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Quantitative analysis of the effects of audio biofeedback on weight-bearing characteristics of persons with transtibial amputation during early prosthetic ambulation

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Abstract—Residual limb recovery after a transtibial amputation depends largely on close monitoring of the weight-bearing activities during the early postoperative stage. Although a biofeedback device, in particular audio biofeedback, was recommended to be used, no quantitative studies regarding its effectiveness in monitoring the weight-bearing activity of a person with amputation were available. In this study, six persons with transtibial amputation were asked to replicate a prescribed amount of weight bearing using a bathroom scale method during their early postoperative ambulatory training. Their weight-bearing characteristics with and without using audio biofeedback were continuously monitored using a load monitoring device and compared with the prescribed load. The results showed that the residual limb would be overloaded using the conventional bathroom scale method during early postoperative ambulatory training if no audio biofeedback was provided. It was demonstrated that audio biofeedback was useful in preventing the residual limb from being overloaded beyond the prescribed load particularly when the prescribed load was low.

Key words: *audio biofeedback, load monitoring device, transtibial amputation, weight bearing.*

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INTRODUCTION

Early mobilization and ambulation are encouraged after amputation as they can speed residual limb recovery and shorten the rehabilitation period (1-6). Thus, ambulatory training often begins as soon as the remaining leg and upper limbs of the patient are strong enough to bear the weight of his/her body. It has been suggested that a suitable amount of weight-bearing activity could improve blood circulation, minimize edema, promote residual limb healing, and provide appropriate proprioceptive feedback from the floor to the residual limb through muscle activities (3). However, it was also reported that too much weight-bearing activity might cause residual limb trauma or interfere with the wound healing process, especially if the individual had a circulation problem. To avoid disruption of the wound healing process, care must be taken not to exert excessive pressure on the residual limb, particularly during the early postoperative period.

Self-reports of persons with amputation, regarding the amount of force that can be tolerated by the residual limb, are used to control the progression of weight-bearing activity. Due to the subjective nature of the reports, it is difficult to regulate the loads transmitted to the prosthesis, especially for individuals with sensory neuropathy. A bathroom scale is usually used to provide visual feedback to assist these persons in controlling the amount of load transmitted through the prosthesis. Although the procedure is logical, and study results have affirmed the clinical usefulness of the scale, it does have several limitations (7). Accuracy of this method, as a means of measuring the exact amount of weight to be exerted on the residual limb, is difficult to achieve and maintain, particularly when the weight to be replicated is minimal. Moreover, the use of this visual feedback device is applicable only in the case of standing, but not in walking.

Different devices with audio biofeedback, such as the System for Control of Ambulation Pressure, the SCAP-I (8), the SCAP-III (9), the Limb Load Monitor (10), and the PRS-MOORE of AJ Moore, of the Prosthetic Research Study (PRS), Seattle, WA (11), have been developed. Although use of these devices helped to monitor the amount of weight to be replicated, the actual amount of force acting on the residual limb during the early ambulatory period was not recorded.

The Pylon transducer (12), a three-dimensional, portable load-measuring device, was developed to measure the load transmitted through the prosthesis to the residual limb during walking. This device has been used to study the biomechanics of the gaits of persons with amputation (13,14). However, it has not been used to study the actual amount of load acting on a residual limb during the early postoperative period. In 1996, a simple load-monitoring device with biofeedback was designed and developed by the authors (15). The device could provide audio biofeedback to the individual when a preset loading level was reached. It could also be used to monitor the amount of axial load transmitted through the prosthesis to the residual limb. The purpose of this study was to evaluate the effects of audio feedback on the weight-bearing patterns of persons with transtibial amputation during their early postoperative ambulatory period, following a standardized clinical protocol.

METHODS

Instrumentation

In this study, a simple load-monitoring device was used to monitor the axial load acting on the residual limb and to provide an audio biofeedback signal to the subject once the amount of prescribed load was reached (15). The device was made by attaching two pairs of single-axis strain gauges to the tube adapter of an endoskeletal prosthesis. One pair was bonded along the longitudinal axis of the adapter, while the other was bonded perpendicularly to the first. This configuration allowed for both moment and thermal compensation. The device was designed to sound a beep once the axial load reached a preset level. In this study, we proposed to use this simple feedback method for our elderly persons with amputation. The audible alarm was designed to be a continuous tone with constant volume.

