Effect of age on treatment outcomes in benign paroxysmal positional vertigo: A systematic review

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Effect of age on treatment outcomes in benign paroxysmal positional vertigo: a systematic review.

Running Title: Effect of age on treatment results in BPPV

Gwen Laurent[a] MBS*, Luc Vereeck[b] PhD*, Evi Verbecque[a,b] PhD, Nolan Herssens[b,c] PhD, Laura Casters[a] PT, Joke Spildooren PhD[a]

*Joint first author – both authors contributed equally to the work

[a]Rehabilitation Research Center (REVAL), Department of Rehabilitation Sciences, Hasselt University, Agoralaan Gebouw A, 3590 Diepenbeek, Belgium.

[b]Department of Rehabilitation Sciences and Physiotherapy/MOVANT, Faculty of Medicine and Health Sciences, University of Antwerp, Wilrijk, Belgium.

[c]Department of Rehabilitation Sciences, Gent university, Gent, Belgium

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Corresponding author:

Joke Spildooren

Agoralaan Gebouw A, 3590 Diepenbeek, Belgium

+32 11 269178

Joke.spildooren@uhasselt.be

@JSpildooren

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KEY POINTS

- *Treating older adults with BPPV is more complex, requires more CRP's and the risk for recurrence is higher*
- *Age does not affect the ability to recover from BPPV*

WHY DOES THIS MATTER?

Musculoskeletal and motivational changes hamper the treatment of older adults with BPPV but this does not affect overall treatment outcome

ABSTRACT

Background: Benign paroxysmal positional vertigo (BPPV) can lead to an increased fall risk in older adults. Therefore, we examined the influence of age on the effectiveness of canalith-repositioning procedures (CRPs) for the treatment of BPPV.

Methods: Pubmed, Web of Science, and the bibliographies of selected articles were searched for studies conducted before September 2020 that examined the effectiveness of treatments for BPPV in various age groups. Meta-analyses were performed to compare treatment effectiveness and recurrence rates for younger and older adults. Odds ratios were calculated in a random-effects model. Mean differences were calculated using a fixed-effects model. A significance level of $p<0.05$ (95% confidence interval) was set. The risk of bias and the methodological quality of all included articles were examined.

Results: Forty-five studies were retrieved after full-text screening, of which 29 studies were included for a qualitative review. The remaining 16 studies were eligible for inclusion in the meta-analysis (3,267 participants with BPPV). The success rate of a single CRP was higher in the younger group (72.5% vs. 67%, $p<0.001$). An average of 1.4 and 1.5 CRPs was needed for complete recovery in the younger and older groups, respectively ($p=0.02$). However, global treatment success did not differ between these groups (97.5% vs. 94.6%, $p=0.41$). The recurrence rate was higher in the older population (23.2% vs. 18.6%, $p=0.007$).

Conclusions: Although more CRPs are needed, the rate of complete recovery in older adults is similar to that observed in younger adults.

KEY WORDS: benign paroxysmal positional vertigo, treatment efficacy, recurrence, older adults, aging

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INTRODUCTION

Vertigo and dizziness occur in 15–35% of the adult population, increasing up to 50% in people aged 80 and older[1,2]. In vestibular clinics, benign paroxysmal positional vertigo (BPPV) is responsible for one-third of the cases in which vertigo or dizziness is the main complaint[1,3,4]. Additionally, BPPV is a common condition, with a known 1-year prevalence of 0.5% in the population aged 18–39, 1.7% in the people aged 40–59, and 3.4% in the population 60 years and older[5].

Usually, BPPV is characterized by intense feelings of positional vertigo lasting about one minute[1,6]. However, adults aged 65 or over often complain of disequilibrium or imbalance, without reporting vertigo[7,8]. These complaints are often misdiagnosed and attributed to other medical, neurological, or age-related changes[9,10,11]. This may lead to the unnecessary use of healthcare services, such as redundant diagnostic testing procedures and therapeutic measures, resulting in an inefficient approach to this problem[4,12]. Moreover, in older adults, BPPV symptoms may also contribute to reduced social and daily activities and reduced physical function, which are associated with increased fall risk[1,13,14]. The timely and accurate diagnosis and treatment of BPPV are important for preventing this decline in quality of life in older adults.

Because the symptom presentation differs between age groups, it is plausible that the effectiveness of the treatment may also differ. Recently, Sim et al. (2019) performed a systematic review and meta-analysis of the treatment outcomes of BPPV in young and old age groups[15]. Improvement in vertigo was shown in both groups, but in the older group, the recovery of dynamic balance was worse, and an increased perception of disability was reported[15]. For the meta-analysis, studies were allocated to either the young or older age

group according to the average age of the study population (above or below 60 years). Consequently, due to the age spread in those studies, some older adults may have been misplaced in the young age group, and *vice versa*, which may have negatively impacted the significance of their results (e.g., similar recurrence rates in both groups)[15].

The aim of the current systematic review and meta-analysis is to investigate the effect of age on treatment efficacy, i.e., global success rate, success rate after one maneuver, the presence of residual dizziness, and recurrence.

METHODS

Protocol and registration

This systematic review was registered in PROSPERO (CRD42020166194) and conducted following the Preferred Reporting Items for Systematic Review and Meta-analysis (PRISMA) guidelines[15].

Data sources and searches

Two researchers (JS, LV) performed a systematic search in Pubmed and Web of Science (last search update on October 26th 2020) using keywords related to Benign Paroxysmal Positional Vertigo, Epley, Sémont, Gans, or Brandt-Daroff. The filter "human" and language filters German, English, Dutch, and French were applied. The specifics regarding the search queries are available in *Supplementary Text S1*.

104 **Eligibility and study selection**

105 Original studies with a cohort, case-control, or controlled study design were considered
106 relevant. Conference proceedings/reports, editorials, case studies/series, abstracts only,
107 (systematic) reviews, and meta-analyses were excluded.

108 To be included, treatment efficacy and/or recurrence had to be compared between patients
109 with BPPV of different ages. For this analysis the pre-determined age cutoff was between 60
110 and 79 years, because the prevalence, because the prevalence of BPPV is almost seven times
111 higher in this age group[5]. Age effects could be investigated by defining age groups *a priori*
112 (e.g., comparing a group of younger versus older BPPV patients), using age *as a covariate in*
113 *the statistical analysis* (e.g., an analysis of variance or regression analysis), or performing *a*
114 *retrograde univariate analysis* (e.g., group composition based on recurrence rates and
115 comparing their mean ages). Treatment efficacy or recurrence after the canalith-
116 repositioning procedure (CRP) had to be measured using appropriate positional tests
117 corresponding to the canals to be tested, and CRPs were defined as all therapeutic maneuvers
118 to remove otoconia from the semicircular canals with/without postural restrictions. Studies
119 using only self-reported treatment, purely medication-based treatment, or surgery were
120 excluded. Finally, studies dealing exclusively with anterior or horizontal canal involvement
121 were excluded.

122 Two independent researchers (JS, LV) applied the selection criteria for the title and abstract
123 (phase 1), followed by a full-text screening (phase 2) in the same sequence: design,
124 population, comparison, and outcome. After each phase, the selection process was discussed
125 in a consensus meeting. To ensure that no relevant articles were missed, the references of all
126 studies included after phase 2 were screened and included if eligible. Global treatment

efficacy was defined as symptom resolution and conversion to a negative positional test after treatment. Residual dizziness was defined as the sensation of lightheadedness or unsteadiness without vertigo or nystagmus during positional testing after successful treatment. The recurrence rate was defined as the reappearance of positional vertigo and nystagmus after remission.

Risk of bias in individual studies

The risk of bias in the individual studies was identified with a modified version of the Scottish Intercollegiate Guidelines Network (SIGN) checklist for cohort trials. Because the effect of age on treatment outcome was rarely the primary research goal of the included studies, the questions were modified to increase the identification of selection, detection, and attrition bias (in relation to our research question). The specifics of the modified checklist are presented in *Supplementary Text S2*.

Data extraction

Information regarding *general population characteristics* (number of subjects, age, and gender), *specific population characteristics* (diagnostic test, canalolithiasis/cupulolithiasis, affected canal, and time since onset of complaints), *the applied treatment procedure*, and *the assessment of treatment efficacy and recurrence rate* (i.e., definition of success and number of maneuvers) was extracted. Unclarities were discussed with the team in a consensus meeting.

Data Synthesis and Analysis

If there was a sufficient number of articles describing treatment effectiveness or recurrence rate as influenced by age (i.e. ≥ 5 studies[16]), meta-analyses were performed using Review Manager 5.3. (Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2014). Odds ratios (ORs) were calculated for dichotomous data, such as the absence of vertigo and/or nystagmus after performing a positional test for measuring treatment effectiveness or the reappearance of vertigo symptoms for measuring recurrence. Between-group comparisons were made using the Mantel-Haenszel method with a random-effects model. Mean differences in the number of CRP maneuvers were calculated using a fixed-effects model. Overall weighted estimates and 95% confidence intervals (95% CIs) were calculated for the individual studies. Significance was set at $p<0.05$.

RESULTS

Study selection

The selection process is presented in a flowchart (Supplementary Figure S1). The search query revealed 792 unique citations. Data from 16 studies were included in the meta-analysis. Twenty-nine additional studies were only used for descriptive data.

Risk of bias in individual studies

Seventeen prospective studies[17-33], four randomized controlled trials[34-37], one non-randomized controlled trial[38], two randomized trials[39,40], and 21 retrospective studies were included[8,25,41-59]. An overview of the methodological quality assessment is provided in *Supplementary Table S1*. In 20 studies, the effect of age on treatment outcome or recurrence was the primary research aim[8,18,23,25,26,29-31,42,43,48-52,54-57,59]. The statistical procedure was well described in 22 of 45 studies. The assessment of treatment efficacy and recurrence rate was described in 29 and 23 studies, respectively. Fifteen studies only included canalolithiasis-type

BPPV[19,20,23,25,27,31-33,38,40,41,44-47], eleven studies also included cupulolithiasis-type BPPV[8,18,22,24,28,39,48,50,55,57,59], and 19 studies did not specify the type of BPPV.

Subject and study characteristics

Across the 45 included studies, a total of 11,451 BPPV patients were included. Their mean age ranged from 48[38] to 72[32] years (Table 1, Supplementary Table S2). In 25 studies, only BPPV of the posterior canal was included[17,19,20,23,25,27-29,32-37,39-41,45-47,51,53,54,56,60], while 18 studies also included horizontal and/or anterior canal BPPV[8,18,21,22,24,26,30,31,38,42,43,48-50,55,57-59], and two studies did not report information on canal involvement[44,52]. Based on the diagnostic tests (i.e., Dix-Hallpike) it could reasonably be assumed that posterior canal BPPV was included in these articles[44,52]. In 23 studies, a diagnosis of BPPV was confirmed via Dix-Hallpike maneuver (DH)[17,19-21,23,27-29,32,34,35,37,39,41,42,44-47,53,54,56,60], while fourteen studies used both DH and the roll test[7,18,25,26,32,31,38,43,49,50,55,57-59]. One study did not specify the diagnostic maneuver[22]. Eleven studies used Frenzel goggles to confirm diagnosis[18,22,28,29,36,39-41,46,49,60], while ten studies used other visual-suppression systems[21,30,31,35,42,48,50,55,59,60].

Characteristics of the treatment procedure

The time between the onset of symptoms and the start of therapy ranged, on average, from less than 24 hours[23] to 20 months[45]. The Epley maneuver or modified Epley maneuver was performed in 14[8,23-26,35,37,39,44,55-58] and 10 studies, respectively,[18-20,23,33,38,39,50,54,59], sometimes in combination with medication[55], vibrations[18], or Brandt-Daroff exercises[39,59]. Seven studies used a Semont Maneuver[18,28-30,32,41,51], of which one occurred in combination with medication intake[32]. One study combined a Semont maneuver with a Galletti-Contrino maneuver[21]. Five studies chose between the Epley and Semont maneuver[17,36,40,43,49], and five studies did not specify which CRP was used[27,42,45,52,53]. The total number of CRPs varied from

one[23,24,27,28,35,37,41,45,46,55] to seven[42] maneuvers. *Table 1 and Supplementary Table S2* provide a detailed description of the study and treatment characteristics.

