The Assessment of semicircular canals', saccule' and utricles' function in older adults

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Abstract

The study aimed at assessing the effect of aging on peripheral vestibular organs in older adults.
Sixty four participants in the age range of 18-70 years were selected for the study. The participants were further divided into four subgroups (18-30, 41-50, 51-60, & 61-70 years). Cervical vestibular-evoked myogenic potential, ocular vestibular-evoked myogenic potential and video head impulse test were used to assess the sacculo-collic, utriculo-ocular and the vestibule-ocular (from lateral semicircular canals only) pathways, respectively.
With the advancing age, there occurred increase in the latency of P1 peak of cVEMP, and n1 and p1 peaks of oVEMP. The amplitude of both cVEMP and oVEMP decreased significantly with increase in age. Individuals in the 61-70 years had significantly poorer cVEMP amplitudes compared to the other groups. The individuals in the 18-30 years age group had significantly higher oVEMP amplitudes compared to the other groups. There was a marginally significant reduction in the VOR gain with increasing age.
cVEMP and oVEMP can be used to effectively predict the extent of vestibular damage due to ageing. vHIT should be complemented with caloric while assessing the lateral semicircular canals due to its poor sensitivity for moderate problems.

Key words: *Reliability, semicircular canals, saccule, utricle.*

Introduction

Increasing age and health of elderly individuals is one of the major growing concerns worldwide. There occurs deterioration in the structure and the function of the human body, including the vestibular system. Due to that increased risks of falls from loss of balance are among health concerns and are considered by the WHO as an important burden on both the health care system and health of the population.

Thirty to forty percent of elderly people living in the community fall each year (Prudham & Evans, 1981), and falling often results in deaths or fractures. This, not only reduces the quality of life of an individual but also is associated with high rates of morbidity and mortality (Peterka & Black, 1990). Falls have been one of the major causes of hospital admission and accidental death in older people (Delbaere, Crombez, Vanderstraeten, Willems, & Cambier, 2004). Although the 60+ year's population represents only 9% of the population, they account for over 40% of hospitalizations due to injuries, a large majority of which occur due to the accidental falls.

These symptoms in elderly often occur due to degenerative changes in the vestibular organs, namely the saccule, utricle, semicircular canals, and vestibular nerve. The saccule is more susceptible to aging-associated degeneration than the utricle. It has been reported that only a moderate amount of changes takes place in the utricle (Schuknecht & McNeill, 2007). Reduction in the sensory epithelia of the crista ampularis occurs in the semicircular canal (Orleans, 1973). Saccular degeneration is often accompanied by loss of statoconia (Johnsson, 1971). Degeneration of the nerve cells up to 40% (Bergstrom, 1972) and the reduction in the cell bodies in the Scarpa's ganglion (Richter & Richter, 2016) are a few of the age-related changes that occur and affect the vestibular system. (Johnsson, 1971).

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Thus, the degenerative changes in the vestibular system cause changes in the sensory end organs, namely the saccule, the utricle, and the three semicircular canals. These changes result in adverse consequences, hence for effective treatment and management of elderly individuals, an effective assessment is required. An effective assessment can occur with the battery of tests including cVEMP, oVEMP, and vHIT, which effectively test the saccule, the utricle, and the three semicircular canals, respectively.

cVEMP determines whether or not the saccule and/or the inferior vestibular nerve are intact and functioning normally. The cVEMP has been found useful in assessing the function of saccule in individuals with Meniere's disease (Taylor et al., 2011; Shin et al., 2012), vestibular neuritis (Adamec, Krbot Skoric, Ozretic, & Habek, 2014; Murofushi, Halmagyi, Yavor, & Colebatch, 1996), BPPV (Kim, Oh, Kim, Yang, & Yang, 2015), and superior semicircular canal dehiscence syndromes (Niesten, McKenna, Herrmann, Grolman, & Lee, 2013).

O-VEMP determines the functioning of the utricle and the superior vestibular nerve function. O-VEMP has been found to be useful in assessing patients with utricular disorder like Meniere's disease(Murofushi & Kaga, 2009a), vestibular neuritis (Shin et al., 2012), superior semicircular canal dehiscence syndrome (Niesten et al., 2013), and vestibular neuritis 85% (Murofushi, Shimizu, Takegoshi, & Cheng, 2001).

