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Posture Stability in Adult Cochlear Implant Recipients

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Dizziness and vertigo are among problems reported after the Cochlear Implant (CI) surgical procedure. The electrodes insertion to the inner part of the cochlea may disturb the vestibular component, which may cause loss of balance or postural instability. The objective of the research is to compare postural stability through the measurement of Limit of Stability (LOS), Centre of Pressure (COP) and Sway Velocity (SV) between adult cochlear implants users and normal hearing subjects in ten sensorial test situations. Ten CI subjects were recruited from the Universiti Kebangsaan Malaysia Cochlear Implant program and the National Cochlear Implant program under the Malaysian Ministry of Health. Another 10 aged matched controlled healthy individuals were also involved. All CI subjects were monaural users with CI experienced ranging between 9 months to 17 years, with no reported surgical complications. A cross-sectional study was done by measuring postural stability using the Balance Rehabilitation Unit (BRU™) posturography. There was no significant difference ($p = 0.436$) between the LOS for the CI group (mean = 158.45±47.83) cm^2 and the control group (mean = 174.11±39.80) cm^2. There was no significant differences between the COP values for both groups in all test situations except for a task (where subjects only received sensory inputs from vestibular system and not the visual and somatosensory); ($p = 0.010$). The sway velocity mean value for the CI group was not significantly different than those in the control group ($p>0.05$) in all situations tested. Based on sensory analysis, the SV and COP values in the vestibular component of the CI group differed than the control group despite not being statistically different. From this study we found that there was no evidence of posture instability in our CI group as compared to the control group except for the COP value. We proposed that the COP measurement which involved all the sensory measures are sensitive in measuring the posture stability.

Key words: Balance, cochlear implants, posturography, posture stability

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INTRODUCTION

Vertigo and dizziness are among the risks after a Cochlear Implant (CI) surgery (Cohen and Hoffman, 1991). A CI recipient may complaint of vertigo and dizziness soon after the surgery or after the activation of the implant (Filipo *et al*., 2006). Delayed onset of dizziness among CI recipients have also been reported (Fina *et al*., 2003; Zanetti *et al*., 2007) and may be due to saccular collapsed or obstructed endolymphatic flow in the ductus reuniens as a consequence of injury in the lateral wall during implantation (Handzel *et al*., 2006). Other studies showed that vestibular system could be affected by cochlear implantation either due to interrupted sensory vestibular function of the labyrinth with unilateral deafferentation of fluctuating vestibulopathy or due to the electrical stimulation of the implants (Buchman *et al*., 2004; Krause *et al*., 2010; Schwab *et al*., 2010). Study on the risks after CI surgery showed that the risk for sacculus impairment was (8-54%) (Melvin *et al*., 2009). Balance problem and vestibular dysfunctions among CI recipients are not uncommon (Migliaccio *et al*., 2005; Enticott *et al*., 2006; Cushing *et al*., 2008; Jacot *et al*., 2009; El-Abd *et al*., 2011). Earlier research showed that 32% of the CI recipients suffered significant disturbances in their vestibular functions a week or more after the surgery (Jacot *et al*., 2009). In another study, positional vertigo was reported in 49% of adult recipients after the surgery (Steenerson *et al*., 2001), possibly due to the vibratory trauma affecting the cochlea during cochleostomy (Viccaro *et al*., 2007). In a study involving 42 patients (age ranged 5-22 years old) who underwent unilateral CI surgery and being considered for second implant found that 60% of them had reduction in the vestibular ocular reflex (VOR) and the overall postural weakness (Licameli *et al*., 2009). Objectively they found that the Vestibular Evoked Myogenic Potential (VEMP) threshold was elevated while the amplitude decreased. In another study conducted pre-and post-cochlear implantation, more than 50% of the implantees had reduced vestibular responses post-operatively (Jacot *et al*., 2009). Recent study indicated that 24.4% of CI adult recipients experienced clinical presentation of vertigo after surgery (Holinski *et al*., 2012). Others also suggested that part of the otolithic organ, the saccule, could easily be damaged by the electrode insertion. This was evident through the absence of VEMP's responses to click stimulation (Jin *et al*., 2006; Basta *et al*., 2008; Licameli *et al*., 2009). Damage on the otolith organs would affect their performances in a posture stability assessment (McCaslin *et al*., 2011). Human's postural stability is derived from the interactions of sensory inputs from the vestibular peripheral organs, somatosensory and visual systems. Absence of one system will be compensated by the other (Friedrich *et al*., 2008). Research on postural control among CI children with associated vestibular hypofunction showed that they compensated on the loss of their vestibular information with the use of visual and somatosensory inputs (Suarez *et al*., 2007). A study on the overall balance ability in profound sensorineural hearing loss children receiving CI showed that these children performed poorly compared to the age-matched control group. The study was conducted using a test of static and dynamic balance function i.e., the Bruininks-Oseretsky Test of Motor Proficiency 2 (Cushing *et al*., 2008).