The load acting on the adapter could also be sampled by a computer data acquisition system. The linearity of the device was calibrated using a standard material testing system (Hounsfield Test Equipment Ltd., UK). The correlation coefficient of the regression line was 0.999 with $p<0.001$. The configuration of the strain gauges eliminated the effect of bending moments acting on the prosthesis. However, there was no compensation for crosstalk from shear forces. As persons with new amputations are only allowed to perform partial weight-bearing activities, their stride length is usually short. Thus, the error in the axial load measurement due to shear force was not significant. There was another advantage for this device over previous designs (8-11): as it was a modification of a standard tube adapter, no additional weight was added to the prosthesis.

Subjects

Six subjects (3 male and 3 female) with mean age of 72 y (range from 66–78 y) were recruited with the following inclusion criteria:

1. Age over 50 y with unilateral transtibial amputation
2. Lost leg due to either vascular disease or trauma
3. No major sight and hearing problems
4. Able to communicate
5. Good physical and ambulatory ability

An informed consent was obtained prior to the testing. Five subjects were diabetic, and one had peripheral vascular disease. None of the subjects had diagnosed neurological problems; three had lost their right legs and three their left.

Procedures

A 5-d standardized, postoperative, transtibial amputation management protocol, with the following weight-bearing regime, was adopted. On the first day of the rehabilitation program, the amount of prescribed load was fixed at 89 N (9.08 kg). It was increased progressively by 22 N (2.24 kg) every day up to the total, maximum load of 178 N (18.15 kg).

The subjects were asked to stand with the prosthetic limb on a bathroom scale every day at the beginning of the rehabilitation. They were required to "report" their "feeling" about the prescribed load. The subjects were then asked to weight bear on the prosthetic limb both with and without switching on the audio biofeedback signal when replicating the prescribed load. Subsequently, the subjects were asked to walk back and forth along a 5-m walkway inside a set of parallel bars (**Figure 1**). They were requested to replicate the prescribed load to the best of their ability.

Four walking trials, including two with audio biofeedback and two without the biofeedback, were conducted on each rehabilitation day. The subjects were free to choose the walking speed. The order of the trials was randomly assigned, and the subjects were informed at the beginning of each whether or not biofeedback would be given. The loads acting on the residual limb during the trials were monitored by the load-monitoring device at 50 Hz.

From the load-time curve of each walking trial, the peak replicated load of each gait cycle was identified. The peak loads of the trials, with or without using biofeedback, were pooled and normalized with the prescribed load. As the magnitudes of the loading cycles were very small when the subjects turned around at the end of the walkway, the peak loads of these cycles were eliminated from the data analysis.

The two-tailed, one-sample t-test was used to examine the differences between the replicated load and the prescribed load. The day-to-day variations of the replicated load on the five rehabilitation days were analyzed using repeated measures ANOVA.