The caloric test detects the function of only the lateral semicircular canals. Measurement techniques involving

high-acceleration head rotations and recording the head and eye movement responses in all three planes presents the possibility of reliably detecting individual semicircular canal lesions. (Aw et al., 1999). Vestibuloocular reflex (VOR) is the ratio of eye velocity to head velocity) gain in yaw, pitch, and roll head movement. VOR gain helps in assessing the deficiency in the functioning of all the six semicircular canals; (Walther et al. 2013).

Video Head Impulse test assesses the VOR gain deficits in various vestibular pathologies like vestibular neuritis (Bartolomeo et al., 2014), Meniere's disease(Mccaslin et al., 2014), with good sensitivity and specificity. Thus using cervical VEMP, Ocular VEMP and Video Head Impulse Test one can assess all the sensory end organs of vestibular system effectively and can give a complete vestibular profile in an elderly population. The study aimed at evaluating the semicircular canal, saccule, and utricle functioning in the elderly population.

Method

The present study consisted of two groups. Group I included 46 participants(27 male and 19 females) in the age range of 40 to 70 years. Further group, I was subdivided into three sub-groups. Subgroup I consisted of 15 participants (mean age = 44.13 yrs, eight male & seven female) in the age range of 41 to 50 years. Subgroup II included fifteen participants (mean age = 55.86 years, nine male & six female) in the age range of 51-60 years, and the subgroup III consisted of 16 (mean age = 64.2 yrs, ten male & six female) participants in the age range of 61-70 years. Group II consisted of 18 participants (nine males and nine females) in the age range of 18 to 30 years(mean age 23.1 years).

Participant selection Criteria:

The participants included in the study had absence any middle ear problem which was confirmed using conventional air conduction and bone conduction audiometry and tympanometry respectively, had hearing loss no more than moderate degree, did not have history of any neurological problem or any history of vestibular dysfunction. No history of spondylitis or present complaints of pain in the neck region. None of the participant included in the study had uncomfortable level less than 100dBSPL.

Instrumentation and test environment

A calibrated two channel clinical audiometer InventisPiano with TDH-39 headphones, housed in MX-41/AR (Telephonics, Farmingdale, NY, USA) ear cushions was used for finding air-conduction thresholds and doing speech audiometry. Radio ear B-71 bone vibrator (Radio ear, KIMMETRICS, smithsburgh, Maryland, USA along with the same audiometer was used for measuring bone conduction thresholds. A calibrated middle ear analyserGrason-Stadler Incorporated (GSI) Tympstar (GSI VIASYS Healthcare, WI, USA) was used for obtaining tympanogram type, static compliance, ear canal volume and acoustic reflex threshold. The Otodynamics ILO 292 V-6 (Otodynamics Ltd., Hatfield, Herts, UK) was used for recording Distortion product optoacoustic emissions(DPOAEs). Cervical and Ocular Vestibular evoked myogenic potential were recorded using Biologic Navigator Pro version 7.2.1 (Natus Medical Incorporated, San Carlos, CA, USA) with SINSER - 012 insert earphones. V-HIT was carried out using ICS Impulse OTOsuite vestibular software version 1.2 (GN Otometrics, Denmark). The patient had to wear frenzel glasses provided by the manufacturer of the OTO-SUITE software All the test were carried out in acoustically treated air-conditioned rooms with permissible noise level as per the guidelines recommended by the American National Standards Institute(ANSI S3.1-1991).

Procedure

Air conduction and bone conduction threshold were tracked from 250 Hz to 8000 and 250 Hz to 4000 Hz respectively at octave frequencies using modified Hughson & Westlake procedure (Carhart & Jerger, 1959) to assess the hearing sensitivity of the participant. PTA was calculated by averaging air conduction thresholds obtained at 500 Hz,1000 Hz, 2000 Hz and 4000 Hz.Uncomfortable level was tested to find if any of the participant exhibited any tolerance problem to loud sounds. Tympanometry was done using 226 Hz probe tone, to rule out any middle ear pathology. Ipsilateral as well as contralateral reflexes were checked at 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz.