The influence of age on treatment success

Treatment efficacy after one maneuver

Sixteen studies evaluated the effect of age on the success rate after one maneuver (*Supplementary Table S3*), of which ten could be included in a meta-analysis (Figure 1A).

A significantly higher success rate was found in the younger age group (OR 1.47; 95% CI 1.23 – 1.77). Non-significant heterogeneity was found (p=0.64), as well as consistency between the studies (I^2=0%).

Of the six articles without numeric age-group data, five studies found no influence of age on treatment outcome after one CRP[23,28,36,41,60]. Korres *et al.* (2005) found a better initial response to treatment in the younger age group (p<.001)[50].

Number of maneuvers needed for successful treatment

Ten studies reported the influence of age on the number of maneuvers needed for successful treatment[8,20,22,31,38,42,48,49,54,59] (*Supplementary Table S3*), of which seven could be used in a meta-analysis (Figure 1B). An average of 1.4 and 1.5 maneuvers were needed for complete resolution in the younger and older groups, respectively (p=0.02). Non-significant heterogeneity was found (p=0.16), as well as consistency between the studies (I^2=36%). Batuecas et al. (2014) showed that adults aged 70 and older had twice the chance of requiring three or more CRPs as compared to younger adults (p=0.02)[8]. In contrast, two studies found no relation between the number of CRPs and age[22,38].

Global treatment efficacy

The influence of age on general treatment efficacy was reported in 21 studies (*Supplementary Table S3*)[18,21,29,32-37,39,40,44,48-51,53-55,58,59], of which eight could be used in a meta-analysis (Fig. 1C). A scoring correction was applied for studies in which a 100% treatment efficacy was found (n=4)[48,49,54,59] to enable their inclusion in the meta-analysis. A detailed description of this correction can be consulted in Supplementary Text S3. The overall treatment efficacy did not differ between the two groups (p=0.41), even though the implemented scoring correction was slightly (but negligibly) in favor of the younger age group. In the younger age group, 97.5% of patients were treated successfully, whereas 94.6% of the older age group was treated successfully. Non-significant heterogeneity was found (p=0.19), as well as consistency between the studies (I^2=30%).

Residual dizziness after successful treatment

Five studies reported residual dizziness, i.e., unsteadiness or lightheadedness without positional nystagmus, after successful treatment for BPPV[24,25,27,30,58]. The influence of age on residual dizziness is inconclusive. Two studies found a significantly higher incidence of residual dizziness with increasing age using a regression analysis [25,30]. Also, the duration of residual dizziness increased with age[30]. Three studies did not find an age-related effect on residual dizziness[24,27,58.]

The influence of age on recurrence rate

The effect of age on recurrence rate was evaluated in 20 studies[8,17-19,22,26,29,31,38,43-48,50,52,55-57] (see *Supplementary Table S3*), of which seven could be included in a meta-analysis (Fig. 1D).

A lower recurrence rate was significantly associated with younger age (OR 0.75; 95% CI 0.61;0.92). Non-significant heterogeneity was found (p=0.46), as well as consistency between the studies (I^2=0%).

Two studies supported these findings[26,50]. Korres *et al.* (2005) did not specify age cut-off value, while Prokopakis *et al.* (2013) had an age cut-off value of 70 years. Eleven studies found no significant relationship between age and recurrence rate[17-19,22,29,44-47,52,55].

Two studies reported no association between time to recurrence and increasing age[45,46], whereas Kao *et al.* (2009) found a longer symptom-free duration before recurrence with higher age[48].

DISCUSSION

This is the first systematic review and meta-analysis examining the effect of age, based on precisely defined age groups, on treatment efficacy and recurrence rate in people with BPPV. The success rate of a single CRP was significantly higher in the younger group as compared to the older group. Overall, the younger group needed 0.1 fewer CRPs as compared to the older group to obtain complete recovery. Even though this discrepancy is statistically significant, the difference is minimal and not clinically important. Indeed this result indicates that only one in ten older adults will require an additional CRP to obtain complete recovery from BPPV as compared to the younger adults. In addition, the rate of complete recovery (i.e., global treatment efficacy) is equal for older and younger adults. However, likely due to the more accurate and reliable division of age groups in our study, we were able to demonstrate that

the recurrence rate is significantly higher for older adults as compared to younger adults, in contrast to the study of Sim et al. (2019).

This is the first meta-analysis examining the effect of age on the success of a single CRP and the total number of CRPs needed for recovery. The findings were supported by some[8, 50] but not all articles used in the qualitative review. A major part of the included articles did not find an age-related effect. The discrepancy may be related to the large variation in the applied protocols, a potential lack of power, and the moderate quality of these studies. The statistical procedure was not well described in 23 of 45 studies, and none of the included articles performed a power calculation *a priori*. Furthermore, studies that did not find an age-related effect on treatment outcome had a shorter follow-up time, ranging from 1h to 96hrs[35,39], whereas the guidelines recommend performing a re-assessment after one month[11].

This is the first systematic review examining the effect of age on residual dizziness. The results regarding residual dizziness were inconclusive. The two studies indicating that older adults were prone to residual dizziness measured this outcome 2 to 3 days[25,28] after the treatment, whereas the other studies evaluated residual dizziness after one week[24,27,58]. Maas et al. (2019) reported that, specifically in older adults, nausea could indeed be a side effect of the Epley maneuver in the first days post-treatment[61].

Potential Explanations for Age Differences in BPPV Treatment Success

Despite the fact that BPPV is the most common vestibular disorder, it has a low recognition rate in primary healthcare, particularly in older adults[4,8,62]. Older adults report disequilibrium or imbalance as the clinical presentation of BPPV, without reporting vertigo. The patient often attributes these symptoms to “ageing” and also takes longer to seek medical attention as

compared to younger adults[7,8,10]. These complaints are often misdiagnosed and attributed to other medical, neurological, or age-related changes, resulting in a delayed diagnosis of BPPV in older adults[9,10,11]. The effect of this delayed diagnosis on treatment effectiveness is still unclear. Batuecas et al. (2013) found that the success rate of the treatment of BPPV decreases the longer the symptoms remain untreated[8]. Others claim that symptom duration is irrelevant to treatment outcome[24,39,50].

The degeneration of the vestibular system may lead to deformities of the semicircular canals in older adults. Furthermore, the continuous demineralization of otoconia that causes detachment from the otoconial membrane can make treatment less effective in older adults[63].

An insufficient ability to rotate and hyperextend the neck may also be one of the reasons older adults require a higher number of maneuvers to obtain complete resolution[8,31]. More precisely, limited neck rotation, spinal arthritis, or other illnesses that require some modification of the standard CRP can impair the effectiveness of the repositioning[42].

Older adults (>70 years) experience significantly more discomfort, nausea, and pain in the neck and back directly after the Epley maneuver and are approximately 2.5 times more likely to refuse potential retreatment as compared to younger adults (<70 years)[61]. Older adults may refuse retreatment due to anxiety, nausea, and a lack of faith in the effectiveness of the treatment, while younger adults may refuse retreatment because of logistic problems and the belief that retreatment would be more incapacitating than their remaining symptoms. Therefore, education on treatment benefits and the impact of BPPV on both daily activities and quality of life is extremely important, especially in older adults because retreatment is often necessary in this group.

Explanations for age differences in recurrence rate

In general, older adults are less mobile and physically active than younger adults, spending longer time periods in a lounging or lying down position, resulting in a higher probability of developing BPPV and a higher risk of recurrence[31]. Also, older adults are less frequently exposed to symptom-provoking movements, potentially explaining the longer symptom free duration before BPPV recurred[48].

In addition, osteoporosis and the protracted state of vitamin D deficiency, which are inevitably related to one another, are significantly associated with a higher recurrence of BPPV[4,38]. Low vitamin D levels affect the bone and the inner ear directly by opening the calcium channels in the gut, stimulating the absorption of calcium, and indirectly via parathyroid hormone (PTH) release[4,64,65]. The release of PTH stimulates the absorption of calcium in the entire body. In the inner ear, calcium carbonate will be absorbed from the otoconia, potentially leading to the fragmentation of the otoconia[4]. In turn, the displacement of these otoconial fragments into the SCCs may cause a recurrence of BPPV[4, 65]. Furthermore, due to the increased calcium resorption in the inner ear, the endolymphatic free-calcium concentration rises, resulting in a diminished capacity to dissolve these dislodged otoconial fragments[65].

Strengths and limitations

This review has several strengths. First, the study selection was performed by two independent reviewers in two databases (i.e., Web of Science and Pubmed). Second, a detailed methodological quality assessment was carried out by three independent reviewers. In both cases, the reviewers discussed the results until a consensus was reached. In addition

to English, articles in Dutch, French, and German were also included. However, some additional information may have been missed due to the remaining language limitations.

Treatment effectiveness and recurrence rate were analyzed using young and old age groups within each article, if such were present, whereas Sim *et al.* (2019) attributed complete articles to either the young or old age group[15]. However, not all included articles investigated the effect of age as a primary goal, and only a minority of studies defined age groups *a priori*. This negatively influenced the assessment of methodological quality in terms of our research question. Still, for most outcome variables, sufficient studies could be included in a meta-analysis. The included studies had a great range in sample size. However, none of the articles performed a power calculation *a priori*. Differences in functional limitations, symptomatology, or time between the onset of symptoms and the diagnosis between younger and older adults on the one hand and a lack of high-quality articles with age as a primary outcome on the other hand make it difficult to provide additional recommendations regarding the appropriate treatment approach in older adults.

Future directions

The results show that the rate of complete recovery in older adults is similar to that in younger adults, even though older adults are more exposed to the disease and require more treatment sessions[39]. The longer treatment duration keeps older people longer at risk of falling. This adds to the already increased risk of falling in older adults as compared to healthy older adults[8,10]. However, balance improves after BPPV with positioning maneuvers[35] and normalizes again to the balance of healthy controls. Still, dynamic balance recovery takes longer for older adults[66], which is highly important in fall prevention. Correct

and timely BPPV diagnosis can decrease the risk of falling. Therefore, future studies should focus on a rapid diagnosis of BPPV in older adults with an increased fall risk.

To limit fall risk, a follow-up should be provided, especially for older adults because they are at a higher risk of recurrence. Parham et al. (2016) stated that the management of BPPV will need to evolve beyond the treatment of acute episodes. It should evolve into global management with education and the prevention of recurrence via monitoring and treating risk factors related to the recurrence of BPPV (i.e., Vitamin D deficiency)[4]. Patients should be educated about predictive symptoms indicating a recurrence of BPPV (i.e., positional vertigo lasting ≤1 minute, nausea, and the feeling of being "off balance") and what to do when they experience a recurrence[11]. Moreover, treating physicians should keep in mind that older adults require a longer time to recover from BPPV and the chances of recurrence are higher. Future studies should examine the effect of post-treatment physical activity in older adults on recurrence rate in this population.

Conclusion

The overall treatment efficacy for BPPV is similar in younger and older adults. Nevertheless, the recognition of the condition in the older population is more complex, treatment requires more CRPs (due to degeneration of the vestibular system, decreased neck mobility and cooperation), and the risk of recurrence is greater.

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Conflict of Interest Checklist:

Elements of Financial/Personal Conflicts	GL		LV		NH		EV		LC		JS	
	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Employment or Affiliation		X		X		X		X		X		X
Grants/Funds		X		X		X		X	X			X
Honoraria		X		X		X		X		X		X
Speaker Forum		X		X		X		X		X		X

Consultant		X		X		X		X		X		X
Stocks		X		X		X		X		X		X
Royalties		X		X		X		X		X		X
Expert Testimony		X		X		X		X		X		X
Board Member		X		X		X		X		X		X
Patents		X		X		X		X		X		X
Personal Relationship		X		X		X		X		X		X

***Authors can be listed by abbreviations of their names**

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REFERENCES

1. Neuhauser HK. The epidemiology of dizziness and vertigo. *Handb Clin Neurol*. 2016;137:67-82. doi:10.1016/b978-0-444-63437-5.00005-4

2. Jönsson R, Sixt E, Landahl S, Rosenhall U. Prevalence of dizziness and vertigo in an urban elderly population. *J Vestib Res*. 2004;14(1):47-52.