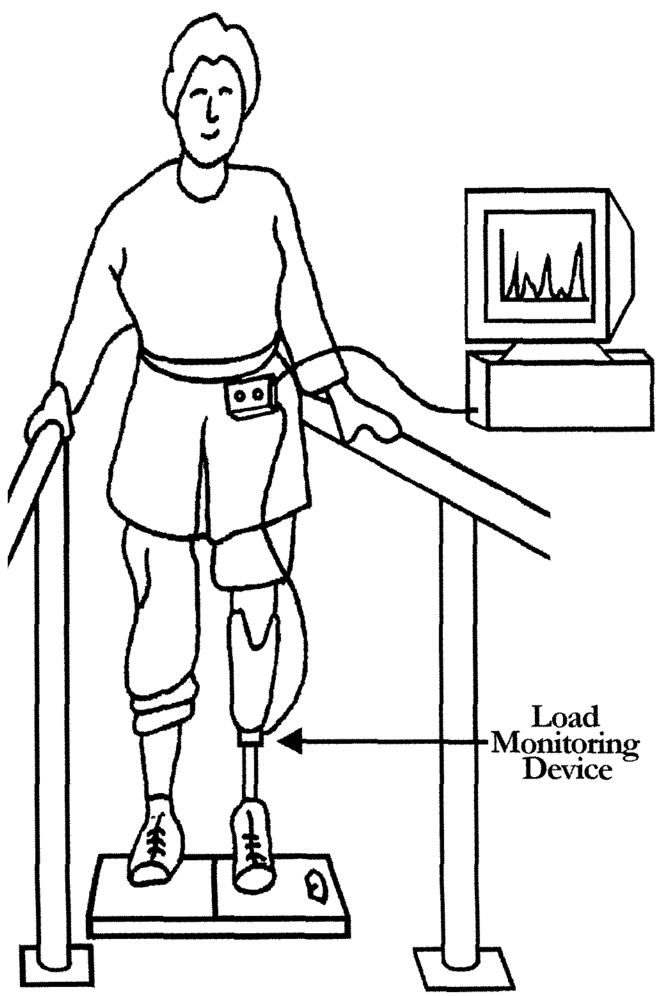

Figure 1.
The subject was standing on a bathroom scale and the load-monitoring device was installed immediately below the socket to monitor the load acting on the residual limb.

RESULTS

It was observed that the load-time curves of the gait cycles recorded by the load-monitoring device for the subjects, with and without use of audio biofeedback, usually had only a single peak. The absolute and normalized peak replicated loads of the subjects, with and without audio biofeedback, were determined and compared with the prescribed load on each rehabilitation day using the 2-tailed, one-sample t-test (**Tables 1** and **2**). The average peak replicated loads of the subjects without using audio biofeedback were found to be *larger* than the prescribed loads on all five rehabilitation days. These differences were statistically significant on the first two rehabilitation days with $p<0.05$ (**Table 1**). The average difference was 25 percent, with a range of 13–41 percent (**Table 2**). In contrast, the average peak replicated loads of the subjects using audio biofeedback were found to be *smaller* than the prescribed loads on all five rehabilitation days; differences were significant on the third and the last rehabilitation days with $p<0.05$ (**Table 1**). The average difference was 10 percent, with values ranging from 5 to 14 percent (**Table 2**).

Figure 2 shows the day-to-day variations of the mean normalized peak replicated load for the subjects with and without using audio biofeedback. It was observed that these variances were consistently larger for the subjects not using audio biofeedback than that for those using it. The decreasing trend in the mean normalized peak replicated load for

Table 1.
Results of average peak replicated load (in N) for the subjects with and without using audio feedback in five rehabilitation days.

	Days Without Audio Biofeedback					Days With Audio Biofeedback				
Subj	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
1	86.0	134.6	112.2	168.3	156.4	68.6	98.2	86.9	132.6	156.0
2	106.8	118.0	124.8	116.7	173.8	78.5	83.4	104.2	99.0	142.8
3	105.7	129.9	148.9	175.3	200.7	88.0	90.4	110.3	135.0	151.4
4	135.5	133.6	147.1	151.0	186.5	85.3	109.2	124.8	150.8	159.9
5	142.1	175.7	216.0	225.1	238.5	99.0	119.2	132.1	159.7	170.1
6	175.3	190.2	270.4	221.5	257.0	89.6	101.4	131.9	138.7	170.5
mean	125.2	147.0	169.9	176.3	202.1	84.8	101.8	115.0	136.0	158.5
SD	32.1	28.8	60.9	41.7	38.7	10.4	13.5	17.9	20.8	10.8
p⁺	0.040*	0.028*	0.208	0.286	0.187	0.368	0.157	0.049*	0.065	0.007*

Subj=Subject; ⁺peak replicated load was compared with the corresponding prescribed load using two-tailed, one-sample t-test; *the differece between the peak replicated load and the prescribed load was statistically significant at $p<0.05$.

Table 2.
Results of average normalized peak replicated load (in % of prescribed load) for the subjects with and without using audio feedback in five rehabilitation days.