For recording VEMP, the site of electrode placement was prepared using a skin preparation gel. Silver chloride disc electrodes were used for recording. Absolute electrode impedance was maintained below 5000 ohms and inter-electrode impedances was below 2000 ohms.

C-VEMP was recorded with the inverting electrode at the ipsilateral sternoclavicular junction, non-inverting at the superior 1/3rdof ipsilateral sternocleidomastoid junction and ground electrode at the forehead. Adequate muscle contraction was assured with e feedback device available in the instrument. The recording was done using 500Hz tone burst, at an intensity of 125 dBSPL. The first positive component occurring around 13ms was marked as P1, while the second negative peak occurring around 23ms was marked as N1 (Fransson et. al.2001). C-VEMP amplitude were calculated from peak of P1 to N1. The subjects across groups were compared on the amplitude and latency parameter.

O-VEMP was recorded with non-inverting electrode being at the contra supra inferior oblique muscle and the inverting electrode just below the non-inverting. Ground electriode was placed at the forehead

(Rosengren et al., 2005). The participant had to look upwards at a spot placed 30 degree elevation without elevating his neck. The recordings was contralateral to that of the stimulated ear. A negative peak occurring around 10 ms aand a positive peak occurring around 15 ms was marked as N1 and P1 respecticvely.

Video Head Impulse Test

Video Head Impulse test was administered using ICS Impulse OTOsuite vestibular software version 1.2 (GN Otometrics, Denmark. Frenzel glasses was used. For calibration, participants were instructed to look straight, and the red beam was on. The two red beams were spaced by an approximately 40 degree. A target was placed at the distance of 1 meter from the subject bisecting the two red beams. The subject was asked to gaze at the target irrespective of the thrust given to the head. A head thrust was given in lateral planes on both sides. 20 accepted recordings from each plane was averaged, and mean VOR gain was calculated. Saccades at the time of headthrust i.e covert saccades and after the head thrust i.e overt saccades was looked for.

Results

Cervical vestibular evoked myogenic potentials

Out of 128 ears included in the study on which cVEMP was administered, 100% of the participants in the subgroup I of group I had the presence of cVEMP. However, in subgroup II and subgroup III of group I, the response rates were 96.67% and 78.12%, respectively. All the participants in group II had present cVEMP. The results of equality of test for proportion revealed that significantly higher percentage of participants in the subgroup III had absent cVEMP responses compared to group II ($Z = 2.96$ $p = 0.00$), subgroup I ($Z = 2.72$ $p = 0.00$) and subgroup II ($Z = 2.18$ $p = 0.02$). Shapiro Wilk test for normality did not show a normal distribution for the most of the parameters ($p<0.05$), non-parametric test was administered. Wilcoxon sign ranked test was administered to check ear effect. Wilcoxon signed rank test did not reveal any significant differences for the cVEMP parameters for the two ears($p>0.05$), the data from the two ears was combined. Table 1 shows the results of the wiloxson sign rank test for the differences between the two ears.

Table-1 : Mean and Standard deviation of cVEMP parameters

cVEMP	P1 latency(msec)		N1 latency(msec)		P1N1 amplitude(µv)	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Group II	15.67	1.7	24.88	1.84	15.64	4.94
	15.67	1.14	24.98	1.6	15.95	3.89
Subgroup I	16.30	1.64	24.48	2.17	16.47	6.43
	16.23	1.31	24.45	1.5	16.22	9.01
Subgroup II	16.16	0.68	24.34	1.46	15.88	11.0
	16.71	1.17	24.41	1.78	16.46	10.94
Subgroup III	16.01	1.7	24.13	2.70	7.73	5.03
	16.11	1.7	23.78	3.8	7.67	6.91

To understand the overall group differences for the various cVEMP parameters, Kruskal Wallis H test was administered. Kruskal Wallis H test revealed overall group difference between groups for the latency of P1 peak (?2(3) = 8.8, p = 0.03), but revealed no difference between groups for the latency of N1 peak (?2(3) = 2.75, p = 0.45). However, there was a significant difference in the amplitude of cVEMP between the different groups (?2(3) = 27.93, p = 0.00). Further, Mann Whitney U test revealed no significant difference for latency of P1 between, group II and subgroup I of group I (Z = 1.38,p = 0.17), group II and subgroup III of group I (Z = 1.6, p = 0.11), but revealed a significant difference for the latency of p1 between group II and subgroup II of group I (Z = 2.1, p = 0.04). Again for P1 latency of cVEMP within group I, Mann Whitney U test revealed no significant differences between subgroup I and subgroup II (Z = 1.4, p = 0.17), no significant differences between subgroup I and subgroup III (Z = 0.81, p = 0.47) and no significant differences between subgroup II and subgroup III (Z = 1.41, p = 0.15).