3. Neuhauser H, Leopold M, von Brevern M, Arnold G, Lempert T. The interrelations of migraine, vertigo, and migrainous vertigo. *Neurology*. 2001;56(4):436-441. doi:10.1212/wnl.56.4.436

4. Parham K, Kuchel GA. A Geriatric Perspective on Benign Paroxysmal Positional Vertigo. *J Am Geriatr Soc*. Feb 2016;64(2):378-85. doi:10.1111/jgs.13926

5. von Brevern M, Radtke A, Lezius F, et al. Epidemiology of benign paroxysmal positional vertigo: a population based study. *J Neurol Neurosurg Psychiatry*. Jul 2007;78(7):710-5. doi:10.1136/jnnp.2006.100420

6. Bisdorff A, Von Brevern M, Lempert T, Newman-Toker DE. Classification of vestibular symptoms: towards an international classification of vestibular disorders. *J Vestib Res*. 2009;19(1-2):1-13. doi:10.3233/ves-2009-0343

7. Dros J, Maarsingh OR, Beem L, et al. Impact of dizziness on everyday life in older primary care patients: a cross-sectional study. *Health and Quality of Life Outcomes*. 2011/06/16 2011;9(1):44. doi:10.1186/1477-7525-9-44

8. Batuecas-Caletrio A, Trinidad-Ruiz G, Zschaeck C, et al. Benign paroxysmal positional vertigo in the elderly. *Gerontology*. 2013;59(5):408-12. doi:10.1159/000351204

9. Barin K, Dodson EE. Dizziness in the elderly. *Otolaryngol Clin North Am*. Apr 2011;44(2):437-54, x. doi:10.1016/j.otc.2011.01.013

10. Oghalai JS, Manolidis S, Barth JL, Stewart MG, Jenkins HA. Unrecognized benign paroxysmal positional vertigo in elderly patients. *Otolaryngol Head Neck Surg*. May 2000;122(5):630-4. doi:10.1067/mhn.2000.105415

11. Bhattacharyya N, Gubbels SP, Schwartz SR, et al. Clinical Practice Guideline: Benign Paroxysmal Positional Vertigo (Update). *Otolaryngol Head Neck Surg*. Mar 2017;156(3_suppl):S1-s47. doi:10.1177/0194599816689667

12. von Brevern M, Lezius F, Tiel-Wilck K, Radtke A, Lempert T. Benign paroxysmal positional vertigo: current status of medical management. *Otolaryngol Head Neck Surg*. Mar 2004;130(3):381-2. doi:10.1016/j.otohns.2003.07.007

13. Agrawal Y, Ward BK, Minor LB. Vestibular dysfunction: prevalence, impact and need for targeted treatment. *J Vestib Res*. 2013;23(3):113-7. doi:10.3233/ves-130498

14. Liao WL, Chang TP, Chen HJ, Kao CH. Benign paroxysmal positional vertigo is associated with an increased risk of fracture: a population-based cohort study. *J Orthop Sports Phys Ther*. May 2015;45(5):406-12. doi:10.2519/jospt.2015.5707

15. Moher D, Shamseer L, Clarke M, et al. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Syst Rev*. Jan 1 2015;4(1):1. doi:10.1186/2046-4053-4-1

16. Bown MJ, Sutton AJ. Quality Control in Systematic Reviews and Meta-analyses. *European Journal of Vascular and Endovascular Surgery*. 2010/11/01/ 2010;40(5):669-677. doi:https://doi.org/10.1016/j.ejvs.2010.07.011

17. Anagnostou E, Mandellos D, Patelarou A, Anastasopoulos D. Benigner paroxysmaler Lagerungsschwindel mit und ohne manifesten Lagerungsnystagmus. *HNO*. 2007/03/01 2007;55(3):190-194. doi:10.1007/s00106-006-1458-8

18. Babac S, Djeric D, Petrovic-Lazic M, Arsovic N, Mikic A. Why do treatment failure and recurrences of benign paroxysmal positional vertigo occur? *Otol Neurotol*. Jul 2014;35(6):1105-10. doi:10.1097/mao.0000000000000417

19. Beynon GJ, Baguley DM, da Cruz MJ. Recurrence of symptoms following treatment of posterior semicircular canal benign positional paroxysmal vertigo with a particle repositioning manoeuvre. *J Otolaryngol*. Feb 2000;29(1):2-6.

20. Casqueiro JC, Ayala A, Monedero G. No more postural restrictions in posterior canal benign paroxysmal positional vertigo. *Otol Neurotol*. Aug 2008;29(5):706-9. doi:10.1097/MAO.0b013e31817d01e8

21. Ciodaro F, Mannella VK, Nicita RA, et al. Therapeutic efficacy of the Galletti-Contrino manoeuvre for benign paroxysmal positional vertigo of vertical semicircular canals in overweight subjects. *Eur Arch Otorhinolaryngol*. Oct 2018;275(10):2449-2455. doi:10.1007/s00405-018-5086-1

22. Do YK, Kim J, Park CY, Chung MH, Moon IS, Yang HS. The effect of early canalith repositioning on benign paroxysmal positional vertigo on recurrence. *Clin Exp Otorhinolaryngol*. Sep 2011;4(3):113-7. doi:10.3342/ceo.2011.4.3.113

23. Domínguez-Durán E, Domènech-Vadillo E, Álvarez-Morujo de Sande MG, et al. Analysis of risk factors influencing the outcome of the Epley maneuver. *Eur Arch Otorhinolaryngol*. Oct 2017;274(10):3567-3576. doi:10.1007/s00405-017-4674-9

24. Kim H-A, Lee H. Autonomic dysfunction as a possible cause of residual dizziness after successful treatment in benign paroxysmal positional vertigo. *Clinical Neurophysiology*. 2014/03/01/ 2014;125(3):608-614. doi:https://doi.org/10.1016/j.clinph.2013.08.008

25. Martellucci S, Pagliuca G, de Vincentiis M, et al. Features of Residual Dizziness after Canalith Repositioning Procedures for Benign Paroxysmal Positional Vertigo. *Otolaryngol Head Neck Surg*. Apr 2016;154(4):693-701. doi:10.1177/0194599815627624

26. Prokopakis E, Vlastos IM, Tsagournisakis M, Christodoulou P, Kawauchi H, Velegrakis G. Canalith repositioning procedures among 965 patients with benign paroxysmal positional vertigo. *Audiol Neurootol*. 2013;18(2):83-8. doi:10.1159/000343579

27. Seo T, Shiraishi K, Kobayashi T, et al. Residual dizziness after successful treatment of idiopathic benign paroxysmal positional vertigo originates from persistent utricular dysfunction. *Acta Otolaryngol*. Nov 2017;137(11):1149-1152. doi:10.1080/00016489.2017.1347824

28. Soto-Varela A, Rossi-Izquierdo M, Santos-Pérez S. Can we predict the efficacy of the semont maneuver in the treatment of benign paroxysmal positional vertigo of the posterior semicircular canal? *Otol Neurotol*. Aug 2011;32(6):1008-11. doi:10.1097/MAO.0b013e3182267f02

29. Soto-Varela A, Rossi-Izquierdo M, Martínez-Capoccioni G, Labella-Caballero T, Santos-Pérez S. Benign paroxysmal positional vertigo of the posterior semicircular canal: efficacy of Santiago treatment protocol, long-term follow up and analysis of recurrence. *J Laryngol Otol*. Apr 2012;126(4):363-71. doi:10.1017/s0022215111003495

30. Teggi R, Giordano L, Bondi S, Fabiano B, Bussi M. Residual dizziness after successful repositioning maneuvers for idiopathic benign paroxysmal positional vertigo in the elderly. *Eur Arch Otorhinolaryngol*. Apr 2011;268(4):507-11. doi:10.1007/s00405-010-1422-9

31. Yeo SC, Ahn SK, Lee HJ, et al. Idiopathic benign paroxysmal positional vertigo in the elderly: a long-term follow-up study. *Aging Clin Exp Res*. Feb 2018;30(2):153-159. doi:10.1007/s40520-017-0763-2

32. Cavaliere M, Mottola G, Iemma M. Benign paroxysmal positional vertigo: a study of two manoeuvres with and without betahistine. *Acta Otorhinolaryngol Ital*. Apr 2005;25(2):107-12.

33. Radtke A, Neuhauser H, von Brevern M, Lempert T. A modified Epley's procedure for self-treatment of benign paroxysmal positional vertigo. *Neurology*. Oct 12 1999;53(6):1358-60. doi:10.1212/wnl.53.6.1358

34. Bruintjes TD, Companjen J, van der Zaag-Loonen HJ, van Benthem PP. A randomised sham-controlled trial to assess the long-term effect of the Epley manoeuvre for treatment of posterior canal benign paroxysmal positional vertigo. *Clin Otolaryngol*. Feb 2014;39(1):39-44. doi:10.1111/coa.12217

35. Cohen HS, Kimball KT. Effectiveness of treatments for benign paroxysmal positional vertigo of the posterior canal. *Otol Neurotol*. Sep 2005;26(5):1034-40. doi:10.1097/01.mao.0000185044.31276.59

36. Oh SY, Kim JS, Choi KD, et al. Switch to Semont maneuver is no better than repetition of Epley maneuver in treating refractory BPPV. *J Neurol*. Sep 2017;264(9):1892-1898. doi:10.1007/s00415-017-8580-2

37. Simoceli L, Bittar RS, Greters ME. Posture restrictions do not interfere in the results of canalith repositioning maneuver. *Braz J Otorhinolaryngol*. Jan-Feb 2005;71(1):55-9. doi:10.1016/s1808-8694(15)31285-4

38. Jang YS, Kang MK. Relationship between bone mineral density and clinical features in women with idiopathic benign paroxysmal positional vertigo. *Otol Neurotol*. Jan 2009;30(1):95-100. doi:10.1097/MAO.0b013e31818f5777

39. Wolf M, Hertanu T, Novikov I, Kronenberg J. Epley's manoeuvre for benign paroxysmal positional vertigo: a prospective study. *Clin Otolaryngol Allied Sci*. Feb 1999;24(1):43-6. doi:10.1046/j.1365-2273.1999.00202.x

40. Radtke A, von Brevern M, Tiel-Wilck K, Mainz-Perchalla A, Neuhauser H, Lempert T. Self-treatment of benign paroxysmal positional vertigo: Semont maneuver vs Epley procedure. *Neurology*. Jul 13 2004;63(1):150-2. doi:10.1212/01.wnl.0000130250.62842.c9

41. Albera A, Boldreghini M, Canale A, Albera R, Gervasio CF. Vertigo returning to the sitting position after the Semont manoeuvre. Is it a prognostic symptom? *Acta Otorhinolaryngol Ital*. Apr 2018;38(2):145-150. doi:10.14639/0392-100x-1815

42. Macias JD, Lambert KM, Massingale S, Ellensohn A, Fritz JA. Variables affecting treatment in benign paroxysmal positional vertigo. *Laryngoscope*. Nov 2000;110(11):1921-4. doi:10.1097/00005537-200011000-00029

43. Zhu CT, Zhao XQ, Ju Y, Wang Y, Chen MM, Cui Y. Clinical Characteristics and Risk Factors for the Recurrence of Benign Paroxysmal Positional Vertigo. *Front Neurol*. 2019;10:1190. doi:10.3389/fneur.2019.01190

44. Dornhoffer JL, Colvin GB. Benign paroxysmal positional vertigo and canalith repositioning: clinical correlations. *Am J Otol*. Mar 2000;21(2):230-3. doi:10.1016/s0196-0709(00)80014-9

45. Hain TC, Helminski JO, Reis IL, Uddin MK. Vibration Does Not Improve Results of the Canalith Repositioning Procedure. *Archives of Otolaryngology–Head & Neck Surgery*. 2000;126(5):617-622. doi:10.1001/archotol.126.5.617

46. Helminski JO, Janssen I, Kotaspouikis D, et al. Strategies to Prevent Recurrence of Benign Paroxysmal Positional Vertigo. *Archives of Otolaryngology–Head & Neck Surgery*. 2005;131(4):344-348. doi:10.1001/archotol.131.4.344

47. Kansu L, Avci S, Yilmaz I, Ozluoglu LN. Long-term follow-up of patients with posterior canal benign paroxysmal positional vertigo. *Acta Otolaryngol*. Sep 2010;130(9):1009-12. doi:10.3109/00016481003629333

