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Remotely controlled biking is associated with improved adherence to prescribed cycling speed

In Cheol Jeong* and Joseph Finkelstein
Chronic Disease Informatics Program, Division of Geriatric Medicine and Gerontology, School of Medicine, Johns Hopkins University, Center on Aging and Health, Baltimore, MD, USA

Abstract.
BACKGROUND: Individuals with mobility impairment may benefit from passive exercise mode which can be subsequently enhanced by an active exercise program. However, it is unclear which exercise mode promotes higher adherence to prescribed exercise intensity.
OBJECTIVE: The goal of this project was to compare adherence to prescribed speed during passive and active cycling exercise.
METHODS: We used cross-over study design in which subjects followed the same cycling intensity prescription for passive and active exercise modes in a random sequence. Coefficient of variation (CV) and speed differences were used to estimate extent of deviation from the prescribed trajectory.
RESULTS: CV varied from 5.2% to 20.4% for the active mode and from 2.8% to 4.5% for the passive mode respectively. Though the CV differences did not reach statistical significance, analysis of cycling speed adherence of 120-second periods showed significantly higher cycling adherence during passive mode for each target cycling speed.
CONCLUSIONS: Our results indicated that the passive mode may promote exercise safety and efficacy by helping patients who have safety concerns such as the frail elderly, patients with cardiovascular conditions or people with other contraindications for excessive exertion during exercise, in following the optimal intensity trajectory prescribed by their provider.

Keywords: Telerehabilitation, cross-over design, exercise, personal health systems, self-management

1. Introduction

Recent reviews documented significant growth of consumer health management applications aimed at health promotion and self-monitoring [1,2]. These applications are particularly effective when they employ patient-centered approach which accounts for patient needs and personal goals [3,4]. In our previous studies, we were able to demonstrate high acceptance of home-based telemanagement applications by adults with various chronic health conditions [7–9]. In this group of patients, particular interest has been expressed in home-based telerehabilitation supporting regular exercise [10,11]. To address this interest, we developed a cycling exercise system which can be controlled remotely and can support both

*Corresponding author: In Cheol Jeong, Chronic Disease Informatics Program, Division of Geriatric Medicine and Gerontology, School of Medicine, Johns Hopkins University, Center on Aging and Health, B-901, 2024 East Monument Street, Baltimore, MD 21205, USA. Tel.: +1 410 502 1864; E-mail: ijeong1@jhmi.edu.

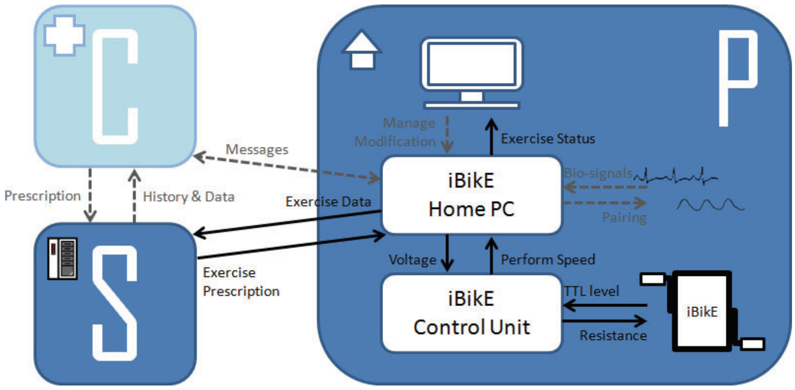

Fig. 1. Remotely controlled iBikE system.

passive and active exercise modes. Deconditioned adults with upper or lower limb mobility impairments may benefit from passive cycling exercise mode which can be subsequently enhanced by an active exercise program [12–15]. The goal of this project was to compare adherence to prescribed cycling speed during passive and active exercise using remotely controlled interactive Biking Exercise System (iBikE).