Generally, balance ability is the outcome between interactions of different sensory systems to ensure stability during stationary and movement. Therefore, any tests that gives information about abnormality in balance ability as a whole is needed to evaluate the ability of an individual to use sensory inputs from the visual, somatosensory and vestibular systems in all types of environment. Posturography is a test that is able to evaluate the postural stability, which is useful to detect balance problem that is not detected by any other tests (Sataloff *et al*., 2005). There are two types of posturography, static and dynamic posturography, which able to provide fast, subtle and objective measures in the evaluation of postural control (Kluenter *et al*., 2009). In static posturography, postural control is measured while patient stands on a stationary platform with eyes open or closed. For dynamic posturography, patient is required to stand on a moving platform (Norre and Forrez, 1986). Many researchers use Computerized Dynamic Posturography (CDP) in the assessment of postural stability which utilised moving platform (Buchman *et al*., 2004; Licameli *et al*., 2009; El-Abd *et al*., 2011). Studies showed that activated CI affects the vestibular system's function under static and dynamic posturography conditions (Schwab *et al*., 2010; Huang *et al*., 2011). Therefore in this study, the Balance Rehabilitation Unit (BRU^{TM}) by Medicaa is used in assessing postural stability and visual-vestibular interaction. This relatively new test technique, developed to evaluate and train patients with balance disorders, vertigo and instability using a static platform and a virtual reality goggle to provide visual stimulation. This test measures the Centre of Pressure (COP) and Sway Velocity (SV) in ten different sensorial stimulation situations and also Limit of Stability (LOS) using the ankle strategy (Natalia *et al*., 2011). COP is the application point as the end result of vertical forces on a support surface (Duarte and Freitas, 2010). In a balance control during standing position, with the feet on the ground, the body's centre of gravity is vertically over the firm surface and measured as the COP (Nashner, 1997). SV measured in this study represents the extent of the COP excursions in ten sensorial situations which are delivered through a virtual reality goggle. In a standing position, a patient must maintain his COP to prevent fall due to gravity influence. This is achieved by swaying back and forth and side by side. This swaying movement is quantified as SV (Nashner, 1997). LOS is defined as the maximum possible COP sway angle as a function of sway direction from the centre position (McCollum and Leen, 1989). It is also known as the greatest distance in any direction a person can lean away from a midline vertical position without falling, stepping, or reaching for support. Balance control is greatly influenced by COP, SV and LOS (Nashner, 1997). Therefore, it is also used in balance assessment among patients with benign paroxysmal positional vertigo (BPPV) and multiple sclerosis. Higher value of COP and SV indicate poor posture stability. The information is useful in designing rehabilitation programs and treatment plans for these patients (Natalia *et al*., 2011; Monteiro *et al*., 2012).