48. Kao CL, Hsieh WL, Chern CM, Chen LK, Lin MH, Chan RC. Clinical features of benign paroxysmal positional vertigo (BPPV) in Taiwan: differences between young and senior age groups. *Arch Gerontol Geriatr*. Dec 2009;49 Suppl 2:S50-4. doi:10.1016/s0167-4943(09)70014-7

49. Korkmaz M, Korkmaz H. Cases requiring increased number of repositioning maneuvers in benign paroxysmal positional vertigo. *Braz J Otorhinolaryngol*. Jul-Aug 2016;82(4):452-7. doi:10.1016/j.bjorl.2015.08.018

50. Korres S, Balatsouras DG, Ferekidis E. Prognosis of patients with benign paroxysmal positional vertigo treated with repositioning manoeuvres. *J Laryngol Otol*. Jul 2006;120(7):528-33. doi:10.1017/s0022215106000958

51. Levrat E, van Melle G, Monnier P, Maire R. Efficacy of the Semont maneuver in benign paroxysmal positional vertigo. *Arch Otolaryngol Head Neck Surg*. Jun 2003;129(6):629-33. doi:10.1001/archotol.129.6.629

52. Luryi AL, Lawrence J, Bojrab DI, et al. Recurrence in Benign Paroxysmal Positional Vertigo: A Large, Single-Institution Study. *Otol Neurotol*. Jun 2018;39(5):622-627. doi:10.1097/mao.0000000000001800

53. Monobe H, Sugasawa K, Murofushi T. The outcome of the canalith repositioning procedure for benign paroxysmal positional vertigo: are there any characteristic features of treatment failure cases? *Acta Otolaryngol Suppl*. 2001;545:38-40. doi:10.1080/000164801750388081

54. Moreno NS, Rego André APd. Number of maneuvers need to get a negative Dix-Hallpike test. *Brazilian Journal of Otorhinolaryngology*. 2009/09/01/ 2009;75(5):650-653. doi:https://doi.org/10.1016/S1808-8694(15)30512-7

55. Otsuka K, Ogawa Y, Inagaki T, et al. Relationship between clinical features and therapeutic approach for benign paroxysmal positional vertigo outcomes. *J Laryngol Otol*. Oct 2013;127(10):962-7. doi:10.1017/s0022215113001990

56. Su P, Liu YC, Lin HC. Risk factors for the recurrence of post-semicircular canal benign paroxysmal positional vertigo after canalith repositioning. *J Neurol*. Jan 2016;263(1):45-51. doi:10.1007/s00415-015-7931-0

57. Tanimoto H, Doi K, Nishikawa T, Nibu K. Risk factors for recurrence of benign paroxysmal positional vertigo. *J Otolaryngol Head Neck Surg*. Dec 2008;37(6):832-5.

58. Wei W, Sayyid ZN, Ma X, Wang T, Dong Y. Presence of Anxiety and Depression Symptoms Affects the First Time Treatment Efficacy and Recurrence of Benign Paroxysmal Positional Vertigo. *Front Neurol*. 2018;9:178. doi:10.3389/fneur.2018.00178

59. Yoon J, Lee JB, Lee HY, Lee BD, Lee CK, Choi SJ. Potential Risk Factors Affecting Repeated Canalith Repositioning Procedures in Benign Paroxysmal Positional Vertigo. *Otol Neurotol*. Feb 2018;39(2):206-211. doi:10.1097/mao.0000000000001634

60. Martellucci S, Attanasio G, Ralli M, et al. Does cervical range of motion affect the outcomes of canalith repositioning procedures for posterior canal benign positional paroxysmal vertigo? *Am J Otolaryngol*. Jul-Aug 2019;40(4):494-498. doi:10.1016/j.amjoto.2019.04.003

61. Maas B, Bruintjes TD, van der Zaag-Loonen HJ, et al. Physical and Emotional Burden of the Epley Maneuver in the Elderly. *Otol Neurotol*. Sep 2019;40(8):1082-1087. doi:10.1097/mao.0000000000002326

62. Ekvall Hansson E, Månsson NO, Håkansson A. Benign paroxysmal positional vertigo among elderly patients in primary health care. *Gerontology*. Nov-Dec 2005;51(6):386-9. doi:10.1159/000088702

63. Balatsouras DG, Koukoutsis G, Fassolis A, Moukos A, Apris A. Benign paroxysmal positional vertigo in the elderly: current insights. *Clin Interv Aging*. 2018;13:2251-2266. doi:10.2147/cia.S144134

64. Lips P, van Schoor NM. The effect of vitamin D on bone and osteoporosis. *Best Pract Res Clin Endocrinol Metab*. Aug 2011;25(4):585-91. doi:10.1016/j.beem.2011.05.002

65. Vibert D, Kompis M, Häusler R. Benign paroxysmal positional vertigo in older women may be related to osteoporosis and osteopenia. *Ann Otol Rhinol Laryngol*. Oct 2003;112(10):885-9. doi:10.1177/000348940311201010

66. Chen Z-J, Chang C-H, Hu L-Y, et al. Increased risk of benign paroxysmal positional vertigo in patients with anxiety disorders: a nationwide population-based retrospective cohort study. *BMC Psychiatry*. 2016/07/15 2016;16(1):238. doi:10.1186/s12888-016-0950-2

TABLES

Table 1 – Simplified study characteristics table

GENERAL STUDY CHARACTERISTICS					TREATMENT CHARACTERISTICS	
AGE GROUPS DEFINED A PRIORI						
Author	**Type of study**	**n =**	**Mean age (years) ± SD**	**% PSCC**	**Treatment**	**Max # CRPs**
Anagnostou et al. (2007)[17]	Prospective study	70	59.5 ± 13.3	100	Epley/Semont	N.S.
Batuecas-Caletrio et al. (2013)[8]	Retrospective cohort study	404	N.S.	82.5	Epley/Lempert/Yacovino	>3
Jang et al. (2009)[38]	Prospective study	78	48,0	39	Modified Epley + PR/ Barbecue + PR	5
Simoceli et al. (2005)[37]	Randomized prospective study	50	60.9 ± 15.3	100	Epley (2X) with/without PR	1
Yeo et al. (2018)[31]	Prospective study, record review	370	59.5 ± 12.3	54.6	Reverse Epley/modified Epley /360° Barbecue	N.S.
Zhu et al. (2019)[43]	Retrospective study	1012	N.S.	76.2	Epley / Semont/ Lempert / Barbecue + Gufoni / modified Semont	N.S.
AGE AS A COVARIATE						
Author	**Type of study**	**n =**	**Mean age (years) ± SD**	**% PSCC**	**Treatment**	**Max # CRPs**
Beynon et al. (2000)[19]	Prospective consecutive series	51	60 ± 13	100	Modified Epley	2

Bruintjes et al. (2014)[34]	Randomized, double-blind, sham-controlled trial	44	59.1 ± 13	100	Epley + PR/ Sham intervention + PR	2
Ciodaro et al. (2018)[21]	Prospective cohort study	408	N.S.	100	Galletti-Contrino/ Semont	2
Cohen et al. (2005)[35]	Prospective, randomized, sham-controlled	124	58.3 ± 12.8	100	Modified CRP/ modified liberatory maneuver/ Brandt-Daroff exercises/ vertigo habituation exercises/sham maneuver	1
Do et al. (2011)[22]	Prospective study	138	51.6 ± 16.4	55.8	Modified Epley/Barbecue	N.S.
Hain et al. (2000)[45]	Retrospective case review	94	58 ± 16	100	CRP with/without vibration + PR	1
Korkmaz et al. (2016)[49]	Retrospective study	153	53.6	87.6	Semont/ Epley/Barbecue + PR	5
Levrat et al. (2003)[51]	Retrospective study	278	Median age 55.5	100	Semont	4
Martellucci et al. (2016)[25]	Prospective cohort study	86	58.2 ± 15	100	Epley	4
Oh et al. (2017)[36]	Prospective randomized controlled trial	506	64 ± 12	100	Epley/Semont	2
Radtke et al. (2004)[40]	Prospective randomized study	70	60 ± 12	100	Epley/Semont	3x daily
Tanimoto et al. (2008)[57]	Retrospective chart review	145	60	72	Epley/Lempert/no treatment	N.S.
Teggi et al. (2011)[30]	Prospective study	60	72 ± 4	76.7	Semont/Gufoni + Lempert/Modified Epley	>3
Wei et al. (2018)[58]	Retrospective study	127	53.9 ± 13.9	84.2	Epley/Barbecue	N.S.
Wolf et al. (1999)[39]	Prospective study	41	N.S.	100	Epley	N.S.
Yoon et al. (2018)[59]	Retrospective study	1426	54.9	39.1	Modified Epley with/without Brandt-Daroff +PR/ Barbecue with vibrations + PR	7
AGE AS A UNIVARIATE FACTOR						

Author	Type of study	n =	Mean age (years) ± SD	% PSCC	Treatment	Max # CRPs
Albera et al. (2018)[41]	Retrospective cohort study	113	62.6 ± 12	100	Semont	1
Babac et al. (2014)[18]	Prospective cohort study	400	58.7 ± 12	86	Modified Epley/semont/ barbecue /inverted Gufoni / Kim Maneuver	4
Casqueiro et al. (2008)[20]	Prospective double-blind consecutive case study	391	57.2	100	Epley with/without PR	5
Cavaliere et al. (2005)[32]	Prospective study	103	N.S.	100	Semont with/without betahistine. Brandt-Daroff with/without betahistine.	N.S.
Dominguez-Duran et al. (2017)[23]	Observational prospective multicenter study	234	62	100	Epley + PR	1
Dornhoffer et al. (2000)[44]	Retrospective study	52	63	N.S.[a]	Epley + PR	3
Helminski et al. (2005)[46]	Retrospective study (and random sample of convenience)	116	57 ± 16	100	Epley with/without vibrations + PR Brandt-Daroff exrcises	1
Kansu et al. (2010)[47]	Retrospective study	118	51.8 ± 14.7	100	CRP with mastoid oscillation + PR	6
Kao et al. (2009)[48]	Retrospective study	218	68.1 ± 14.4	78.4	Epley/Semont/Barbecue	3
Kim et al. (2014)[24]	Prospective study	58	55.8 ± 10	36.2	Epley/Barbecue Maneuver with/without mastoid vibrations + PR/Reverse Epley	1
Korres et al. (2006)[50]	Retrospective study	155	59.9 ± 12.6	82.6	Moddified Epley/Vannucchi	2
Luryi et al. (2018)[52]	Retrospective study	1105	64.6 ± 14.6	N.S[a]	CRP appropriate for the SCC	≥3
Macias et al. (2000)[42]	Retrospective study	259	58.6	93.1	CRP appropriate for the SCC	7
Martellucci et al. (2019)[60]	Retrospective study	47	62.1 ± 13.1	100	Epley	4

Monobe et al. (2001)[53]	Retrospective study	62	Median age of 63	100	CRP + PR	2
Moreno et al. (2009)[54]	Retrospective study	71	54.9	100	Modified Epley	4
Otsuka et al. (2013)[55]	Retrospective study	357	60	65	Epley/Medication/Lempert/non-specific physical techniques	1
Prokopakis et al. (2013)[26]	Prospective study	965	range 18 - 87 years	88	Modified Epley + vibrations+ PR/ modified Barbecue + PR	>3
Radtke et al. (1999)[33]	Prospective study	54	54.8 ± 11.7	100	Brandt-Daroff exercises /Modified Epley.	3x daily BD
Seo et al. (2017)[27]	Prospective study	44	N.S.	100	CRP	1
Soto-Varela et al. (2011)[28]	Prospective study	135	60.9	100	Semont	1
Soto-Varela et al. (2012)[29]	Prospective study	412	58	100	Semont/Epley/Brandt-Daroff exercises	4
Su et al. (2016)[56]	Retrospective study	247	57.5 ± 13.9	100	Epley	6

Note: [a]Based on the diagnostic tests (i.e. Dix-Hallpike) it could be assumed that posterior canal BPPV was included in these articles.