2. Methods

2.1. System

The remotely-controlled iBikE system supporting internet-controlled home-based cycling exercise has been previously described [16]. The design of remotely-controlled iBikE system is presented in Fig. 1. The system consists of the clinician unit, the iBikE server and the home unit. The home unit consists of the iBikE touch screen tablet, the iBikE control unit, the cycle machine (SF-B02 Motorized Mini Bike, Sunny Health Fitness, USA) and wireless bio-signal sensors. The iBikE software was developed using LabVIEW 2011 SP1 (National Instruments, USA) for Microsoft Windows operating system. The iBikE control unit comprises of a low-cost data acquisition device (NI USB-6008, National Instruments, USA) which has plug-and play and full-speed USB connectivity. It is designed to control the speed of cycling exercise by maintaining voltage output levels corresponding to predefined cycling speeds. The controlled voltage output adjusts the frequency of photo-coupler to drive the motor of cycle machine. This allows the bicycle to pedal itself when the passive mode is turned on. Specifically, if patients take their feet off the pedals in the passive mode, the pedals go around by themselves at the prescribed speed. During the active mode the subjects are instructed to cycle independently following prescribed speed trajectory displayed in an exercise dashboard located in front of them.

2.2. Cross-over assessment

The characteristics of speed adherence during the active mode based on self-effort and the passive mode based on guidance by the motor were compared by investigating differences between the target speed and the performed speed. An active mode and a passive mode arm cycling were performed by 8 healthy volunteers whose age ranged from 24 to 56 years old. Each subject performed cycling exercise both in active and passive modes which were sequenced in a random order. At each mode, 5 different levels of consecutive 2-minute target speeds (0.5, 1.0, 1.5, 1.25 and 0.75 miles/hour) were provided by iBikE server through TCP/IP network. During the volunteers' cycling the following parameters were

Table 1
Descriptive statistics for all 120-second periods and initial 15-second periods stratified by mode and target speed

Data set	Target speed	Mode	N = Number of cycles Max	Min	Mean	Total	S = Performed speed (miles/hour) Max	Min	Mean	SE	SD	CV
All 120 sec	0.50	A	47	40	42.3	343	1.46	0.36	0.5366	0.00592	0.10964	20.43
		P	41	41	41.0	328	0.55	0.37	0.4993	0.00077	0.01394	2.79
	1.00	A	86	81	83.1	667	1.63	0.79	1.0033	0.00268	0.06915	6.89
		P	83	82	82.6	661	1.13	0.75	0.9977	0.00123	0.03155	3.16
	1.50	A	126	122	124.0	993	2.01	1.21	1.4854	0.00246	0.07750	5.22
		P	126	125	125.6	1005	1.72	1.19	1.4963	0.00157	0.04977	3.33
	1.25	A	105	101	103.3	826	1.53	0.94	1.2418	0.00248	0.07133	5.74
		P	106	103	104.5	834	1.41	1.06	1.2483	0.00128	0.03688	2.95
	0.75	A	75	60	65.8	518	1.15	0.39	0.7750	0.00335	0.07616	9.83
		P	64	62	63.1	506	0.91	0.42	0.7474	0.00148	0.03330	4.46
Initial 15 sec	0.50	A	9	4	5.6	41	1.46	0.36	0.5780	0.02906	0.18610	32.20
		P	5	5	5.0	40	0.55	0.37	0.4923	0.00506	0.03200	6.50
	1.00	A	11	9	9.9	78	1.63	0.79	0.9883	0.01412	0.12470	12.62
		P	10	9	9.8	77	1.07	0.85	0.9880	0.00540	0.04738	4.80
	1.50	A	16	15	15.5	124	2.01	1.26	1.4640	0.00867	0.09654	6.59
		P	16	15	15.9	127	1.63	1.32	1.4929	0.00455	0.05132	3.44
	1.25	A	14	13	13.1	106	1.53	0.94	1.2427	0.01033	0.10637	8.56
		P	13	13	13.0	104	1.41	1.13	1.2505	0.00457	0.04663	3.73
	0.75	A	10	5	9.4	64	1.15	0.39	0.8080	0.01877	0.15014	18.58
		P	8	7	7.8	62	0.91	0.42	0.7383	0.00853	0.06715	9.10

