Vestibology

Influence of extero- and proprioceptive afferents of the plantar surface in determining subjective visual vertical in patients with unilateral vestibular dysfunction

Il contributo delle afferenze estero-propriocettive plantari nella determinazione della verticale visiva soggettiva del paziente affetto da deficit vestibolare monolaterale

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Dedicated to Antonio Gonnella, a brilliant young medical researcher

SUMMARY

Subjective visual vertical refers to an individual's ability to indicate what, in his or her opinion, is a perfectly vertical line in specific experimental conditions. Although the otolith organs play a key role in the perception of verticality, the contribution of other sensory systems, e.g. the visual and proprioceptive systems, cannot be overlooked. The aim of this study was to test the hypothesis that extero- and proprioceptive afferent signals, particularly from the plantar surface of the foot, can influence the temporal evolution of altered subjective visual vertical following unilateral acute vestibular dysfunction. Subjective visual vertical was studied in 40 consecutive patients: 19 females and 21 males (mean age 46.4 years). It was first measured at diagnosis (1-2 days after onset of symptoms). For this measurement, a baseline test was performed (patient standing in direct contact with the floor), followed by a provocation test with a soft support between the patient's feet and the floor. Based on a comparison between the baseline and provocation tests, the patients were divided into three groups: Group A – patients showing a significant increase ($p < 0.05$) in subjective visual vertical$_0$ values in the provocation test compared to baseline values; Group B – patients showing a significant decrease ($p < 0.05$) in subjective visual vertical$_0$ values in the provocation test compared to baseline values; Group C – patients showing no significant changes ($p < 0.05$) in subjective visual vertical$_0$ values in the provocation test compared to baseline values. The baseline test was repeated at 30, 90 and 180 days. At the end of the follow-up, a persistent change in subjective visual vertical was noted in 87% of the patients from Group B, 31% of the patients from Group C but none of the patients from Group A, all of whom were able to correct the perception error during the second examination. The study demonstrates that normalisation of subjective visual vertical in subjects with unilateral vestibular lesions seems to be influenced by the possibility of exploiting extra-vestibular sensory information, particularly extero- and proprioceptive information from the plantar surface.

KEY WORDS: Subjective visual vertical • Vestibular dysfunction • Otolith function • Proprioceptive afferents

RIASSUNTO

Per Verticale Visiva Soggettiva (VVS) s'intende la capacità di un soggetto di indicare quella che, a suo giudizio ed in determinate condizioni sperimentali, è una linea perfettamente verticale. Nella percezione della verticalità giocano un ruolo essenziale gli organi otolitici; tuttavia non può essere trascurato il contributo di altri sistemi sensoriali come quello visivo e propriocettivo. Scopo del presente studio è stato quello di verificare l'ipotesi di una influenza da parte di segnali afferenti estero-propriocettivi, in particolare di origine plantare, sull'evoluzione temporale di una alterazione della VVS, insorta a seguito di un episodio di deficit vestibolare acuto (DVA) monolaterale. La VVS è stata studiata in 40 pazienti consecutivi, 19 femmine e 21 maschi (età media 46,4 anni). La misurazione è avvenuta una prima volta al momento della diagnosi di DVA (1-2 giorni dall'inizio della sintomatologia). In tale occasione veniva eseguito un test basale (paziente in posizione eretta a contatto diretto con il suolo) ed un test di provocazione con svincolo podalico (interposizione di un appoggio morbido tra piedi del paziente e suolo). Il confronto test basale vs test di provocazione consentiva di individuare tre gruppi di pazienti: Gruppo A – Pazienti che mostravano un aumento significativo ($p < 0,05$) dei valori di VVS$_0$ al test di provocazione rispetto ai valori basali. Gruppo B – Pazienti che mostravano una diminuzione significativa ($p < 0,05$) dei valori di VVS$_0$ al test di provocazione rispetto ai valori basali. Gruppo C – Pazienti che non mostravano variazioni significative ($p > 0,05$) dei valori di VVS$_0$ al test di provocazione rispetto ai valori basali. Il test basale è stato successivamente ripetuto a 30, 90 e 180 giorni. Al termine del follow-up, una alterazione persistente della VVS riguardava l'87% dei pazienti di Gruppo B, il 31% dei pazienti di Gruppo C ed in nessun caso pazienti di Gruppo A, i quali già in occasione del 2° controllo erano stati tutti in grado di correggere l'errore percettivo. Lo studio mostra come la normalizzazione della verticale visiva soggettiva in soggetti con deficit vestibolare monolaterale appare condizionato dalla possibilità di poter utilizzare al meglio informazioni sensoriali extravestibolari, in particolare di natura estero-propriocettivo di origine plantare.