Abbreviations: SD: standard deviation; SCC: semicircular canal; PSCC: posterior semicircular canal; CRP: canalith repositioning procedure; max # CRPs: maximum number of canalith repositioning procedures; PR: postural restrictions

LEGENDS

Figure 1: Impact of age on treatment efficacy after one CRP, number of CRPs and recurrence rate.

A. Impact of age on treatment efficacy after one CRP: comparison of success rate after one maneuver between younger adults (<70 years) and older adults (≥70 years).

*Legend: * Articles with an age cut-off value of 65 years, defining younger adults as persons <65 years and older adults as persons* ≥65 years old*. ** Articles with an age cut-off value of 60 years, defining younger adults as persons <60 years and older adults as persons* ≥60 years old*. A significant result is visualized by the diamond shape not crossing the central vertical line. CI confidence interval, M-H Mantel-Haenszel.*

B. Impact of age on number of maneuvers: comparison of number of CRP between younger(<70 years) adults and older adults (≥70 years)..

*Legend: ** Articles with an age cut-off value of 65 years, defining younger adults as persons <65 years and older adults as persons* ≥65 years old*. CI confidence interval, M-H Mantel-Haenszel.*

C. Impact of age on global treatment efficacy: comparison of global success rate between younger adults (<70 years) and older adults (≥70 years).

*Legend: * Articles with an age cut-off value of 65 years, defining younger adults as persons <65 years and older adults as persons* ≥65 years old*. ** Articles with an age cut-off value of 60 years, defining younger adults as persons <60 years and older adults as persons* ≥60 years old*. CI confidence interval, M-H Mantel-Haenszel*

D. Impact of age on recurrence rate: comparison of recurrence rate between younger adults (<70 years) and older adults (≥70 years).

*Legend: * Articles with an age cut-off value of 65 years, defining younger adults as persons <65 years and older adults as persons* ≥65 years old*, ** Articles with an age cut-off value of 60 years, defining younger adults as persons <60 years and older adults as persons* ≥60 years old*. CI confidence interval, M-H Mantel-Haenszel*

Supplementary Text S1 - Search string

Supplementary Text S2 – Modified version of the SIGN checklist for cohort studies

Supplementary Text S3– Detailed description of the correction for studies reporting 100% global treatment efficacy

Supplementary Figure S1 – Flow chart of the selection process

Supplementary Table S1 – Risk of bias assessment

Supplementary Table S2 – Detailed description characteristics of the included studies

Supplementary Table S3*:* Treatment efficacy and recurrence rate influenced by age.

Supplementary Table S4 – PRISMA 2009 Checklist

1

2

SUPPLEMENTARY MATERIALS

Supplementary Text S1 - Search string

Pubmed

("Benign Paroxysmal Positional Vertigo"[MeSH] OR "Benign Paroxysmal Positional Vertigo"[title/abstract] OR "BPPV"[title/abstract]) AND ("Epley"[title/abstract] OR "Sémont"[title/abstract] OR "Gans"[title/abstract]OR "Reposition"[title/abstract] OR "hybrid"[title/abstract] OR "liberatory"[title/abstract] OR "habituation"[title/abstract] OR "Brandt-Daroff"[title/abstract])

Web of Science

TS=(("Benign Paroxysmal Positional Vertigo" OR "BPPV") AND ("Epley" OR "Sémont" OR "Gans" OR "Reposition"[title/abstract] OR "hybrid"[title/abstract] OR "liberatory" OR "habituation" OR "Brandt-Daroff")) OR TI=(("Benign Paroxysmal Positional Vertigo" OR "BPPV") AND ("Epley" OR "Sémont" OR "Gans" OR "Reposition"[title/abstract] OR "hybrid"[title/abstract] OR "liberatory" OR "habituation" OR "Brandt-Daroff")

Supplementary Text S2 – modified version of the SIGN checklist for cohort studies

1. Was the effect of age on treatment outcome or recurrence the primary goal or clearly stated as a secondary goal of the study?
    a. Yes
    b. No
2. How was the effect of age investigated?
    a. Anterograde composition of age groups
    b. Covariate (analysis of variance, regression analysis)
    c. Retrograde univariate analysis – E.g. recurrence rate used as a grouping variable and mean age/ age groups is compared between outcome groups.
3. Was the statistical procedure to study the age effect well described in the methods section?
    a. Yes
    b. No, but available in results or tables
    c. No, not available in results or tables
4. Which type of BPPV was included (cupulo- versus canalolithiasis)?
    a. Only canalolithiasis
    b. Canalolithiasis and cupulolithiasis
    c. Not reported
5. Which canals were included (studies dealing with anterior or horizontal canal involvement only were excluded a priori)?
    a. Only posterior canal
    b. Posterior canal and horizontal and/or anterior canal
    c. Not reported
6. Were the type of BPPV and the affected canals accounted for in the statistical analysis?
    a. Yes
    b. No
    c. Not applicable (only PSCC canalolithiasis studies)
7. Was the treatment procedure clearly described?
    a. Yes
    b. No
8. Was the assessment of treatment efficacy clearly defined in the methods section?
    a. Yes
    b. No
    c. Not applicable (treatment efficacy not studied)
9. Was the assessment of recurrence clearly defined in the methods section?
    a. Yes
    b. No
    c. Not applicable (recurrence not studied)
10. Were the number of recruited and included participants reported?
    a. Yes: … % included
    b. No
    c. Not applicable (in case of retrospective analysis)
11. Were the dropouts reported?
    a. Yes: … % dropout
    b. No (Q12, N/A)
    c. Not applicable (in case of retrospective analysis)
12. Were dropouts compared to the full participants?

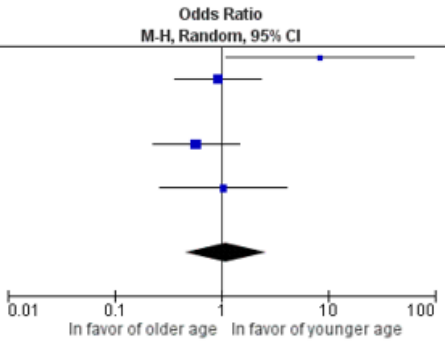
a. Yes
b. No
c. Not applicable

Supplementary Text S3– Detailed description of the correction for studies reporting 100% global treatment efficacy

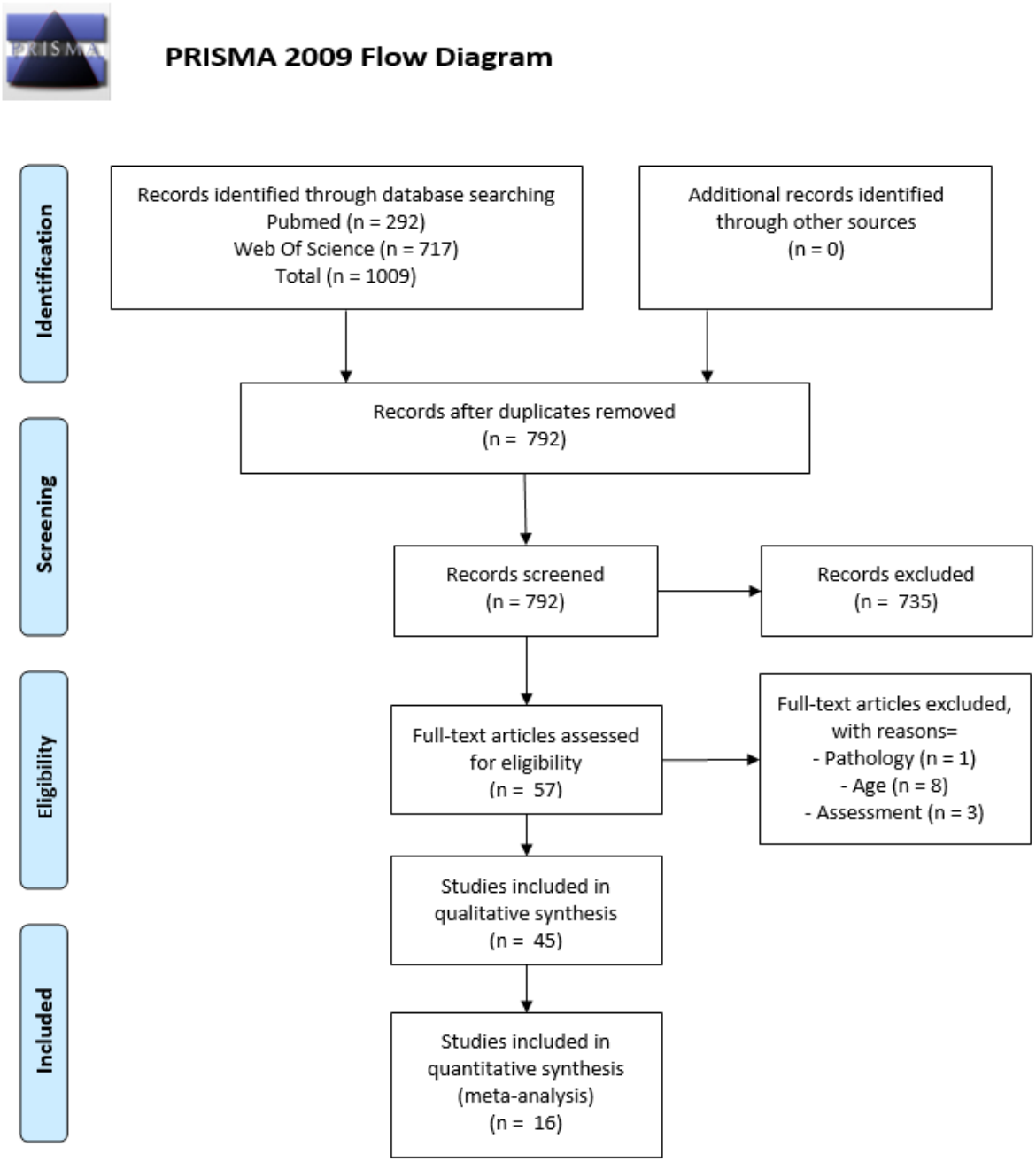
Four of the included studies reported a treatment effectiveness of 100% in the older and the younger group[48, 49, 54, 59]. The odds ratio cannot be calculated for studies if there are no events, therefore a scoring correction of -1 was applied to these studies in both groups based on the Revman handbook chapter 9.2.2.2. Leading to 1 event in the younger and older age group[48, 49, 54, 59]. This correction was unfavorable for the older age group, because the proportion of older adults was smaller (n=851). Although the treatment correction was in favor of the younger age group, the global treatment efficacy did not differ (OR 1.35; 95% CI 0.66 – 2.74).