All 120 sec = 120-second periods of 5 different levels of consecutive 2-minute target speeds (0.5, 1.0, 1.5, 1.25 and 0.75 miles/hour), initial 15 sec = initial 15-second periods at 5 different levels of consecutive 2-minute target speeds, A = active mode, P = passive mode, Max(N) = maximum number of cycles within all 8 volunteers, Min(N) = minimum number of cycles within all 8 volunteers, Mean(N) = mean number of cycles for all 8 volunteers, Total(N) = total number of cycles for all 8 volunteers, Max(S) = maximum performed speed within all 8 volunteers, Min(S) = minimum performed speed within all 8 volunteers, Mean(S) = mean performed speed for all 8 volunteers, SE(S) = standard error of performed speed for all 8 volunteers, SD(S) = standard deviation of performed speed for all 8 volunteers, CV(S) = coefficient of variation of performed speed for all 8 volunteers, all Target Speed and Performed Speed units are in [miles/hour], all Number of cycle unit are [number of times], and CV unit is [%].

presented in real time on the iBikE dashboard delivered via a touch screen tablet: target speed, actual speed, target distance, actual distance, performed exercise time, calories burned, heart rate, and oxygen saturation.

Actual cycling speeds for both modes were obtained by detecting TTL signals generated by an electromagnetic sensor in the cycle machine with 50 Hz sampling rate. To compare the functionality of speed adherence between the active mode and the passive mode, we employed two evaluation procedures for two different timeframes: 1) for all 120 seconds of cycling speed data obtained during each 2-min target speed level; 2) for the initial 15 seconds of cycling data for each cycling speed level. The comparison was made between the target speed and the actually performed speed at each of five speed levels. The first analysis was performed to compare the overall adherence during passive and active modes to prescribed cycling speeds at each level. The second analysis was aimed at characterizing cycling speed adherence specifically at the initial phase of each new cycling speed level since this phase appeared to be particularly variable during cycling exercise. The results were stratified by each mode and each target speed to elucidate effect of active and passive exercise modes on cycling speed adherence.

3. Results

The summary of descriptive statistics for cycling performance at each mode and each target speed is

Table 2
Coefficient of variations' statistics and paired t-test between the active mode and the passive mode

CV mode	Mean	SD	Pair	Mean	SD	t	Sig. (2-tailed)
A120	9.62	6.30	A120–P120	6.28	6.48	2.169	0.096
P120	3.34	0.66					
A15	15.71	10.29	A15–P15	10.20	9.01	2.531	0.065
P15	5.51	2.34					

A120 = CV of each 120-second period at 5 different levels of consecutive 2-minute target speeds (0.5, 1.0, 1.5, 1.25 and 0.75 miles/hour) in the active mode, P120 = CV of each 120-second period at 5 different levels of consecutive 2-minute target speeds in the passive mode, A15 = CV of each initial 15-second period at 5 different levels of consecutive 2-minute target speeds in the active mode, P15 = CV of each initial 15-second period at 5 different levels of consecutive 2-minute target speeds in the passive mode, SD = standard deviation, Sig. (2-tailed) = two tailed probability, unit of all means and standard deviations is [%].