PAROLE CHIAVE: *Verticale visiva soggettiva • Deficit vestibolare • Funzione otolitica • Afferenze propriocettive*

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Introduction

Subjective visual vertical (SVV) refers to an individual's ability to indicate what, in his or her opinion, is a perfectly vertical line in specific experimental conditions. A healthy subject standing in a dark room can vertically align a dimly lit bar (30 x 1 cm), set 1.5 metres away, with an error of ± 2° with respect to the Earth-vertical axis [1-3]. In the event of a sudden unilateral loss of vestibular function, the subject tilts the upper end of the bar towards the affected ear, shifting by several degrees – substantially in some cases – with respect to the gravitational axis [4 5]. This is due to the fact that the subject feels that the bar is tilted towards the healthy side. Consequently, he or she will shift it towards the side with the lesion in order to re-establish a perception of verticality that is objectively wrong, as the bar was already perfectly aligned according to the direction of gravity. The mechanisms generating this perception error are not entirely understood yet. The misperception could be caused by asymmetry in the otolith afferents, triggering altered internal representation of the gravitational vertical [6]. Despite the dysfunction, however, the subject will not sense that his or her body is leaning. Another possible explanation is ipsilesional ocular torsion as an integral part of a postural synkinesis known as ocular tilt reaction (OTR) [7-9]. Consequently, SVV could be the result of ocular torsion that arises following reduced neuronal discharge activity of the ipsilesional vestibular nuclei due to the loss of peripheral utricular afferents, which is manifested through decreased tone of the extrinsic eye muscles [10].

Despite the fact that the otolith organs, position receptors that can detect gravitational acceleration, play a key role in the perception of verticality, the contribution of other sensory systems, e.g. the visual and proprioceptive systems, cannot be overlooked [11 12]. In fact, it has been demonstrated that vibratory stimuli applied to different neck muscles can modify SVV both in normal subjects [13] and in patients with unilateral vestibular lesions [14]. Nevertheless, creating a perfectly dark room, in order to eliminate any visual references, is essential for performing the test.

The aim of this study was to test the hypothesis that extero- and proprioceptive afferent signals, particularly from the plantar surface of the foot, can influence the temporal evolution of altered SVV following unilateral acute vestibular dysfunction (AVD).

Materials and Methods

SVV was studied in 40 consecutive patients, 19 females and 21 males (mean age 46.4 years), with unilateral vestibular dysfunction. The patients were referred to the Clinic on account of symptoms that included vertigo, neurovegetative phenomena, prevalently horizontal spontaneous nystagmus observed with and/or without Frenzel's goggles, and poor static and dynamic posture. Canal function tests confirmed significant unilateral hyporeflexia/areflexia, whereas diagnostic imaging ruled out any disorders of the central nervous system in those cases in which disorders were suspected.

For the test, a fluorescent bar, 50 cm high, was used, the entire length of which was dimly lit. This was placed in a darkened room and set 1 metre away from the patient. The bar is mounted on a central rod, on the wall, and can thus be rotated manually in both directions. The upper end has a pointer that slides with the bar on a graduated scale, on which 0° corresponds to perfect alignment of the longitudinal line of the bar with the direction of gravity. Rotation of the pointer to the left corresponds to negative angles and rotation to the right to positive angles. Overall, 6 measurements were performed, alternating the bar from a 45° angle to the right and then to the left, for a total of three measurements each side. The subjects were then asked to rotate the bar until they thought it was perfectly vertical.