	Younger age group		Older age group			Odds Ratio
Study or Subgroup	Events	Total	Events	Total	Weight	M-H, Random, 95% CI
Babac et al. (2014)	94	95	280	305	13.6%	8.39 [1.12, 62.79]
Cavaliere et al. (2005)**	50	71	23	32	32.1%	0.93 [0.37, 2.35]
Kao et al. (2009)*	71	71	141	141		Not estimable
Korkmaz et al. (2015)	130	130	23	23		Not estimable
Levrat et al. (2003)	79	92	84	92	31.9%	0.58 [0.23, 1.47]
Moreno et al. (2009)	58	58	13	13		Not estimable
Simocelli et al. (2005)	26	35	11	15	22.4%	1.05 [0.27, 4.15]
Yoon et al. (2017)	1196	1196	230	230		Not estimable
Total (95% CI)		**1748**		**851**	**100.0%**	**1.11 [0.46, 2.65]**
Total events	1704		805			

Heterogeneity: Tau² = 0.39; Chi² = 6.19, df = 3 (P = 0.10); I² = 52%
Test for overall effect: Z = 0.23 (P = 0.81)



Supplementary Figure S1 – Flow chart of the selection process



Supplementary Table S1 – Risk of bias assessment

	Question number											
Author	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Albera et al. (2018)[41]	B	C	B	A	A	C	A	A	C	C	C	C
Anagnostou et al. (2007)[17]	B	A	B	C	A	B	B	C	A	100	B	C
Babac et al. (2014)[18]	A	C	B	B	B	B	A	A	A	B	B	C
Batuecas-Caletrio et al. (2013)[8]	A	A	A	B	B	A	A	A	A	C	C	C
Beynon et al. (2000)[19]	B	B	A	A	A	C	A	A	A	100	0	C
Bruintjes et al. (2014)[34]	B	B	A	C	A	C	A	A	C	7.3	13.6	A
Casqueiro et al. (2008)[20]	B	C	B	A	A	C	A	A	B	100	5.9	B
Cavaliere et al. (2005)[32]	B	C	B	A	A	C	A	A	A	100	B	C
Ciodaro et al. (2018)[21]	B	B	A	C	B	A	A	A	C	B	B	C
Cohen et al. (2005)[35]	B	B	A	C	A	C	A	A	C	B	16.2	B
Do et al. (2011)[22]	B	B	B	B	B	A	A	A	A	100	B	C
Dominguez-Duran et al. (2017)[23]	A	C	B	A	A	C	A	A	C	61	12.7	B
Dornhoffer et al. (2000)[44]	B	C	B	A	A	C	A	A	A	100	A	C
Hain et al. (2000)[45]	B	B	B	A	A	C	A	A	A	C	C	C
Helminski et al. (2005)[46]	B	C	B	A	A	C	A	C	A	B	B	C
Jang et al. (2009)[38]	B	A	A	A	B	A	A	A	C	68	20	B
Kansu et al. (2010)[47]	B	C	B	A	A	C	A	A	A	73.3	C	C
Kao et al. (2009)[48]	A	C	A	B	B	B	A	A	A	B	C	C
Kim et al. (2014)[24]	B	C	A	B	B	A	A	A	C	64.5	0	C
Korkmaz et al. (2016)[49]	A	B	A	C	B	A	A	A	C	C	C	C
Korres et al. (2006)[50]	A	C	A	B	B	A	A	A	A	100	89.6	B
Levrat et al. (2003)[51]	A	B	A	C	A	C	A	A	C	C	C	C
Luryi et al. (2018)[52]	A	C	A	C	C	B	B	C	A	36.7	B	C
Macias et al. (2000)[42]	A	C	B	C	B	A	B	A	C	C	C	C
Martellucci et al. (2016)[25]	A	B	A	A	A	C	A	A	C	100	11.3	B
Martelucci et al. (2019)[60]	B	C	B	C	A	C	A	A	C	100	0	C
Monobe et al. (2001)[53]	B	C	B	C	A	C	A	A	C	C	C	C
Moreno et al. (2009)[54]	A	C	A	C	A	B	A	A	C	C	C	C
Oh et al. (2017)[36]	B	B	A	C	A	B	A	A	C	92	0	C
Otsuka et al. (2013)[55]	A	C	B	B	B	A	A	B	A	9.4	0	C
Prokopakis et al. (2013)[26]	A	C	A	C	B	B	A	A	B	B	7.3	B
Radtke et al. (1999)[33]	B	C	B	A	A	C	A	A	C	87.1	0	C
Radtke et al. (2004)[40]	B	B	B	A	A	C	A	A	C	100	11.4	B
Seo et al. (2017)[27]	B	C	B	A	A	C	A	A	C	72.1	9.1	B
Simoceli et al. (2005)[37]	B	A	B	C	A	C	A	A	C	B	0	C
Soto-Varela et al. (2011)[28]	B	B	A	B	B	B	A	A	A	75.7	1.7	B
Soto-Varela et al. (2012)[29]	A	C	A	C	A	C	A	A	C	100	0	C
Su et al. (2016)[56]	A	B	A	C	A	C	a	A	A	C	1.6	B
Tanimoto et al. (2008)[57]	A	B	B	B	B	A	A	A	A	98	8.3	B
Teggi et al. (2011)[30]	A	B	A	C	B	A	A	A	C	100	0	C
Wei et al. (2018)[58]	B	B	A	C	B	A	A	A	A	92.7	3.8	B

Wolf et al. (1999)[39]	B	B	B	C	A	C	A	A	B	82	B	C
Yeo et al. (2018)[31]	A	A	A	A	B	B	A	A	A	41	0	B
Yoon et al. (2018)[59]	A	B	B	B	B	A	A	A	A	C	B	C
Zhu et al. (2019)[43]	A	A	A	C	B	B	A	A	A	96.7	3.3	B

Supplementary Table S2 – detailed description characteristics of the included studies

GENERAL STUDY CHARACTERISTICS						TREATMENT CHARACTERISTICS				
AGE GROUPS DEFINED A PRIORI										
Author	**Type of study**	**Included (nr) (%women)**	**Mean age (years) ± SD**	**Affected SCC (%)**	**Diagnostic test**	**Treatment**	**Max # CRPs**	**Definition success**	**Definition recurrence**	**Definition RD**
Anagnostou et al. (2007)[17]	Prospective study	70 (61.4)	59.5 ± 13.3 Group 20-39 years Group 40-59 years Group >59 years	PSCC 100%	DH	Epley Semont	N.S.	N.S.	N.S.	N.S.
Batuecas-Caletrio et al. (2013)[8]	Retrospective cohort study	404 (61)	Group <70 years: 53.8 (n=193) Group ≥70 year: 77.7 (n=211)	PSCC 82.5% HSCC 10.4% ASCC 5.9% Multiple 1% Can 84.9% / Cup 15.10%	DH+RT	PSCC: Epley HCSS: Lempert ACSS: Yacovino	>3	Negative HD or RT (after 7-11 days)	N.S.	N.S.
Jang et al. (2009)[38]	Prospective study	78 (100)	48 Group A: 20-39 years (n=20) Group B: 40-49 years (n=21) Group C: 50-59 years (n=18) Group D: 60-69 years (n=19)	PSCC 71.8% HSCC 28.2%	DH / lateral head turn	PSCC: modified Epley + avoid bending over, sleep with the head elevated HSCC: Barbecue maneuver + lie on 1 side (affected ear up)	5	No vertigo and negative provocative test	Condition in which patients had intermittent episodes of position-induced vertigo of at least 1 month before the first visit.	N.S.
Simoceli et al. (2005)[37]	Randomized prospective study	50 (68)	60.9 ± 15.3 <40 years (n=3) 40-60 years (n=16) 60-70 years (n=16) >70 years (n=15)	PSCC 100%	DH	Epley (2X) with/without restrictions (sleep with head elevated using two pillows; not perform sudden head movements, ; not to sleep over the affected ear)	1	Absence of dizziness and/or nystagmus in Dix-Hallpike test	Partial improvement or absence of improvement and positive DH	N.S.
Yeo et al. (2018)[31]	Prospective study,	370 (67)			DH/RT video	ASCC= reverse Epley PSCC: modified Epley	N.S.	N.S.	N.S.	N.S.

	reviewing records		59.6 ± 12.3 ≥65 years (n=136) <65 years (n=234)	PSCC 54.6% HSCC 41.4% ASCC 4%	nystagmogram (ambiguous results)	HSCC: 360° Barbecue maneuver				
Zhu et al. (2019)[43]	Retrospective study	1012(67.2)	Group 18-45 years: 37.1 ± 6.5 (n=208)Group 45-60 years: 53.6 ± 4.2 (n=489)Group >60 years: 67.7 ± 5.9(n=315)	PSCC 76.2% HSCC 23.8%(Of which 4% both)	DH+RT	PSCC: Epley / Semont HSCC: Lempert / Barbecue + Gufoni / modified Semont	N.S.	The absence of vertigo and nystagmus on positional testing.	Recurrence positional vertigo + nystagmus (DH/RT) after successful treatment for 1 week	N.S.
AGE AS A COVARIATE										
Author	**Type of study**	**Included (nr) (% women)**	**Mean age (years)**	**Affected SCC (%)**	**Diagnostic test**	**Treatment**	**Max # CRPs**	**Definition success**	**Definition recurrence**	**Definition RD**
Beynon et al. (2000)[19]	Prospective consecutive series	51 (67)	60 ± 13	PSCC 100%	DH	Modified Epley	2	Negative DH (after 1-2 weeks)	Recurrence of positional provoked vertigo after a negative DH	N.S.
Bruintjes et al. (2014)[34]	Randomized, double-blind, sham-controlled trial	44 (59)	59.1 ± 13	PSCC 100%	DH	Epley / Sham intervention Both groups postural restrictions: sleep with the head elevated (48 h) and avoid lying down on the affected side (48 h)	2	Negative DH	N.S.	N.S.
Ciodaro et al. (2018)[21]	Prospective cohort study	408 (57)	Overweight: 55.5 ± 4.1 non-overweight: 54.2 ± 3.4	PSCC 91% ASCC 9%	DH + videonystagmoscopy	Galletti-Contrino/ Semont	2	N.S.	N.S.	N.S.
Cohen et al. (2005)[35]	Prospective, randomized, sham-controlled	124 (61.3)	58.3 ± 12.8	PSCC 100%	DH + Electro-oculography	The five treatment groups : 1) modified CRP (n = 24) 2) modified liberatory maneuver (LM) (n = 25) 3) Brandt-Daroff exercise (n = 25) 4) Vertigo habituation exercises (n = 25) 5) Sham maneuver (n = 25).	1	The absence of vertigo on positional testing (DH).	N.S.	N.S.

Do et al. (2011)[22]	Prospective study	138 (66.7)	51.56 ± 16.39	PSCC 55.8% HSCC 34.8% (Can 58.3%/ Cup 41.6%) Multiple 9.4%	Positional testing, Frenzel glasses of video image	PSCC: Modified Epley HSCC: Barbecue maneuver	N.S.	Disappearance of vertigo and nystagmus during positional maneuver	The reappearance of a similar whirling dizziness or similar rotating nystagmus.	N.S.
Hain et al. (2000)[45]	Retrospective case review	94(77)	58 ± 16	PSCC 100%	DH	CRP without vibration (1991 - 1997) CRP with vibration (1994 - 1996) Both groups --> Avoid the following: sleeping withthe ear in a dependent position, rapid head movements, extreme flexion and extension of the neck, and provoking po-sitions.	1	Relieving symptoms	BPPV in the same ear or opposite ear redeveloped BPPV symptoms (25-day to 5.25 year follow-up)	N.S.
Korkmaz et al. (2016)[49]	Retrospective study	153 62.1% women	53.6	PSCC 87.6% HSCC 7.8% ASCC 3.3% Multiple 1.3%	DH+RT Frenzel glasses	PSCC+ASCC: Semont/ Epley HSCC: Barbecue maneuver Both groups postural restrictions: sleep with the head elevated (48 h) and avoid up and down movements of the head (48 h)	5	Absence of both nystagmus and vertigo during DH or RT.	N.S.	N.S.
Levrat et al. (2003)[51]	Retrospective study	278 (65)	Median age 55.5 (range, 13.5 to 91.5 years).	PSCC 100%	Triggering maneuver of Brandt-Daroff	Semont	4	Symptoms had completely disappeared	N.S.	N.S.
Martellucci et al. (2016)[25]	Prospective cohort study	86 (62)	58.23 ± 14.98	PSCC 100%	DH + RT (to exclude HSCC BPPV)	Epley	4	Absence of both vertigo and positional nystagmus	N.S.	Residual dizziness (i.e. unsteadiness and/or light-headedness and/or dizziness) without true vertigo and nystagmus.

Oh et al. (2017)[36]	Prospective randomized controlled trial	506(59.9)	64 ± 12	PSCC 100%	DH + straight head hanging test Frenzel glasses or video-oculography	1st Maneuver: Epley (n=506)2nd Maneuver non-responders: Epley/Semont	2	Absence of both vertigo and positional nystagmus	N.S.	N.S.
Radtke et al. (2004)[40]	Prospective randomized study	70 (86)	60 ± 12	PSCC (100%)	Lateral head hanging position Frenzel glasses	Self-treatment at home using Epley or Semont (3 times a day, until positional vertigo had ceased for at least 24 hours)	3x daily	Absence of both vertigo and positional nystagmus	N.S.	N.S.
Tanimoto et al. (2008)[57]	Retrospective chart review	145 (63)	60	PSCC 72% HSCC 25.9% (Can 73.6% /Cup 26.3%) Multiple 1.4%	DH+RT	PSCC: Epley HSCC: Lempert (Can), no treatment (Cup)	N.S.	Absence of both vertigo and positional nystagmus	History of nystagmus and BPPV in both the same ear and the other ear.	N.S.
Teggi et al. (2011)[30]	Prospective study	60 (70)	72 ± 4	PSCC 76.7% HSCC 15% ASCC 3.3% Multiple 5%	DH + Pagnini-McClure test Videonystagmography system	PSCC: Semont HSCC: Gufoni + Lempert ASCC: Modified Epley	>3	Absence of positional nystagmus		The sensation of unsteadiness or light headedness without rotational and/or positional vertigo.
Wei et al. (2018)[58]	Retrospective study	127 (64)	53.9 ± 13.93	PSCC (84.2%) non-PSCC (15.8%)	DH + RT	PSCC +ASCC: Epley HSCC: Barbecue Maneuver	N.S.	Absence of both vertigo and positional nystagmus	Confirmed relapse of vertigo and nystagmus according to DH or RT after successful treatment.	N.S.
Wolf et al. (1999)[39]	Prospective, study	41 (56)	Group 1: 46.2 ± 13.1 Group 2: 44.7 ± 14.4 Group 3: 45.5 ± 15.5	PCSS (100%)	DH Frenzel glasses	Epley	N.S.	Absence of both vertigo and positional nystagmus	Recurrent episodes through telephone questionnaire	N.S.