This study aimed to evaluate the overall postural control function among adult CI users and to compare to normal hearing individuals using BRU™ posturography. Displacement area of the body mass COP and its sway velocity in ten different sensory stimulations were measured. Overall information from the vestibular, somatosensory and visual systems supplied by the BRU™ posturography will be used as a benchmark in the balance assessment among CI recipients following CI surgery. This will lead to better management of every individual implantees. The results obtained from this study could also provide new insight of the BRU™ posturography in the overall posture and balance ability among CI recipients.

MATERIALS AND METHODS

This controlled cross-sectional study was carried out between August 2012 until January 2013 at the Balance and Vestibular Research Lab, Universiti Kebangsaan Malaysia (UKM) and at the Department of Otolaryngology, Universiti Kebangsaan Malaysia Medical Centre (UKMMC), Kuala Lumpur. CI subjects were recruited from UKM CI program and the National CI program under the Ministry of Health Malaysia. Prior research approval was obtained from the Secretariat of Medical Research and Innovation, UKMMC and the Ethics and Medical Research Board from the Ministry of Health Malaysia. Twenty age-matched individuals (ten males, ten females; aged between 21-43 years) were involved in this study. They were divided into the CI and the control groups. The inclusion criteria for the CI group was CI adult recipients who are able to understand simple verbal instructions and the exclusion criteria for this group who having major spine or mobility problem (they need to stand on the platform). Five patients received CI on the left side and five patients on the right side. All patients underwent standard procedure for cochlear implantation involving a cochleostomy method from facial recess approach (Niparko, 2004). Seven of them were users of the Nucleus 24 and three were users of the Nucleus 22 CI system. All had full electrode insertion and no surgical complication. The control age-matched group consists of ten healthy individuals with no history of vertigo and balance problem and had normal hearing bilaterally. Both the CI and control groups underwent pre-assessment hearing evaluation which include otoscopic examination, pure tone audiometry and tympanometry to ensure the hearing and middle ear status. The CI group also underwent aided hearing assessment using their normally-used speech processor settings. CI group were interviewed to get information for any symptoms of dizziness experienced before and after the CI surgery.

All participants underwent the BRU™ posturography in ten sensorial situations based on visual, vestibular and somatosensory stimulation. The test conditions are listed in Table 1. The BRU™ posturography consists of a

Table 1: The balance rehabilitation unit (BRU)™ posturography protocol

Test conditions	Test situations	Duration (sec)
**	*Platform fruits, Limit of stability	32
1	No stimulus (eyes open, firm surface)	30
2	No stimulus (eyes closed, firm surface)	30
3	Saccadic (eyes open, firm surface)	30
4	Optokinetic, Train left to right (eyes open, firm surface)	30
5	Optokinetic, Train right to left (eyes open, firm surface)	30
6	Optokinetic, Train top to bottom (eyes open, firm surface)	30
7	Optokinetic, Train bottom to top (eyes open, firm surface)	30
8	Visual Vestibular, circular train left to right (eyes open, firm surface)	30
9	Visual Vestibular, circular train top to bottom (eyes open, firm surface)	30
10	No stimulus (eyes closed, foam)	

*To measure limit of stability, **Task 1-task 10 measure centre of pressure (cm^2) and sway velocity ($cm\ sec^{-1}$)