SVV was first measured when AVD was diagnosed (1-2 days after onset of symptoms). At this point, a test was performed with the patient standing in direct contact with the floor (baseline test); the test was then repeated with a soft support (a cushion measuring 40 x 40 cm) placed between the patient's feet and the floor (provocation test). The comparison between the baseline and provocation tests allowed us to divide the patients into three groups:

- Group A – patients showing a significant increase ($p < 0.05$) in SVV_0 values in the provocation test compared to baseline values;
- Group B – patients showing a significant decrease ($p < 0.05$) in SVV_0 values in the provocation test compared to baseline values;
- Group C – patients showing no significant changes ($p < 0.05$) in SVV_0 values in the provocation test compared to baseline values.

Furthermore, SVV was studied in baseline and provocation conditions in 30 healthy volunteers who did not present significant differences ($p > 0.05$), in terms of sex and age variables, with respect to the group of patients with vestibular deficits.

All patients were observed at 30-day follow-up, during which only the baseline test was performed and SVV_0 was recalculated. Those who still had dysfunctional SVV_0 values were checked again at 90 days and, in some cases, 180 days. In the latter case, caloric tests were also repeated on all 40 patients who were initially recruited. The study examined the distribution of the three groups of patients into subjects with normal SVV_0 and those with dysfunctional SVV_0 at follow-up.

Statistical analysis

The mean value of the six measurements with the subject's head upright (SVV_0) was the main study parameter (Table I). In accordance with general standards, SVV_0 values of 0-±2 are considered normal [1 6-15]. Applying Student's t-

Table I. Example of the calculation of SVV_0 in patients with unilateral vestibular dysfunction and in normal subjects. Among patients with vestibular lesions, mean values were always higher compared to the control group and the bar was always tilted to the dysfunctional side.

Subject	1st test	2nd test	3rd test	4th test	5th test	6th test	SVV_0
Right deficit	+3	+3	+5	+5	+4	+4	**+4**
Left deficit	-4	-3	-3	-5	-5	-4	**-4**
Normal	+1	-1	+1	+1	+1	0	**+0.5**

test, in normal subjects and patients with unilateral vestibular lesions, the differences between mean values (SVV_0) in the different conditions that were tested (baseline and provocation tests) were significant ($p < 0.05$).

Results

Baseline and provocation tests

During the acute phase, all patients recruited for the study had SVV_0 values higher than ±2° during the baseline test,

Table II. Distribution of patients into groups (A, B, C) based on the SVV_0 values recorded during the tests that were performed (provocation test *vs.* baseline test).

Patient	Baseline test		Provocation test		p value	Group
	VVS_0	SD	VVS_0	SD		
MC	4.50	0.55	4.83	0.41	0.26	C
AG	3.83	0.75	4.33	0.52	0.20	C
CI	4.67	0.82	6.33	0.52	0.00	A
MC	5.50	0.55	5.83	0.41	0.26	C
OI	4.50	0.84	5.00	0.89	0.34	C
GR	3.50	0.55	5.00	0.63	0.00	A
AF	5.67	0.52	5.17	0.75	0.20	C
GC	5.33	0.82	6.67	1.21	0.04	A
MD	5.17	0.75	3.67	0.52	0.00	B
PV	3.00	0.63	3.67	0.82	0.14	C
CP	5.93	0.75	5.23	0.52	0.09	C
VP	5.00	0.89	3.50	0.55	0.00	B
CC	3.67	0.52	4.50	0.84	0.06	C
SB	4.50	0.84	5.67	0.82	0.03	A
AC	5.33	0.82	7.00	1.55	0.04	A
GG	5.33	0.52	4.83	0.75	0.20	C
FB	3.33	0.52	3.83	0.98	0.29	C
AC	5.17	0.75	6.00	0.89	0.11	C
BD	3.33	0.82	4.83	0.41	0.00	A
GM	4.83	0.98	3.83	0.41	0.04	B
MG	4.50	0.55	7.17	0.75	0.00	A
EP	3.67	0.52	4.17	0.98	0.29	C
TD	6.33	0.52	7.00	0.89	0.14	C
CR	6.00	0.89	4.50	0.55	0.00	B
MM	5.50	0.55	7.17	0.75	0.00	A
DM	4.60	0.89	4.75	0.85	0.77	C
AS	5.40	0.60	7.30	0.75	0.00	A
MM	5.50	0.55	5.83	0.41	0.26	C
LC	3.33	0.52	3.67	0.89	0.43	C
GA	5.50	0.55	4.50	0.55	0.01	B
PP	3.50	0.85	4.83	0.41	0.00	A
VM	5.00	0.89	3.67	0.82	0.02	B
MF	6.33	0.52	4.17	0.98	0.29	C
BL	5.33	0.82	7.00	1.55	0.04	A
MG	5.25	0.75	3.83	0.98	0.01	B
PC	4.83	0.55	4.00	0.41	0.01	B
RP	5.40	0.75	6.90	0.89	0.01	A
LC	4.00	0.63	3.67	0.82	0.45	C
CG	6.00	0.89	5.50	0.75	0.31	C
CC	6.50	0.55	7.50	0.82	0.03	A