Mann Whitney U test also revealed a significant difference between the peak to peak amplitude of P1N1 of subgroup III of group I and group II (Z = 5.0, p = 0.00), subgroup III and subgroup I (Z =4.16, p = 0.00), and subgroup III and subgroup II (Z = 3.50, p = 0.00). However no significant difference for the amplitude of N1-P1 complex was observed between subgroup I and subgroup II (Z = 0.50 p = 0.61), between group II and subgroup III (Z = 0.064 p = 0.949), between group II and subgroup III (Z = 0.44, p = 0.66).

To summarize the results, a significant difference was observed for p1 latency across the younger and the older groups, however, within the older group, there was no significant difference between any of the two subgroups for the latency of P1. The latency of N1 latency did not differ across the group. The amplitude of P1-N1 was least for 60-70 years old individuals compared to 18 - 30 years, 41 - 50 years and 51 - 60 years.

Ocular vestibular evoked myogenic potentials

The percentage of ears having the presence of oVEMP in subgroup I was 93.3%, in subgroup II, it was 83%, in subgroup III, it was 68.75% and group II which consisted of individuals in the age range of 18 - 30 years had the presence of oVEMP in all the participants in both the ears. The test of equality for proportion revealed that older age group participants had a higher percentage of individuals in whom there was an absence of oVEMPs in either ear compared to the lower age group participants. There was a significant difference in terms of response rates for oVEMP between subgroup III and group II (Z = 3.63 p = 0.000), between subgroup II and group II (Z = 2.54 p = 0.01), and between subgroup I and subgroup III (Z = 2.44 p = 0.01).

Shapiro Wilk test was administered to check whether the data follows the normal distribution or not. Shapiro Wilk test for normality did not show a normal distribution for the entire data ($p<0.05$), and hence a non-parametric test was administered. Wilcoxon sign ranked test did not show a significant difference between the two ears for any of the groups($p>0.05$). Therefore the data for the two ears were combined for both the groups. Table 2 shows the mean and the standard deviation for parameters of oVEMP for the groups with combined data for two ears.

Table 2 : Mean, and standard deviation of latencies of N1, P1 and peak to peak amplitude of N1P1 of oVEMP

oVEMP		Group II	Group I		
		18-30 years	40-50 years	50-60 years	60-70 years
N1 Latency(msec)	Mean	11.28	11.80	11.73	12.7
	SD	0.99	1.40	1.24	1.44
P1 Latency(msec)	Mean	16.30	16.65	17.08	18.19
	SD	2.0	1.0	1.03	1.88
N1P1 amplitude(uv)	Mean	5.43	2.78	2.59	1.94
	SD	4.0	2.74	2.26	3.29

Kruskal Wallis H test revealed a significant difference in latency of N1 across groups (?2(3) = 16.61, p = 0.01) and latency of P1 across groups (?2(3) = 20.74, p = 0.00). There was also a significant difference for the amplitudes of oVEMP across group (?2 (3) = 33.98, p = 0.00).

Further, to understand the significant differences between different groups and subgroups Mann Whitney U test revealed a significant difference for the latency of N1 between group II and subgroup III of group I (Z = 3.91 p = 0.00). There was no significant difference between group II and subgroup I of group I (Z = 1.76 p = 0.08), between-group II and subgroup II of group I (Z = 1.6, p = 0.11), subgroup I and subgroup II (Z = 0.05, p = 0.96), however, it showed a significant difference between subgroup I and subgroup III (Z = 2.5 p = 0.01) and between subgroup II and subgroup III (Z = 2.4, p = 0.01).