Yoon et al. (2018)[59]	Retrospective study	1426(66.1)	54.9	PSCC 39.1% HSCC 30.6% bilateral 14% Multiple 16.3%	DH + RT Videonystagmography	PSCC: Modified Epley with/without Brandt-Daroff HSCC (can): 360° Barcebecue maneuver HSCC(cup): Barbecue maneuver vibration was first applied to the affected ear for 10 seconds. Then the head was immediately rotated through 360 degrees. All groups: avoid rapid head movement, extreme neckflexion and extension, and positions that provoked vertigosymptoms, for 48 hours.	7	Absence of positional nystagmus for ≥ 1 months, within 4 CRP session.	Recurrence of symptoms and nystagmus, combined with a positive positional test, following complete recovery.	N.S.
AGE AS A UNIVARIATE FACTOR										
Author	**Type of study**	**Included (nr) (% women)**	**Mean age (years)**	**Affected SCC (%)**	**Diagnostic test**	**Treatment**	**Max # CRPs**	**Definition success**	**Definition recurrence**	**Definition RD**
Albera et al. (2018)[41]	Retrospective cohort study	113 (64%)	62.6 ± 12	PSCC 100%	DH Frenzel glasses or videonystagmography	Semont	1	Absence of both vertigo and positional nystagmus	N.S.	N.S.
Babac et al. (2014)[18]	Prospective cohort study	400 (70.2%)	58.75 ± 12	PSCC 86% HSCC 12.25% ASCC 1.75% Bilateral 0.5% Multiple 0.7%	DH + RT Frenzel glasses	PSCC: Modified Epley/semont (with mastoid vibrations) HSCC: Barbecue maneuver (Can), inverted Gufoni (Cup) ASCC: Kim Maneuver	4	Negative DH or RT (after 4 maneuvers)	Recurrent symptoms along with positive diagnostic tests, after a successful recovery	N.S.
Casqueiro et al. (2008)[20]	Prospective double-blind consecutive case study	391 (70.6)	57.2	PSCC (100%)	DH	Epley with/without postural restrictions	5	Negative DH (absence of both vertigo and positional nystagmus)	Number of patients that came back with another episode of vertigo after resolution of their previous episode.	N.S.

Cavaliere et al. (2005)[32]	Prospective study	103 (65)	LM group 51.6 ± 10.6 LM-BE group: 48.6 ± 9.7 BD group: 49.6 ± 11.4 BD-BE group: 50.5 ± 9.1	PSCC (100%)	DH	LM: Semont without betahistine LM-BE: Semont with betahistine BD: Brandt-Daroff (3X/day) with betahistine. BD-BE: Brandt-Daroff (3X/day) without betahistine	N.S.	Evaluated using Epley's criteria: disappeared, improved, partially resolved, unchanged	N.S.	N.S.
Dominguez-Duran et al. (2017)[23]	Observational prospective multicenter study	234 (71)	62	PSCC 100% Can 100%/Cup 0	DH	Epley + sleep with head elevated (30°)	1	Lack of nystagmus in DH, regardless of the presence of vertigo symptoms in that position.	N.S.	N.S.
Dornhoffer et al. (2000)[44]	Retrospective study	52 (75)	63	N.S. Bilateral 7%	DH	Epley + sleep with head elevated at least 30° (48h)	3	Complete response (elimination of nystagmus and symptoms), im-proved response (elimination of nystagmus but with some re-sidual symptoms), or no response (continued nystagmus and symptoms).	Complete initial response to repositioning followed by a later return of symptoms.	N.S.

Helminski et al. (2005)[46]	Retrospective study (and random sample of convenience)	116 (72)	57 ± 16	PSCC 100% 28%	DH video-Frenzel system	Epley with/without vibrations Postural restrictions: sleep with head elevated (48 h), avoid rapid head movements, extreme flexion and extension of the neck, and positions that provoke symptoms of vertigo, such as placing the involved ear in a dependent position while sleeping (for 1 week) Brandt-Daroff exercises (daily)	1	Cured	Sporadic periods of BPPV symptoms over time.	N.S.
Kansu et al. (2010)[47]	Retrospective study	118 (62.7)	51.8 ± 14.7	PSCC 100% Bilateral 4.2%	DH	CRP with mastoid oscillation. Postural restrictions: avoid abrupt head movements, sleep with head elevated, avoid turning to the affected ear during sleep (48 h)	6	Negative DH (absence of both vertigo and positional nystagmus)	Episodes of BPPV	N.S.
Kao et al. (2009)[48]	Retrospective study	218(66)	68.1 ± 14.4	PSCC 78.4% HSCC 3.7% Bilateral 12.8%Sub BPPV: 4.1%Multiple 0.9%	DH + RT Infra-red video fixation goggles	PSCC: Epley (Can), Liberatory maneuver (Cup)HSCC: Barbecue (Can), Liberatory maneuver (Cup)	3	No signs of BPPV	As recurrent symptoms of vertigo with a positive Dix-Hallpike test after at least one month of symptom free status.	N.S.
Kim et al. (2014)[24]	Prospective study	58 (69)	55.8 ± 10	PSCC 36.2% HSCC 48.3% ASCC 12.1% Multiple 3.4%	DH + supine head turning test	PSCC: Epley HSCC (Can): Barbecue Maneuver + sleep on healthy side (24 h) HSCC (Cup): Barbecue Maneuver + mastoid vibration/ Brandt-Daroff exercise ASCC: Reverse Epley	1	Absence of positional vertigo and nystagmus during the maneuver.	N.S.	The sensation of light headedness or unsteadiness without positional vertigo or nystagmus at

										the time of testing .
Korres et al. (2006)[50]	Retrospective study	155 (57.4)	59.9 ± 12.6	PSCC 82.6% HSCC 9% ASCC 1.9% Bilateral 4.5% Multiple 1.9%	DH + RT Electro-nystagmography	PSCC+ASCC: Moddified Epley HSCC: Vannucchi	2	Negative DH (absence of both vertigo and positional nystagmus)	Recurrence of symptoms	N.S.
Luryi et al. (2018)[52]	Retrospective study	1105 (71.5)	64.6 ± 14.6	N.S. Bilateral 17.40%	DH or other diagnostic maneuver	CRP	≥3	Complete relief from symptoms or relief from the majority of symptoms with conversion to a negative diagnostic maneuver.	Recurrence of subjective symptoms with a diagnostic maneuver positive for subjective vertigo and objective nystagmus in either ear.	N.S.
Macias et al. (2000)[42]	Retrospective study	259 (72)	58.6	PSCC 93.1% HSCC 1.9% Multiple 5.0%	Dix-Hallpike Electronystagmogram	CRP appropriate for the SCC	7	Negative DH (absence of both vertigo and positional nystagmus)	Recurrence of any positional symptoms	N.S.
Martellucci et al. (2019)[60]	Retrospective study	47 (57)	62.1 ± 13.1	PSCC 100%	Dix-Hallpike Infrared video-frenzel goggles	Epley	4	Negative DH (absence of both vertigo and positional nystagmus)	After successful CRP, positive DH in the same side	N.S.

Monobe et al. (2001)[53]	Retrospective study	62(66)	Median age of 63	PSCC 100%	DH	CRP Postural restrictions: keep head upright for 10 h, not sleep on the affected ear for 2 weeks	2	1) all vertigo (and nystagmus) resolved. 2) BPPV resolved but other vertigo remains.3) Partially resolved, non-positional nystagmus remains	N.S.	N.S.
Moreno et al. (2009)[54]	Retrospective study	71 (65)	54.9	PSCC 100%	DH	Modified Epley	4	Symptom resolution and negative Dix-Hallpike	N.S.	N.S.
Otsuka et al. (2013)[55]	Retrospective study	357 (68.1)	60	PSCC 65% HSCC 32% (Can 60%/ Cup 40%) Multiple 2.80%	DH + RT Infrared charge-coupled device camera	PSCC: Epley (group 1), medication (group 2) HSCC (Can): Lempert (group 1), medication (group 2) HSCC (Cup): medication + non-specific physical techniques such as Brandt-Daroff exercises/head shaking	1	Cured	Reappearance of symptoms after a symptom-free interval or more than 21 days.	N.S.
Prokopakis et al. (2013)[26]	Prospective study	965 (50.2)	range 18 - 87 years	PSCC 88% HSCC 10% ASCC 2%	DH +RT	PSCC+ASCC: Modified Epley + ispilateral mastoid vibration (80 Hz) at second position of CRP/ manually shaking the head or tapped the cranium during CRP. HSCC: variant of Barbecue maneuver Postural restrictions: don't bend over, move their head up or down, or lie supine (48 h)	>3	No vertigo or nystagmus provoked during RT or DH.	Positive result on provoking maneuver	N.S.
Radtke et al. (1999)[33]	Prospective study	54 (72)	54.8 ± 11.7	PSCC 100%	Lateral head hanging position	Self-treatment at home using Brandt-Daroff exercises/ Modified Epley. Both 3 times daily until positional vertigo had subsided for 24 hours.	3x daily BD	Absence of both positional vertigo and positional nystagmus on DH after 1 week	N.S.	N.S.

Seo et al. (2017)[27]	Prospective study	44 (59)	non-RD: 48.8 ± 9.6 RD group: 46.1 ± 9.3	PSCC 100%	DH	CRP	1	No positional nystagmus or vertigo present	N.S.	Persistent and non-positional atypical dizziness.
Soto-Varela et al. (2011)[28]	Prospective study	135(65)	60.9	PSCC 100%	DH Frenzel goggles videonystagmography (in doubtful cases)	Semont	1	Negative DH (absence of both vertigo and positional nystagmus)	N.S.	N.S.
Soto-Varela et al. (2012)[29]	Prospective study	412 (65)	58	PSCC (100%)	DH Frenzel goggles videonystagmography (in doubtful cases)	Semont (1x) → not cured: Epley (max. 3x) → not cured Brandt-Daroff ex.	4	Negative DH (absence of both vertigo and positional nystagmus)	After a cure compatible symptoms and a positive Dix–Hallpike test	N.S.
Su et al. (2016)[56]	Retrospective study	247 (80.7)	57.5 ± 13.9	PSCC (100%)	DH	Epley	6	Negative DH (absence of both vertigo and positional nystagmus)	Vertigo evoked by changing position 3 months after successful treatment with Epley	N.S.

Supplementary Table S3*:* Treatment efficacy and recurrence rate influenced by age.