and, in all cases, they tilted the bar to the dysfunctional side. The provocation test showed a significant increase in SVV_0 values in 13 patients (Group A), but a significant reduction was recorded in 8 cases (Group B); in 19 patients the test did not significantly alter the baseline values (Group C) (Table II). None of the subjects in the control group showed dysfunctional SVV_0 baseline values and the provocation test did not induce significant variations in these values.

First follow-up

At the first follow-up, the baseline test was repeated, showing normalisation of SVV_0 values in 10 patients, versus persistence of otolith dysfunction in 30 cases. Of the 10 patients with normal SVV_0 values, 8 were from Group A and 2 from Group C. Dysfunctional SVV_0 values, on the other hand, were maintained in 5, 8 and 17 patients, from Groups A, B and C, respectively (Fig. 1).

Second follow-up

Thirty patients underwent the second follow-up: 9 had normal SVV_0 values (5 patients from Group A, 1 from Group B, 3 from Group C), whereas abnormal values persisted in the remaining 21 (7 from Group B, 14 from Group C). Overall, at the end of the two follow-ups, all of the patients from Group A, 12.5% of those from Group B and 26.3% of those from Group C, recovered utricular otolith function (Fig. 2).

Third follow-up

Eight of the 21 patients examined during the third follow-up – all of whom from Group C – showed functional recovery. The other 13 continued to present SVV_0 values in excess of ±2 (7 patients from Group B and 6 from Group C). Therefore, at the end of the follow-up, altered SVV was found to affect 87% of the patients from Group B and 31.5% of the patients from Group C, but none of those from Group A (Fig. 1).
Repetition of the caloric tests showed functional recovery in 9 patients (3 from Group A, 2 from Group B and 4 from Group C).

Discussion

In recent years, new methods have been introduced in the semiotic study of the vestibular system, permitting investigation of vestibular reflexes originating in the macula, offering the possibility to formulate an overall opinion regarding the functionality of the posterior labyrinth. Of these, the determination of SVV is a simple and inexpensive way to study otolith function originating primarily in the utricle.
Results of the study showed that the judgement of verticality, in normal subjects, is not affected by partial proprioceptive deprivation induced by placing a cushion under the individual's feet. The otolith organs alone, can provide