40×40 cm static pressure platform, a computer running a BRU™ software, a metal structure with support loops and safety harness belt, a virtual reality-goggles and an accelerometer. The accelerometer is attached to a goggle. The pressure platform has an area of 1600 cm^2, with marks for both the vertical and horizontal coordinates, an 8 cm horizontal or intermalleolar line for foot placement and a 12 cm vertical line to intercept the middle point of the intermalleolar line (Ghiringhelli and Gananca, 2011). During testing, subjects were required to stand barefooted with their arms aside on the static force platform. Their foot must be placed on the marked line for foot placement. The applied pressure on the platform was converted into electrical signals and three measurements were deducted, i.e., the COP, SV and LOS. Subjects were instructed to wear the safety harness belt prior to the assessment. They were also instructed to wear the virtual reality-goggles, facing to the front (that is, 0° angle). during all the sensorial test situations except for test conditions 7 and 8 (Table 1). The LOS threshold was measured with the visual stimuli given to help the subjects to move in four different directions (i.e., forward-backward-left-right) and to reach their optimum LOS. During the LOS measurement, subjects were instructed to use their ankle strategy or sway the body as a unit over the feet, not to lift their feet from the platform and avoid using their hip strategy or sway the body which centred at the hip joint with opposing ankle joint rotations. Subjects were advised not to move their feet while performing the task. All the task were administered twice. Data were analysed using SPSS statistical software for Windows, version 20.0 (2011). Descriptive statistical analysis was performed to compare the posture stability of the CI experimental group and the age-matched controlled group. The data were normally distributed based on the Shapiro-Wilk test results ($p>0.05$). Therefore independent t-test was used to determine the postural stability differences between the CI and the control groups with significance level set at $p\leq 0.05$. The effect of each balance function system (visual, vestibular and somatosensory) was determined using an algorithm suggested by Schwab *et al.* (2010). The algorithm for each of the balance function system was calculated based on ten different test situations. This is to determine the effect of each sensory on the responses. Table 2 shows the details of the algorithm for the sensory analysis.

RESULTS

A total of 10 post lingual CI adult subjects participated in the study, age ranged between 21-43 years (mean 28.5±6.2 years). The mean age for the age-matched control group was 28.1±6.4 years. There was no statistical difference between the mean age of the control group and the study group ($p = 0.861$). Table 2 shows the demographic details of the CI group. The duration of implant experienced ranged from 9 months to 17 years. Fifty percent of the subjects were implanted on the right ear and the rest had the implant on the left side. More than half from subjects in CI group has progressive post-lingual deafness, followed with 30% of them has congenital hearing loss and 10% of them loss their hearing due to trauma. Both the CI and the control group had no history of dizziness or having symptoms of impaired balance function.

Table 2: Characterization of cochlear implants patients

Characteristic	Value
Age (years) (mean±SD)	
At testing	28.6±6.2
At implantation	21.8±9.3
Duration of implant use (years)(mean±SD)	6.6±6.8 (9 months to 17 years)
Etiology of hearing loss (%)	
Head trauma	10
Congenital	30
Progressive post-lingual deafness	60

Independent t-tests indicate no significant differences between the two groups for the LOS ($p = 0.436$) and the SV ($p>0.05$) for all test conditions. As for the COP values, no significant differences were noted for all test conditions ($p>0.05$) except for task number ten (i.e., medium density foam pillow and closed eyes); ($p = 0.010$) (Table 3). In test condition number ten (Table 1), the somatosensory and visual inputs were interrupted (because subjects were instructed to stand on the medium density foam pillow with their eyes closed). Therefore only the vestibular input plays a role in maintaining balance. The CI subjects as a group had significantly higher mean COP than the control group in this task suggesting poorer posture control in CI group in situations where input from visual and somatosensory were inaccurate.

As an attempt to separately analyse each specific sensory system that are involved in the balance function (i.e. the visual, vestibular and somatosensory systems), an algorithm was proposed based on Schwab *et al.* (2010). The algorithm are presented in Table 4. The SV and the COP values for each component of the sensory system (i.e., the visual, vestibular and the somatosensory system) were calculated based on the algorithm and compared between the CI subjects and the control groups. The mean values for the COP and SV which calculated based on the algorithm on each component of the sensory system was not significantly different ($p>0.05$). However,

Table 3: Mean±SD and p-values for centre of pressure (COP) and sway velocity (SV) in ten test situations for cochlear implant and control groups