	Days Without Audio Biofeedback					Days With Audio Biofeedback				
Subj	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
1	96.7	121.2	83.8	107.9	87.8	77.0	88.5	64.9	85.0	87.7
2	119.9	106.3	93.1	74.8	97.6	88.2	75.1	77.8	63.5	80.2
3	118.7	117.0	111.1	112.4	112.8	98.9	81.5	82.3	86.6	85.1
4	152.2	120.4	109.8	96.8	104.8	95.8	98.4	93.1	96.7	89.8
5	159.6	158.3	161.2	144.3	134.0	111.2	107.4	98.6	102.4	95.6
6	196.9	171.3	201.8	142.0	144.4	100.7	99.5	98.4	88.9	95.8
mean	140.7	132.4	126.8	113.0	113.6	95.3	91.7	85.9	87.2	89.0
SD	36.1	26.0	45.5	26.7	21.7	11.6	12.2	13.4	13.3	6.1

Subj=Subject.

the subjects without using audio biofeedback with the rehabilitation day was analyzed using repeated measures ANOVA and found to be statistically significant with $p=0.014$ (<0.05). For the subjects using audio biofeedback, the mean normalized peak replicated load was found to be nearly constant for all five rehabilitation days. Repeated measures ANOVA test demonstrated that the variation of the normalized peak replicated load with rehabilitation day was not statistically significant with $p=0.137$ (>0.05).

DISCUSSION

From the results, it was found that there were variations in the peak axial load acting on the residual limb from step to step, with or without using audio biofeedback. It was thought that these variations were caused by the different degrees of control required by the subjects to maintain the equilibrium of their gait pattern. It was noted that the variation of the peak replicated loads for the subjects was less when audio biofeedback was used, suggesting that the audio biofeedback could provide additional information to persons with amputation in maintaining the equilibrium of their gait cycle.

On some occasions, overloading was inevitable, because of the response time lag. It has been shown that the time from cessation of the tone to motor response was about 150–250 ms, no matter whether the signals were loud or soft, long or short (16). This response time lag was expected to be even longer for elderly persons with

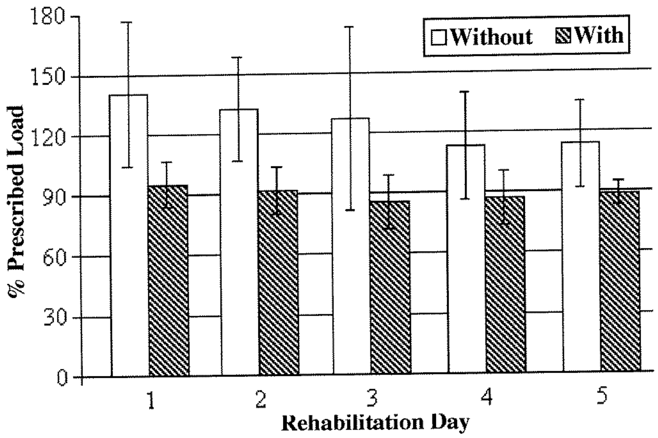

Figure 2.
Day-to-day variations of the mean normalized peak replicated loads of the subjects, with and without using audio biofeedback, on the five rehabilitation days.

amputation, since they might not respond quickly enough to avoid overloading.

It was observed that the peak replicated load was consistently larger than the prescribed load when no audio biofeedback was provided. The mean percentage of overload was higher when the prescribed load was low. The average difference was about 25 percent of the prescribed load, with a range of 13–41 percent. Overloading of the residual limb is not desirable as it may cause tissue breakdown. Therefore, it is recommended that clinicians take this possible discrepancy into account when prescribing the amount of weight bearing if the conventional bathroom scale method is used without an audio biofeedback device. It was important to note that when audio biofeedback was used, the average peak load attained by the subjects was always lower than the prescribed load by an average of about 12 percent (8–14 percent). Although this phenomenon might imply that audio biofeedback could prevent overload of the residual limb beyond the prescribed load, it is contrary to the original objective, namely, that the residual limb should be loaded at a prescribed level to achieve an optimal rate of wound healing. It is proposed that further investigation should be conducted to determine the most appropriate type of audio biofeedback to be used for geriatric persons with amputation. Nevertheless, if one considers setting the triggering level of the audio biofeedback device higher than the prescribed load, particular care must be taken in order to avoid any possibility of overloading the residual limb.