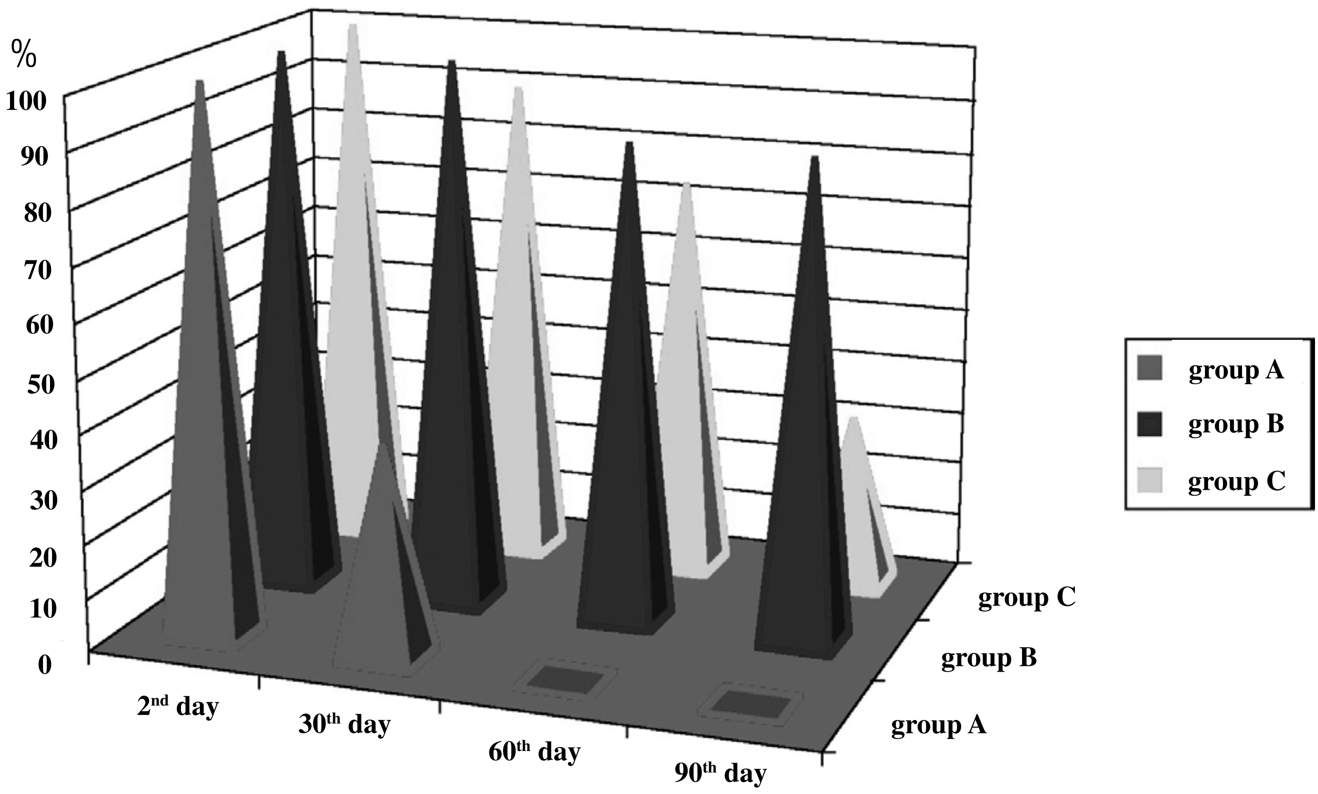

Fig. 1. Distribution (%) of patients with dysfunctional SVV_0 values according to the groups examined in follow-up examinations.