Mann Whitney U test revealed a significant difference for latency of P1 for oVEMP between group II and subgroup III of group I (Z = 3.83, p = 0.00) and for group I, between subgroup I and subgroup III (Z = 3.6, p = 0.00). There was no significant difference between group II and subgroup Iof group I (Z = 1.19, p = 0.23), and subgroup II and subgroup III (Z = 0.04, p = 0.97), however it showed a significant difference between group II and subgroup II of group I (Z = 2.28, p = 0.02), subgroup II and subgroup I (Z = 1.95, p = 0.05).

Mann Whitney U test revealed a significant difference for amplitude N1P1 between group II and subgroup I of group I (Z = 3.9, p = 0.00), between-group II and subgroup II of group I (Z = -3.6, p = 0.00), between group II and subgroup III of group I (Z = 5.14, p = 0.00). For group I Mann Whitney U test revealed significant difference between subgroup I and subgroup III (Z = 3.1, p = 0.003), and between subgroup II and subgroup III (Z = 2.61, p = 0.00). There was no significant difference between subgroup I and subgroup II (Z = 0.192, p = 0.847).

Video Head Impulse test

The VOR gain was calculated for all the participants and VOR gain lesser than 0.8 was considered to be abnormal. As age increased, the number of participants having abnormal VOR gain also increased. The percentage of individuals having reduced VOR gain in group II was 2.7%, in subgroup I, it was 16.7%, in subgroup II, it was 13.3% and in subgroup III it was 25%. The proportion of individuals having VOR gain less than 0.8 was significantly higher in age group 60 - 70 years compared to age group 18 - 30 years (Z = 2.7 p = 0.007). Descriptive statistics was done to find out the mean, median and standard deviation of individuals in lateral planes. Table 3 gives the descriptive statistics for VOR gain for right as well as left lateral planes.

Table 4.3.1: Mean, median and standard deviation of VOR gain for right and left lateral planes

	Group II		Subgroup I		Subgroup II		Subgroup III	
vHIT	RL	LL	RL	LL	RL	LL	RL	LL
x̄	0.94	0.95	0.95	0.98	1.0	0.97	0.90	0.88
M	0.92	0.91	0.94	0.91	0.98	0.99	0.88	0.86
SD	0.12	0.15	0.16	0.11	0.17	0.85	0.14	0.27

Note: x̄ = mean; *M* = median; SD = standard deviation; RL = right lateral, LL = left lateral

To find the difference between the groups for VOR gain Kruskal Wallis H test was used. The test revealed there was existed marginally significant difference between the VOR gain values across groups ($X^2(3) = 7.78$, p = 0.05). Mann Whitney U test revealed no significant difference for VOR gain values between group II and subgroup I (Z = 0.28, p = 0.77), group II and subgroup II (Z = 1.8, p = 0.07), group II and subgroup III(Z = 1.56, p = 0.12), subgroup I and subgroup II (Z = 1.53, p = 0.13), subgroup I and subgroup III (Z = 1.06, p = 0.28), however it showed a significant difference between subgroup II and subgroup III (Z = 2.55, p = 0.01).

Discussion

Cervical vestibular evoked Myogenic Potentials:

Previous studies have found similar results on the parameters of latency of P1 and N1 i. e increase in the latency of P1 (Maleki, Jafari, Zarrinkoob, & Akbarzadeh Baghban, 2014; Singh, Kashyap, Supreetha, & Sahana, 2014) and decrease in the latency of N1 with advancing age. However few studies have shown to have no significant effect aging on the latency of P1 and N1 as the effect of aging (Layman et al., 2015; Nguyen, Welgampola, & Carey, 2010). There was an increasing trend seen for latency of P1 as well as N1 in the study by Nguyen et al, 2010 which was similar to our findings however their results did not differ significantly between age groups.

In the present study there was no significant difference in latency between different groups, however only latency of P1 was prolonged for 51-60 years age group only. Thus prolongation of P1 peak did not show any kind of definite pattern of aging effect. The equivocal findings in literature could be due to the different population tested. For example, study by Layman et al (2015) showed significant effect of aging on latency parameters in males and not in females. Also the different age groups taken for the different studies are different.