Finally, because different treatment regimes are used by different hospitals, one should consider these possible discrepancies when applying the results of this study.

CONCLUSION

It was found that the residual limb would be overloaded using the conventional bathroom scale method during early postoperative ambulatory training if no audio biofeedback device was provided. It was shown that audio biofeedback was useful in preventing the residual limb from being overloaded beyond the prescribed load particularly when the prescribed load was low. It is recommended that an audio biofeedback device should be used as an adjunctive modality in early postoperative ambulatory activity, with further study necessary for determining the most appropriate type of audio biofeedback to be used for geriatric persons with amputation.

REFERENCES

1. Burgess EM. Immediate postsurgical prosthetic fitting: a system of amputee management. Phys Ther 1971;51(2):139–43.
2. Burgess EM, Romano RL. The management of lower extremity amputees using immediate postsurgical prostheses. Clin Orthop 1968;57:137–56.
3. Folsom D, King T, Rubin JR. Lower-extremity amputation with immediate postoperative prosthetic placement. Am J Surg 1992;164(4):320–2.
4. Harrington IJ, Lexier R, Woods JM, McPolin MF, James GF. A plaster-pylon technique for below-knee amputation. J Bone Joint Surg Br 1991;73(1):76–8.
5. Sarmiento A, May BJ, Sinclair WF. Immediate postoperative fitting of below-knee amputations. Phys Ther 1970;50(1):10–18.
6. Warren CG, Lehmann JF. Training procedures and biofeedback methods to achieve controlled partial weight bearing: an assessment. Arch Phys Med Rehabil 1975;56(10):449–55.
7. Peper E, Robertson JA. Biofeedback use of common objects: the bathroom scale in physical therapy. Biofeedback Self Regul 1976;1(2):237–40.
8. Gerhardt JJ, King PS, Fowlks EW, Usselman LB, Pfeiffer EA. A device to control ambulation pressure with immediate postoperative prosthetic fitting. Bull Prosthet Res 1971;153–60.
9. King PS, Gerhardt JJ, Pfeiffer EA, Usselman LB, Fowlks EW. System for controlling ambulation pressure (SCAP-3) in patients with disabilities of the lower extremity. Am J Phys Med 1972;51(1):9–15.
10. Wannstedt GT, Craik RL. Clinical evaluation of a sensory feedback device: the limb load monitor. Bull Prosthet Res 1978;29:8–38.
11. Moore AJ, Byers JL. A miniaturized load cell for lower extremity amputees. Arch Phys Med Rehabil 1976;57(6):294–6.

12. Berme N, Lawes P, Solomonidis S, Paul JP. A shorter pylon transducer for measurement of prosthetic forces and moments during amputee gait. Eng Med 1976;4:6–8.
13. Zahedi MS, Spence WD, Solomonidis SE, Paul JP. Repeatability of kinetic and kinematic measurements in gait studies of the lower limb amputee. Prosthet Orthot Int 1987;11(2):55–64.
14. Syminton DC, Lowe PJ, Olney SJ. The pedynograph: a clinical tool for force measurement and gait analysis in lower extremity amputees. Arch Phys Med Rehabil 1979;60(2):56–61.
15. Cheng CTK, Chow DHK, Tsang PWH. A new load monitoring device for studying weight-bearing characteristics of new transtibial amputee in ambulatory training. Proceedings of the International Conference on Biomedical Engineering; 1996 Jun 3-5; Hong Kong SAR, China. Hong Kong SAR, China: Biomedical Division, The Hong Kong Institution of Engineers; 1996. p. 329–32.
16. Sanford AJ. Criterion effects in simple reaction time: results with stimulus intensity and duration manipulations. J Exp Psychol Hum Percept 1972;95(2):370–4.

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