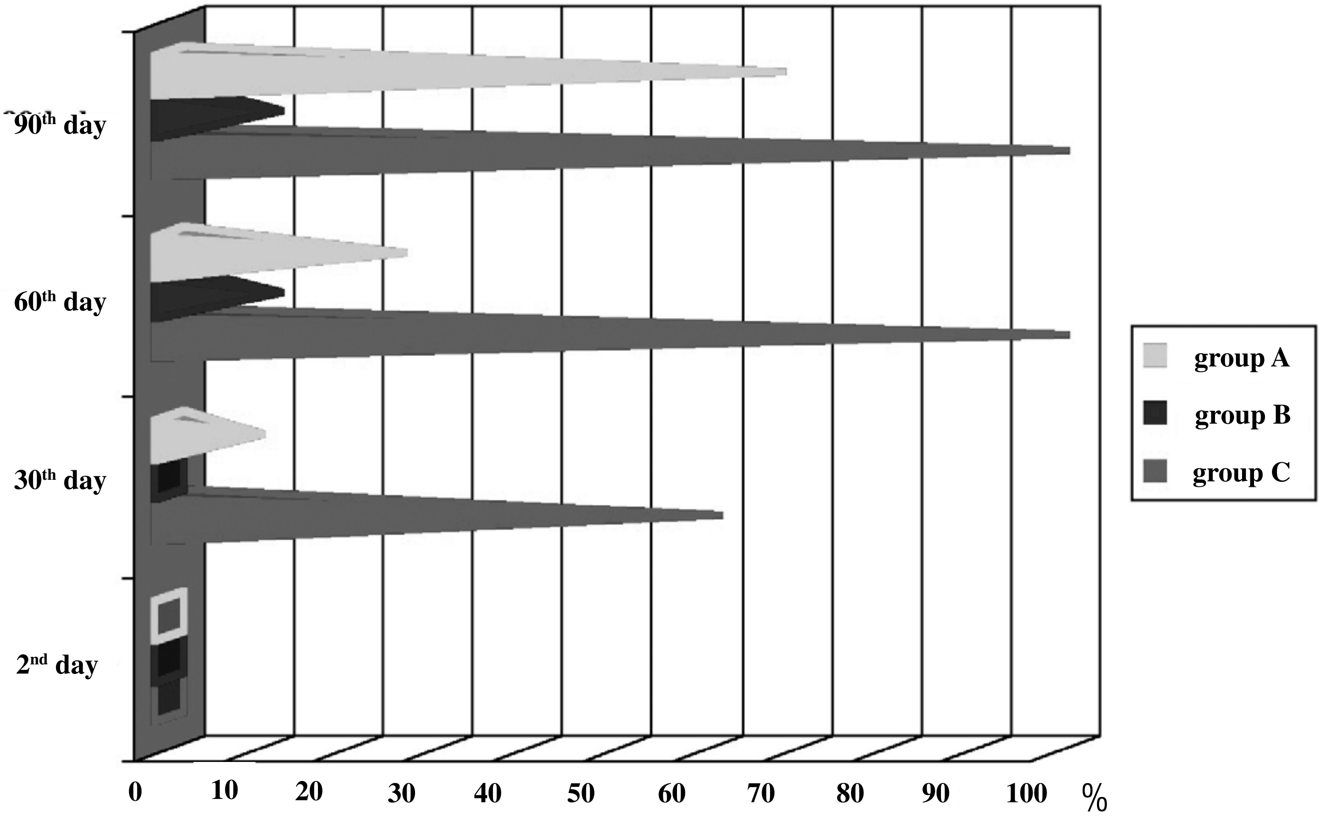

Fig. 2. Distribution (%) of patients with normalisation of SVV_0 values according to the groups examined in follow-up examinations.

the information needed to construct SVV, independently of important extero- and proprioceptive inputs (such as those from the plantar surface) and visual inputs, the latter eliminated by creating a completely dark room. In the case of vestibular dysfunction, perception error – determined by the asymmetry of afferent firing from the otoliths to the vestibular neuron groups – is often affected by changes induced in the extra-vestibular sensory systems, the proprioceptive one in this case. Nevertheless, sensory afferent gain can produce different effects in the responses of patients with vestibular dysfunctions. In fact, while an increase in perception error was observed in some cases as a result of reduced ascending sensory inputs caused by the cushion under the patient's feet, in other patients the same experimental conditions seemed to make identification of the subjective vertical easier, as they tilted the bar to a lesser degree. On the whole, these observations reflect the individual postural strategies used to judge verticality. Consequently, to compensate for unilateral otolith dysfunction, the patients from Group A preferred to rely on the extra-vestibular input, in general, and proprioceptive input, in particular. Inversely, for the same function, Group B patients favoured a condition of proprioceptive deprivation, since this input proved to be destabilising. Nevertheless, many of the patients showed that they were not significantly conditioned by external sensory input with respect to information coming from the vestibular system (Group C).

Recovery of the previously damaged function, demonstrated by the caloric tests, occurred in 22% of the cases, which refer to 23% of the patients from Group A, 25% of those from Group B and 21% of those from Group C. Therefore, this function does not seem to be significantly affected by the behaviour observed during the provocation tests. Instead, normalisation of the SVV occurred in 67% of the patients examined, also expressing the evolution of vestibular compensation in the macular function. This behavioural difference may stem from an effective capacity for functional recovery of the otolith organs, which seems to be superior to that of the canal. At the same time, however, it appears to indicate vicarious extra-vestibular inputs in correcting perception error. In all cases, the time needed to achieve the latter objective seems to be strongly conditioned by the possibility of exploiting extero- and proprioceptive sensory input from the plantar surface of the foot.

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