Author	N =	1CRP	Number of CRPs	Global treatment efficacy	Recurrence rate	Time to recurrence	Residual Dizziness	Duration Residual dizziness
AGE GROUPS DEFINED A PRIORI								
Anagnostou et al. (2007)[17]	70				=			
Batuecas-Caletrio et al. (2013)[8]	404	↓	↑		↑			
Jang et al. (2009)[38]	78	=	=		↑↑↑			
Simoceli et al. (2005)[37]	50	=						
Yeo et al. (2018)[31]	370		=		=			
Zhu et al. (2019)[43]	1012				=			
AGE AS A COVARIATE								
Beynon et al. (2000)[19]	51				=			
Bruintjes et al. (2014)[34]	44			=				
Ciodaro et al. (2018)[21]	408			=				
Cohen et al. (2005)[35]	124			=				
Do et al. (2011)[22]	138		=		=			
Hain et al. (2000)[45]	94				=	=		
Korkmaz et al. (2016)[49]	153	=	=					
Levrat et al. (2003)[51]	278			=				
Martellucci et al. (2016)[25]	86						↑↑	
Oh et al. (2017)[36]	506	=		↓↓				
Radtke et al. (2004)[40]	70			=				
Tanimoto et al. (2008)[57]	145				=			
Teggi et al. (2011)[30]	60						↑	↑
Wei et al. (2008)[58]	127			=			=	
Wolf et al. (1999)[40]	41			=				

Yoon et al. (2018)[59]	1426	↓↓	↑					
AGE AS A UNIVARIATE FACTOR								
Albera et al. (2018)[41]	113	=						
Babac et al. (2014)[18]	400			↓	=			
Casqueiro et al. (2008)[20]	391	=	=					
Cavaliere et al. (2005)[32]	103	=		=				
Dominguez-Duran et al. (2017)[23]	234	=						
Dornhoffer et al. (2000)[44]	52			=	=			
Helminski et al. (2005)[46]	116				=	=		
Kansu et al. (2010)[47]	118				=			
Kao et al. (2009)[48]	218	=	=		=	↑		
Kim et al. (2014)[24]	58						=	
Korres et al. (2006)[51]	155	↓↓↓		=	↑↑↑			
Luryi et al. (2018)[52]	1105				=			
Macias et al. (2000)[42]	259	↓↓	=					
Martellucci et al. (2019)[60]	47	=						
Monobe et al. (2001)[53]	62			=				
Moreno et al. (2009)[54]	71	=	=					
Otsuka et al. (2013)[55]	357			↓	=			
Prokopakis et al. (2013)[26]	965				↑↑↑			
Radtke et al. (1999)[33]	54			=				
Seo et al. (2017)[27]	44						=	
Soto-Varela et al. (2011)[28]	135	=						
Soto-Varela et al. (2012)[29]	412			=	=			
Su et al. (2016)[56]	247				=			
Total	11451	16	10	16	20	3	5	1

Abbreviations: N: number of study participants; 1CRP: 1 canalith repositioning procedure; #CRPs: number of canalith repositioning procedures;

RR: recurrence rate; RD: residual dizziness

Note: =, No significant impact of age on outcome

↓, Significantly less effective in the older group compared to the younger group ($p<0.05$)

↓↓, Significantly less effective in the older group compared to the younger group ($p<0.01$)

↓↓↓, Significantly less effective in the older group compared to the younger group (<0.001)

↑, Significantly higher in the older group as compared to the younger group ($p<0.05$)

↑↑, Significantly higher in the older group as compared to the younger group ($p<0.01$)

↑↑↑, Significantly higher in the older group as compared to the younger group ($p<0.001$)

Supplementary Table S4 – PRISMA 2009 checklist

Section/topic	#	Checklist item	Reported on page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	1
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	3
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	4-5 {76-98}
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	5 {96-98}
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	5 {100-103}
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	6 {111-126}
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	5 {105-108}
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	Supplementary Text S1
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	6 {111-126}
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	7 {145-150}

Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	6-7 {118-143}
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	7 {144-150}
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	7 {158-168}
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	7 {158-168}

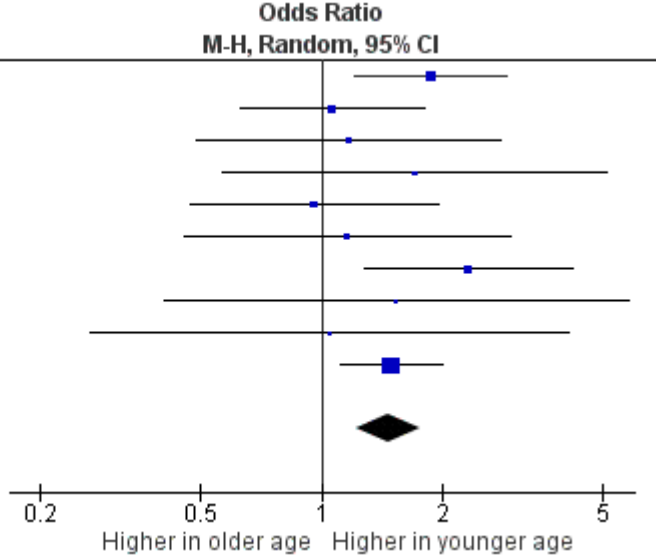
Section/topic	#	Checklist item	Reported on page #
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	16 {328-330}
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	/
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	8 {163-166} Supplementary Figure S1
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	9 {177-188} Table 1 Supplementary Table S2
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	8 {168-176} Supplementary Table S1
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	10-12 {200-249} Figure 1

Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	10-12 {200-249} Figure 1
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	15 {335-337}
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	/
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	12-13 {258-285}
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	16 {328-330}
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	16 {331-342}
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	1 {26-27} 21

A

Study or Subgroup	Younger age group Events	Total	Older age group Events	Total	Weight	Odds Ratio M-H, Random, 95% CI
Batuecas-Caletrio et al. (2013)	149	193	136	211	17.7%	1.87 [1.20, 2.90]
Casqueiro et al. (2008)	232	300	77	101	12.0%	1.06 [0.62, 1.81]
Cavaliere et al. (2005)**	27	71	11	32	4.5%	1.17 [0.49, 2.80]
Jang et al. (2009)**	44	59	12	19	2.8%	1.71 [0.57, 5.15]
Kao et al. (2009)*	57	71	119	147	6.7%	0.96 [0.47, 1.96]
Korkmaz et al. (2015)	89	130	15	23	3.9%	1.16 [0.45, 2.95]
Macias et al. (2000)	150	189	43	69	9.4%	2.33 [1.28, 4.24]
Moreno et al. (2009)	45	58	9	13	1.9%	1.54 [0.41, 5.82]
Simocelli et al. (2005)	26	35	11	15	1.8%	1.05 [0.27, 4.15]
Yoon et al. (2017)	849	1196	143	230	39.3%	1.49 [1.11, 2.00]
Total (95% CI)		**2302**		**860**	**100.0%**	**1.47 [1.23, 1.77]**
Total events	1668		576			

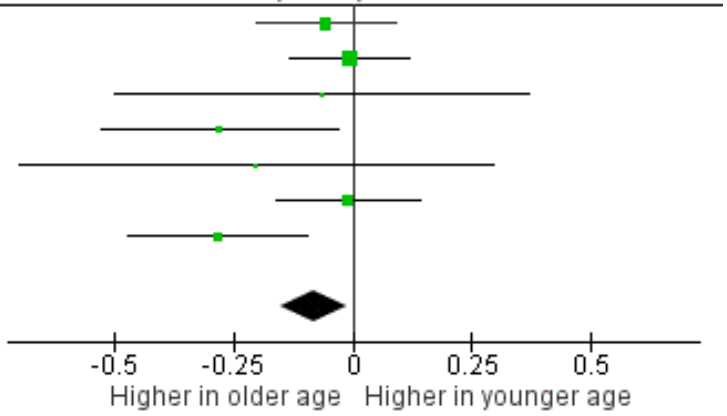
Heterogeneity: Tau² = 0.00; Chi² = 7.01, df = 9 (P = 0.64); I² = 0%
Test for overall effect: Z = 4.12 (P < 0.0001)



B

Study or Subgroup	younger age Mean	SD	Total	older age group Mean	SD	Total	Weight	Mean Difference IV, Fixed, 95% CI
Casqueiro et al. (2008)	1.29	0.578	300	1.346	0.67	101	22.5%	-0.06 [-0.20, 0.09]
Kao et al. (2009)*	1.197	0.401	71	1.204	0.523	147	30.4%	-0.01 [-0.13, 0.12]
Korkmaz et al. (2015)	1.5	0.883	130	1.565	0.992	23	2.6%	-0.06 [-0.50, 0.37]
Macias et al. (2000)	1.286	0.724	189	1.565	0.962	69	7.7%	-0.28 [-0.53, -0.03]
Moreno et al. (2009)	1.259	0.548	58	1.461	0.877	13	1.9%	-0.20 [-0.70, 0.30]
Yeo et al. (2018)*	1.3	0.76	234	1.31	0.68	136	21.3%	-0.01 [-0.16, 0.14]
Yoon et al. (2017)	1.535	1.073	1196	1.817	1.383	230	13.5%	-0.28 [-0.47, -0.09]
Total (95% CI)			**2178**			**719**	**100.0%**	**-0.08 [-0.15, -0.01]**

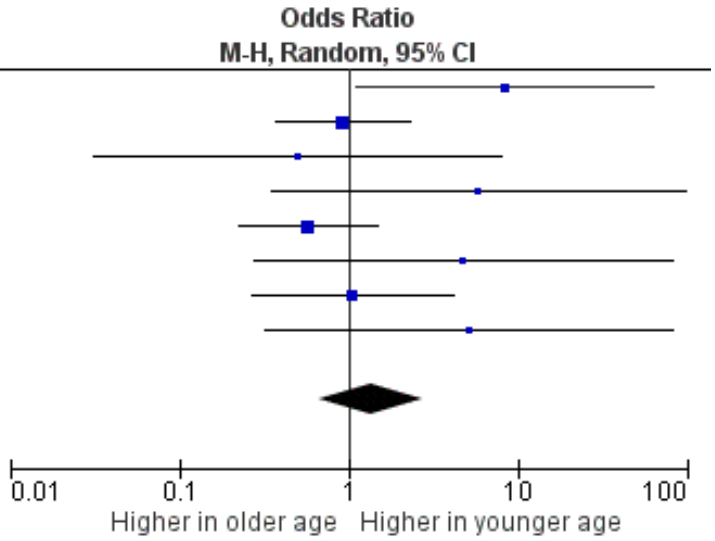
Heterogeneity: Chi² = 9.31, df = 6 (P = 0.16); I² = 36%
Test for overall effect: Z = 2.32 (P = 0.02)



C

Study or Subgroup	Younger age group Events	Total	Older age group Events	Total	Weight	Odds Ratio M-H, Random, 95% CI
Babac et al. (2014)	94	95	280	305	9.8%	8.39 [1.12, 62.79]
Cavaliere et al. (2005)**	50	71	23	32	25.6%	0.93 [0.37, 2.35]
Kao et al. (2009)*	70	71	140	141	5.7%	0.50 [0.03, 8.11]
Korkmaz et al. (2015)	129	130	22	23	5.6%	5.86 [0.35, 97.24]
Levrat et al. (2003)	79	92	84	92	25.4%	0.58 [0.23, 1.47]
Moreno et al. (2009)	57	58	12	13	5.5%	4.75 [0.28, 81.37]
Simocelli et al. (2005)	26	35	11	15	16.8%	1.05 [0.27, 4.15]
Yoon et al. (2017)	1195	1196	229	230	5.7%	5.22 [0.33, 83.73]
Total (95% CI)		**1748**		**851**	**100.0%**	**1.35 [0.66, 2.74]**
Total events	1700		801			

Heterogeneity: Tau² = 0.29; Chi² = 10.06, df = 7 (P = 0.19); I² = 30%
Test for overall effect: Z = 0.82 (P = 0.41)



D

Study or Subgroup	Younger age group Events	Total	Older age group Events	Total	Weight	Odds Ratio M-H, Random, 95% CI
Batuecas-Caletrio et al. (2013)	30	193	50	211	17.2%	0.59 [0.36, 0.98]
Jang et al. (2009)**	26	59	6	19	3.6%	1.71 [0.57, 5.10]
Kao et al. (2009)*	9	71	32	147	6.7%	0.52 [0.23, 1.16]
Su et al. (2015)*	31	170	15	73	9.1%	0.86 [0.43, 1.72]
Tanimoto et al. (2008)*	12	72	19	73	6.6%	0.57 [0.25, 1.28]
Yeo et al. (2018)*	25	234	13	136	8.7%	1.13 [0.56, 2.29]
Zhu et al. 2019**	164	697	91	315	48.1%	0.76 [0.56, 1.02]
Total (95% CI)		**1496**		**974**	**100.0%**	**0.75 [0.61, 0.92]**
Total events	297		226			

Heterogeneity: Tau² = 0.00; Chi² = 5.71, df = 6 (P = 0.46); I² = 0%
Test for overall effect: Z = 2.71 (P = 0.007)