio of saccade velocity to head velocity of anti-compensatory saccades in patients with various peripheral vestibular pathologies.
- The systematic review also aids in understanding the various physiological mechanisms responsible for the abnormality of VOR gain, gain asymmetry, and the presence or absence of anti-compensatory saccades in patients with various peripheral vestibular pathologies.
- This systematic review also enables the readers to understand the association and dissociation between the two vHIT paradigms, i.e., HIMP and SHIMP, in assessing various peripheral vestibular disorders.

5.2 Research Gaps of the Systematic Review

The current systematic review did not include SHIMP findings in the peripheral vestibular pathologies other than vestibular neuritis, vestibular schwannoma, and unilateral & bilateral vestibular hypofunction. Thus, future research needs to focus on SHIMP findings in other peripheral pathologies such as Meniere's disease, BPPV, Semicircular canal dehiscence, Etc.

Even though a study by Roh et al. (2019) included various other peripheral pathologies, it was difficult to compare the SHIMP VOR gain or asymmetry parameters among different groups of patients, since the mean VOR gain reported in the study was measured as a whole, compiling the VOR gain values of all the peripheral vestibular disorders. It would be more comprehensive to demonstrate how the SHIMP parameters vary in each peripheral pathology if the values are grouped according to the disorder.

The VOR Gain asymmetry parameter is much underrated compared to the other two (VOR gain and anti-compensatory saccades). This measure has been demonstrated to provide much useful information regarding the severity of unilateral pathology. Thus, the upcoming researches need to highlight the asymmetry ratio along with the VOR gain.

Future studies need to include all the anti-compensatory saccade parameters, including frequency of saccadic responses, the ratio of saccade velocity to head velocity, and peak saccadic velocity, so that it would be of a mount utility to study the compensation and the recovery process in depth in various peripheral vestibular pathologies.

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