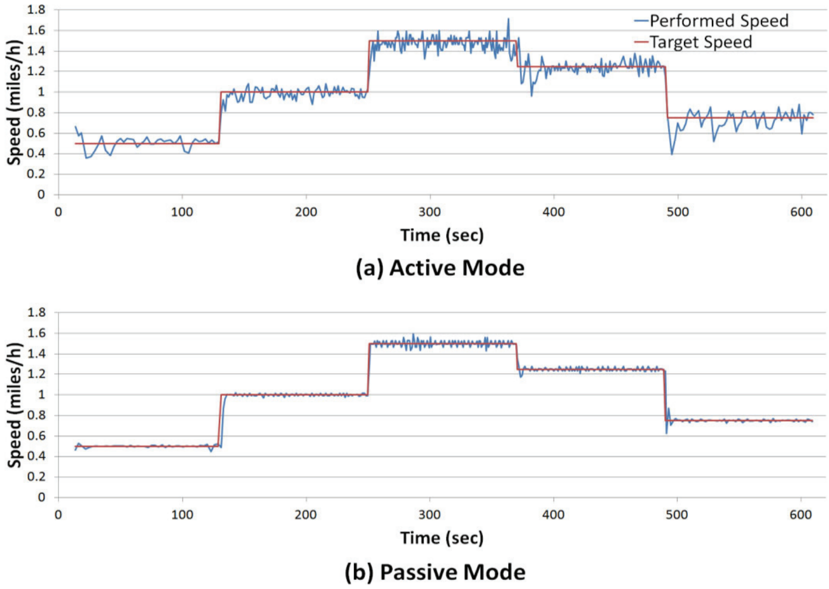

Fig. 2. Correspondence between the target speed and actual cycling speed for one of the volunteer's during active and passive cycling.

provided in the Table 1. Differences between the target speed and the performed speed were used to assess the cycling speed adherence at each mode. The results presented in the Table 1 demonstrate how close the target and actual cycling speeds corresponded each other during passive and active cycling at different levels of cycling. An example of correspondence between the target speed and the performed speed for one of the volunteers is presented in the Fig. 2.

The cross-over study demonstrated that the passive mode resulted in higher adherence with cycling speed prescription. CV varied from 5.2% to 20.4% for the active mode and from 2.8% to 4.5% for the passive mode respectively. However difference in CV between passive and active mode did not reach statistical significance as indicated in the Table 2. Also, the averaged absolute mean differences between the target speed and the performed speed were 0.046 to 0.060 miles/hour for the active mode, and 0.010 to 0.037 miles/hour for the passive mode respectively.

Analysis of the initial 15-second periods at each target speed demonstrated that differences existed at lower target speeds, 0.5 and 0.75 miles/hour. CVs were 6.59 to 32.20% for the active mode, and 3.44 to 9.10 for the passive mode respectively at these speed levels. Also, the averaged absolute mean

Table 3
Differences between the performed speed and the target speed, and paired samples t-tests between two differences

Data set	Target speed	Mode	S1 = [Performed − target] speed (miles/h)			Paired samples T test				
			Mean	SD	SE	Mean	SD	SE	t	Sig. (2-tailed)
All 120 sec	0.50	A	0.0366	0.10964	0.00592	0.03956	0.11287	0.00623	6.347	0.000
		P	−0.0007	0.01394	0.00077					
	1.00	A	0.0033	0.06915	0.00268	0.00576	0.07551	0.00294	1.961	0.050
		P	−0.0023	0.03155	0.00123					
	1.50	A	−0.0146	0.07750	0.00246	−0.01137	0.09213	0.00292	−3.888	0.000
		P	−0.0037	0.04977	0.00157					
	1.25	A	−0.0082	0.07133	0.00248	−0.00682	0.07939	0.00276	−2.467	0.014
		P	−0.0017	0.03688	0.00128					
	0.75	A	0.0250	0.07616	0.00335	0.02750	0.08194	0.00364	7.550	0.000
		P	−0.0026	0.03333	0.00148					
Initial 15 sec	0.50	A	0.0780	0.18610	0.02906	0.08735	0.18717	0.02959	2.952	0.005
		P	−0.0078	0.03200	0.00506					
	1.00	A	−0.0117	0.12470	0.01412	0.00060	0.13729	0.01565	0.038	0.970
		P	−0.0120	0.04738	0.00540					
	1.50	A	−0.0360	0.09654	0.00867	−0.03007	0.11144	0.01001	−3.005	0.003
		P	−0.0071	0.05132	0.00455					
	1.25	A	−0.0073	0.10637	0.01033	−0.00804	0.11866	0.01164	−0.691	0.491
		P	0.0005	0.04663	0.00457					
	0.75	A	0.0580	0.15014	0.01877	0.06674	0.14987	0.01903	3.507	0.001
		P	−0.0117	0.06715	0.00853					

All 120 sec = each 120-second period at 5 different levels of consecutive 2-minute target speeds (0.5, 1.0, 1.5, 1.25 and 0.75 miles/hour), initial 15 sec = each initial 15-second period at 5 different levels of consecutive 2-minute target speeds, A = active mode, P = passive mode, Mean(S1) = mean of different speeds between the performed speed and the target speed for all 8 volunteers, SE(S1) = standard error of different speeds between the performed speed and the target speed for all 8 volunteers, SD(S1) = standard deviation of different speeds between the performed speed and the target speed for all 8 volunteers, all [Performed − Target] Speed units, and Mean, SD and SE of Paired Samples T Test unit are [miles/hour].