			Center of pressure (cm^2)		Sway velocity (cm sec^{-1})	
Test conditions	BRU	Groups	Mean±SD	p-value	Mean±SD	p-value
1	FS/EO/No stimulus	CI	7.74±8.38	0.129	1.20±0.79	0.244
		Control	3.22±2.19		0.88±0.31	
2	FS/EC/No stimulus	CI	4.83±3.83	0.293	1.13±0.67	0.643
		Control	3.25±2.55		1.00±s0.47	
3	FS/Saccadic	CI	5.15±5.13	0.094	1.28±0.38	0.101
		Control	2.04±1.49		0.97±0.43	
4	FS/Optokinetic/Left to right	CI	2.47±3.04	0.857	0.83±0.36	0.785
		Control	2.27±1.54		0.88±0.40	
5	FS/Optokinetic/Right to Left	CI	3.44±3.31	0.413	0.93±0.71	0.897
		Control	2.44±1.76		0.89±0.44	
6	FS/Optokinetic/Top to Bottom	CI	6.06±9.38	0.325	0.86±0.48	0.774
		Control	2.93±1.82		0.91±0.40	
7	FS/Optokinetic/Bottom to Top	CI	5.87±7.47	0.299	0.98±0.46	0.944
		Control	3.17±2.33		0.96±0.40	
8	Visual vestibular (Left to Right)	CI	5.79±5.56	0.266	1.77±0.83	0.578
		Control	3.38±2.10		1.58±0.69	
9	Visual vestibular (Top to Bottom)	CI	5.33±3.82	0.682	2.45±0.77	0.421
		Control	6.13±4.74		2.17±0.75	
10	Foam/EC	CI	26.75±16.83	*0.010	4.89±2.78	0.051
		Control	9.57±3.12		2.84±1.08	

FS: Firm surface, EC: Eyes closed, EO: Eyes open, Significance Level at = 0.05 *Independent t-test $p<0.05$

Table 4: Algorithm for sensory analysis

	Comparison	*p Functional relevance
Somatosensory system (SOM)	T1/T2	Ability to use input from somatosensory
Visual system (VIS)	(T3+T4+T5+T6+T7)/T2	Ability to use input from visual
Vestibular system (VEST)	T10/T1 + (T8+T9)/(T3+T4+T5+T6+T7)	Ability to use input from vestibular

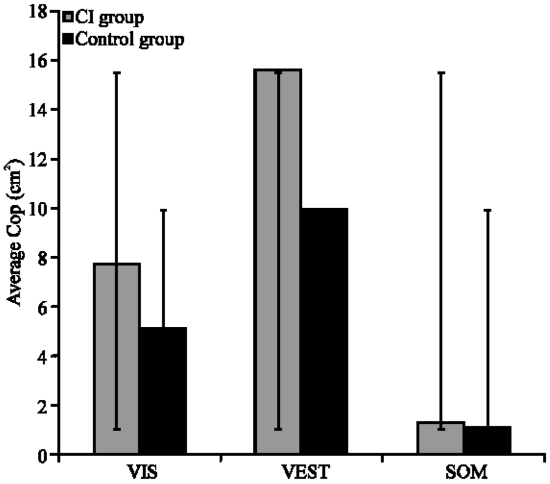

Fig. 1: Sensory analysis for the Centre of Pressure (COP) involving the visual (VIS), vestibular (VEST) and somatosensory (SOM) systems. Error bar indicates the standard deviation values

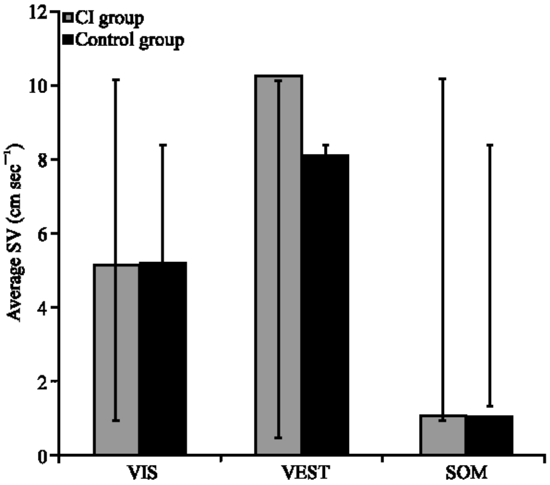

Fig. 2: Sensory analysis for the Sway Velocity (SV) involving the visual (VIS), vestibular (VEST) and somatosensory (SOM) systems. Error bar indicates the standard deviation value