The cVEMP amplitude decreases as age increases (Agrawal et al., 2012; Layman et al., 2015; Maes et al., 2010; Maleki et al., 2014; Singh et al., 2014) It has been reported in literature that there occurs decline in the amplitude of the cVEMP by 0.14 microV after every decade (Layman et al., 2015) irrespective of the stimulus used (Nguyen et al., 2010). It has also been reported that the response rate for presence of cVEMP is less for people above 65 years of age. (Maes et al., 2010). Similar results were found in our study. The participants above 60 years of age had significantly reduced amplitude compared to younger groups. However, Singh et al., 2014 have reported no change in the amplitude of cVEMP up to the age of 50 years, however, the rate of decline after 50 years is more rapid. The study by singh et al, 2014 was done as a cross sectional study on large sample of 280 participants. The difference in the result could be due to their large sample size.

Reduction in the amplitude of cVEMP could be attributed to age related deterioration in the vestibular apparatus in the human body with increasing age. There occur structural changes from the vestibular hair cells up to the vestibular nerve fibres. The reduction in the nerve fibres occurs by around 2000 nerve fibres per decade and reaches upto 40 % reduction by the age of by the age of 60 years (Bergström, 1972). The loss of nerve fibres start to occur at 40 years of age (Park, Tang, Lopez, & Ishiyama, 2001) hence with this loss of nerve fibres with increasing age there decline in the carrying capacity of the vestibular nerve which could have resulted in increase in latency with aging. The effect of aging is also results in loss of haircells (Bergström, 1972; Rosenhall, 2009) and decrease in the density of otoconia in the maculae of saccule (Johnsson, 1971). Thus loss of haircell and reduction in otoconia density could have resulted in reduced stimulation of the saccule and hence reduced amplitude in the individuals with 61 - 70 years.

Ocular vestibular evoked Myogenic Potentials

The structural changes in the vestibular system the due to the effect of ageing i.e reduction in the otoconia density (Johnsson, 1971) in the uticle, reduction in the nerve fibres and reduction in the number of cell bodies in the scarpas ganglion (Richter & Richter, 2016) could have resulted in prolonged latency and reduced amplitude as a function of ageing.

Previous studies have shown similar results that as age increase, there is an increase in the latency of N1 and P1 (Layman et al., 2015) and this effect on latency due to aging is more significant in males compared to females (Nguyen et al., 2010). There was a significant difference in the amplitude of oVEMP seen among participants of the groups which had a difference of 20 years. Studies have reported that there occurs reduction in the amplitude of oVEMP by by 2.14 microvolt for

every decade beyond 40 years (Chang, Young, & Cheng, 2012; Maheu, Houde, Landry, & Champoux, 2015). This rapid reduction could have resulted obvious change in the amplitude of oVEMP as a function of ageing.

Video head impulse test

The normal VOR gain is considered to be normal between 0.8 to 1.2 (Patterson, Bassett, Mollak, & Honaker, 2015), individuals having VOR gain below 0.8 was considered to be abnormal. Agrawal et al.(2012) reported that there is not much change seen in the VOR gain upto the age of 50 years, however the mean reduction in the VOR gain beyond 60 years. One of the earlier studies utilising the VHIT to calculate the VOR gain values, has reported significant reduction in VOR gain with advancing age beyond 60 years. (Mossman, Mossman, Purdie, & Schneider, 2015). In the present study also the VOR gain was reduced for 61-70 years age group.

Histopathological studies have shown that there occurs degeneration in the semicircular canals due to ageing. There occurs hair cell loss and reduction in significant reduction in the hair cell density in individual beyond 70 years of age. The sensitivity of vHIT to assess the functioning of the semicircular canals is less for individuals upto moderate problems (Bartolomeo et al., 2014; Chen et al., 2015).

Conclusions

As age increases there occurs increase in the latency of P1 of cVEMP and increase in the latency of both N1 and P1 of oVEMP and decrease in the amplitude of both cVEMP and oVEMP. The VOR gain reduces as age increases but a significant effect of ageing is seen in individuals beyond 60 years of age on the vestibular test results. There also exists comparative difference for vestibular test results between young group and individuals beyond 40 years. To conclude that the three tests administered were able to detect the vestibular deficits in different structures of the vestibular system. The degeneration pattern revealed for the vestibular system in this study indicates that there is an overall degeneration in the vestibular system. Thus, to understand the different mechanisms underlying the vestibular degeneration one must administer different tests. Also, along with the audiological tests the tests for the vestibular system should be administered for these individuals.

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