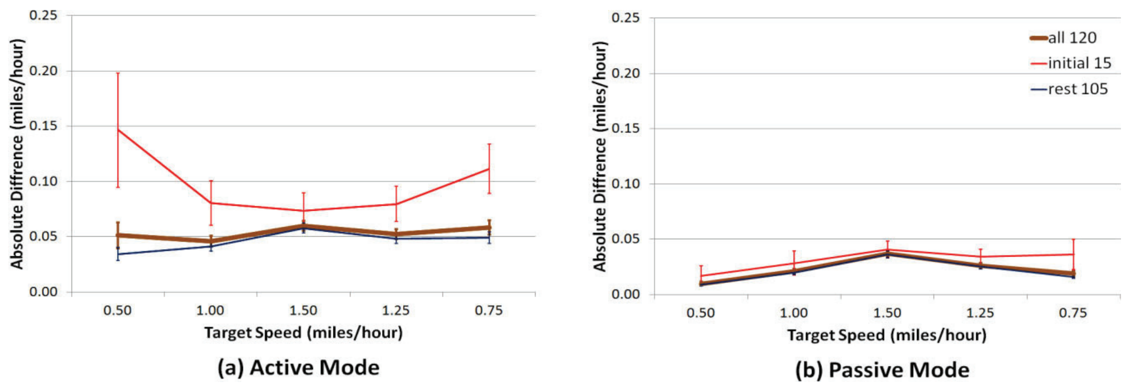

Fig. 3. Absolute differences and standard errors between target speed and performed speed.

differences between the target speed and the performed speed were 0.074 to 0.146 miles/hour for the active mode, and 0.017 to 0.041 miles/hour for the passive mode respectively.

Differences between the performed speed and the target speed were categorized by modes and data sets, and then each categorized difference was analysed based on their means and standard deviations. Paired t-tests were conducted in stratified data sets (all 120-second periods and initial 15-second periods) to investigate whether cycling speed adherence differed during passive and active modes at each of 5 cycling levels. As presented in the Table 3, this analysis demonstrated significant differences in cycling adherence at each speed level for all 120-second periods and for the majority of the 15-second periods. Absolute differences and standard errors between target speed and performed speed are depicted in the Fig. 3.

4. Discussion

The iBikE system was developed as an example of a telerehabilitation system that could support safety and efficacy during patients' home-based exercise [17]. Our previous technical evaluation demonstrated high fidelity of the proposed remotely-controlled iBikE system and reliability of controlling individualized exercise prescription for a home-based cycling equipment via internet [16].

In this project, passive and active modes of cycling exercise were compared to assess which mode results in better adherence to prescribed cycling speed. Based on the results of this cross-over study, passive mode results in higher adherence with cycling speed prescription. Our results indicated that the passive mode may promote exercise safety and efficacy by helping patients in following the intensity trajectory of their cycling exercises recommended by their provider. Thus, passive exercise may be particularly attractive option in individuals who may have safety concerns such as frail elderly, patients with cardiovascular conditions or people with other contraindications for excessive exertion during exercise. Older adults with cognitive deficits may potentially also benefit from the passive exercise mode. Passive mode also can be beneficial in individuals with partial or complete paralysis of upper or lower limbs [5,6,18,19]. Applications of the proposed remotely controlled cycling are warranted for further investigation in this group of patients since it can ensure appropriate adherence with individually prescribed cycling trajectories tailored to particular disability and allowing remote monitoring and management of these patient progress by rehabilitation team.

Further development of this approach will include clinical studies in different populations identifying optimal combination of passive and active cycling exercise and its effect on clinical outcomes, quality of life, and patient satisfaction.

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