from this sensory analysis, there were poorer mean values of SV (10.26±5.99) and COP (15.74±16.30) in the vestibular component of the CI subjects as compared to the control group (SV = 8.17±3.02; COP = 9.99±9.13) despite not statistically significant. Fig. 1 and 2 show the mean values of (COP) and (SV) based on the sensory analysis which calculated based on the algorithm.

DISCUSSION

Past studies indicated that posture instability might occur before and after CI surgery despite caloric test revealing normal findings (Di Fabio, 1995; Kluenter *et al.*, 2009). A study on 24 adolescents with at least 5 years usage of unilateral cochlear implantation showed or posture control on stabilometry as compared to their normal hearing peers (Huang *et al*., 2011). In the present study all participated subjects had no history of dizziness and other significant vestibular disorders pre-and post-surgery and had not underwent any vestibular function tests before. Therefore the postural control assessment was conducted to reflect their balance control as a whole. The BRU™ posturography is a relatively new test that is useful for the overall balance control assessment and to measure patients' progress in a balance rehabilitation program (Ghiringhelli and Gananca, 2011). In the present study, we measured the COP, SV and LOS in the given static conditions and using visual stimulation. We found that the CI patients had no significant difficulties to move their bodies COP on the platform with maximum sway angles, without falling, stepping to the side or reaching for support. This is indicated by the insignificant LOS value between the two groups. Earlier studies using BRU™ posturography on patients with BPPV and multiple sclerosis revealed similar insignificant results than the normal (Natalia *et al*., 2011; Monteiro *et al*., 2012). Therefore, the insignificant responses between the CI and the normal groups may suggest that the surgery experienced by all the CI subjects had not interfere with their vestibular organ's function. This is contrary with previous findings, which suggested the electrode insertion may injured the lateral wall of membranous labyrinth and interrupt the sensory vestibular function (Suarez *et al*., 2007; Basta *et al*. 2008; Friedrich *et al*., 2008; McCaslin *et al*., 2011). It was also evident from our study that the long term electrical stimulation from the implant did not affect the balance function of the users, as suggested by previous findings (Basta *et al*. 2008).

The COP values in ten different sensorial situations tested on the BRU™ posturography showed no significant differences ($p>0.05$) between the two groups except on the last task (with the eyes closed and standing on a foam pad), which gave significant result ($p = 0.01$). The results indicated that the CI group showed higher COP than the control group. This suggests poorer postural control in the CI group when the inputs from both the visual and somatosensory systems are absent. When patients are standing on a non-solid surface i.e., on a foam pad and at the same time with their eyes closed, there will be conflicting inputs from both the somatosensory and visual systems, resulting in poor postural control. When this happens, patients will be entirely depending on their vestibular input for their postural and balance control. This finding agrees with a study which found that when there was a conflict in the sensory input (between somatosensory and vestibular inputs), CI children were unable to control their body balance when they had to solely depend on vestibular input (Cushing *et al*., 2008). Our findings also showed poorer COP and SV mean values in the vestibular component from the sensory analysis among CI recipients as compared to the control group. A previous study which was done on a group of children with CI and vestibular hypofunction also showed poorer mean COP value than the normal-hearing children (Suarez *et al*., 2007). Although there was suggestion that the vestibular component does not play the most sensitive role in the overall balance control as other sensory inputs (Schwab *et al*., 2010), however, it is still very crucial when the somatosensory and visual inputs are absent (Allum *et al*., 1989). Past research also showed that the postural control in a CI patients under eyes closed and modified surfaces test condition were significantly different than the normal group before and after surgery suggesting the possibility of vestibular disorders which may have pre-existed among the CI patients before the surgery (Kluenter *et al*., 2009; Migliaccio *et al*., 2005). A study on vestibular impairment pre-and post-CI surgery found that 50% of the CI candidates have vestibular deficits (Jacot *et al*., 2009). However, in our study, we did not have the baseline clinical record on the postural function of the CI subjects prior to the CI surgery.

As for the SV, the mean values in all sensorial test conditions for the CI group were not significantly different from the control group. This indicates that the CI recipients had optimum body sway oscillation in maintaining the COP within the LOS and within the range exhibited by the control group. In situation number 10 (standing on a foam pad with the eyes closed), the mean SV for the CI subjects were poorer than the control group. This happens when both the visual and somatosensory inputs were unavailable in balance control, forcing vestibular input to play the only role in maintaining SV. Body sway is easily influenced when there was lack of inputs from visual and somatosensory system than inputs from vestibular system (Bles *et al*., 1984; Allum *et al*., 1989). This could be the reason why there were differences in sway velocity in CI group as compared to control group in test situation number ten (standing on foam pad with eyes closed) which there was modified visual and somatosensory inputs. Our finding which indicates poorer SV responses in the CI patients were consistent with other studies (Sataloff *et al*., 2005). This result suggest that the input from the vestibular system has lesser impact on the postural control among the CI patients as compared to control group whenever there were no visual inputs and somatosensory inputs.

Inferring to this result, it further indicates that the vestibular system was affected in the CI patients following the CI surgery and prolonged exposure to electrical stimulation. Nevertheless, our insignificant SV results between the CI and the normal groups could be due to the relatively small sample size.

We had attempted to measure the visual, vestibular and somatosensory components separately by deducting an algorithm which was able to give separate information on the three sensory components involved. We found that there were similar COP and SV in both the visual and somatosensory components between the two groups but there were differences in the COP and SV in the vestibular component, with the CI group having higher COP and SV than the control group. This indicate poor postural stability in the CI group when they are totally relying on the vestibular component. Therefore we proposed that the vestibular component in the overall balance system in the CI group are impaired than the control group and this is only evident when the visual and somatosensory systems contribution are eliminated.

The insignificant differences in the responses between the CI and the control groups maybe due to the vestibular adaptation mechanism which plays a role in maintaining balance and may also be induced by the CI activation (Buchman *et al*., 2004). Several studies (Buchman *et al*., 2004; Cushing *et al*., 2008; Schwab *et al*., 2010) showed improvement in the patients' balance performance with their CI processor "on" than when it is "off". This could be due to the electrical stimulation by the CI which influenced the vestibular system's function (Cushing *et al*., 2008; Schwab *et al*., 2010). However, in this present study, postural stability in the CI patients was assessed with their processor "on". Therefore the results may be influenced by the electrical stimulation of the implant on their vestibular system's function.

Present study showed that the BRU™ posturography is a test that provides useful information concerning the CI patients' postural control. Preoperatively balance information could serve as a baseline data should there be any queries post-operatively related to the postural control of the patients. The information from the BRU™ posturography could be used in the balance rehabilitation program and monitoring overall balance function for better CI patients' management.

CONCLUSION

Overall we found that the postural stability of the experimental CI group have no significant difference with the normal control group in most tests situations, except for the COP value in one specific test situation, in which both the visual and somatosensory inputs was interrupted and modified. Therefore we proposed that the BRU™ posturography is sensitive in identifying abnormalities in the postural control of CI patients. In conclusion, the COP and SV value in BRU™ posturography is useful in postural control assessment and rehabilitation program among CI recipients. Furthermore, the COP and SV values could be analysed by using the algorithm proposed in discriminating the vestibular response than the other sensory systems. This might give useful insight towards measuring the vestibular ability from other sensory systems in maintaining postural balance.

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