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ORIGINAL

Quantitative Analysis on the Variations of Ground Reaction Force during Ascent and Descent of Bus Stairs in Women

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Objective: The aim of the study was to compare & analyze on the variations of ground reaction force during ascending and descending of bus stair.

Method: Simulated wooden stair of bus (raiser: 37.66 cm, width: 109 cm, tread: 29 cm) and GRF system (AMTI-OR-7/ AMTI., USA) was set up within experimental room. Adult female (n=8) performed ascending & descending of simulated bus stair, and variables analyzed consisted of TT (transfer-time), PVF (peak vertical force), LR (loading rate), DR (decay rate), CV (coefficient of variation) and AI (asymmetry index). Sample data from GRF cut off at 1,000 Hz.

Results: TT showed shortest variation at phase 1 during descending, but longest variation at phase 1 during ascending of stair. PVF19 (Fz2, 100%) showed large pattern during descending than that of ascending, but rather showed small pattern during ascending of stair in case of PVF2 (Fz4). LR showed larger pattern during descending than that of ascending, but rather during ascending of stair in case of DR. Variation of CV (%) did not show difference between LR and DR, but showed higher possible occurrence of variation during descending of stair. Also AI (%) showed higher index during ascending than that of descending of stair.

Conclusion: Because introduction of lowered bus stair has various realistic problems, if lined up at designated bus stopage exactly, rather can solve problems of inconvenience, reduce impulsive force and secure a stability of COG during ascending & descending of stair.

Keywords: Bus stairs, Ascending, Descending, Asymmetry index, Coefficient of variation

INTRODUCTION

Generally stair ascending & descending was designed to perform easily, particularly when transferring point was placed at different height on the basis of level in such various case as walking road, outside & inside of building, tracking & climb course, vehicles etc.. But Injuries related with falling during locomotion of COG (center of gravity) occurs on incline & stair track ost frequently (Sheehan & Gottschall, 2012), risk possibility of falling injuries higher 3 times when compared with stair (Cohen, Templer, & Archea, 1985).

Thus Quantitative studies using data of GRF & COP (center of pressure) occurred over 3 axis (mid-lateral, anterior-posterior, vertical) had been performed by healthy male & female for injuries prevention & efficiency gait (Zachazewski, Riley, & Krebs, 1993), by ages (Christina & Cavanagh, 2002; Hamel, Okita, Bus, & Cavanagh, 2005; Reeves, Spanjaard, Mohagheghi, Baltzopoulos, & Maganaris, 2008; Stacoff, Diezi, Luder, Stüssi, & Kramers-de Quervain, 2005), by weight carrying types (Hong & Li, 2005; Moon & Chun, 2013), and by width of stair (Yoon, 2008) etc.

Usually type of PVF (peak vertical force) occurring during level gait shows "M" characters meaning 2 peak value typically (Perry, 1992; Winter, 1991), but did not show the former type during ascending & descending of stair (Stacoff et al., 2005; Yoon, 2008).

Particularly The 1st vertical peak value at occurring of vertical GRF is correspond to passive force of impact force, which is occurred by inactive components of ligament, tendon, and muscle, Hatze (1997), Ryu (2013). The 2nd vertical peak value of active force value is occurred by muscular contraction of near articular system. That is, the 1st vertical value is occurred at 1st touch-down during descending when COG of body transfer to forward-gravity direction, and the 2nd vertical peak value is occurred when COG of body transfer to forward-antigravity direction during ascending (Hyun & Ryew, 2015).

As such, impulsive & active force has close relation with vertical height of stair during stair gait, as usual bus for public transportation has higher height of stair than that of the others of building, tracking & climb course, vehicles etc.. Stair standard of domestic bus's vertical height of bus showed 27.00±1.32 cm of 1st, 26.50±2.17 cm of 2nd stair, and 37.66±0.28 cm of 3rd stair on the basis of descending (Ryew & Hyun, 2013). Also if lined up at designated bus stoppage exactly, stair height of 19.66 cm was rather higher slightly than 18 cm of architectural standard (Yoon, 2008) except for vertical height (18 cm) of side walk block,

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but never inconvenience.

GRF variables during common stair gait showed 1.2 times at ascending and 2.6 times of body weight in PVF (Savvidis & von der Decken, 1999), but showed 2.54±0.59 N/BW on sidewalk block, and 3.70±0.41 N/BW of asphalt at touch down during descending from bus stair in a bare foot, which over 2~3 times of sprinting (Whittle, 1996).

Thus the higher vertical height, the more load & falling injuries on lower leg's articulation due to heavy impulsive force at touch down during descending from bus can occur (Ryew & Hyun, 2013), but most case of studies focus on the movement analysis of lower's leg using kinematic data. Furthermore studies on the stair gait using GRF data has been performed, it was confined to descending of common stair, Particularly 25% delayed during ascending time on bus stair was more delayed by 25% than that of common stair in the course of locomotion of COG & secure of safety (Hyun, Jin, & Ryew, 2017).

It is essential to investigate components of impulsive & active force during ascending & descending on bus stair to minimize potential danger of injuries & inconvenience for bus passengers. Therefore the aim of the study is to provide useful information for both engagers and passengers through comparison & analyzation of GRF variables occurring during ascending and descending of bus stair.

METHOD

1. Subject

Adult female (n=8) participated as subjects with no making a diagnostic evaluation on orthopedic defects of lower leg within 1 year recently after enough explanation on the aim & content of the study and voluntary participating sign (Table 1).

Table 1. Characteristics of subjects

Section	Age (yrs)	Heights (cm)	Body mass (kg)
M ± SD (n=8)	21.50±0.82	165.95±2.52	56.56±3.80

2. Experimental procedure

The standards of bus stair made of wood (Ryew & Hyun, 2013) was manufactured with 37.66 cm of raiser, 109 cm of width and 29 cm of tread and GRF (AMTI-OR-7., USA) was set up on the last point of ground area (#1) during descending and 1st point of wooden stair during ascending from 37.66 cm of height, 29 cm of width, 109 cm of tread and 52.40° of whole incline of stair (Figure 1).

All subjects was more induced forward gait of 5 stride after 1st touch-down (GRF contact) during descending and induced upward gait to 3rd (#4) after 1st touch-down (GRF contact (Figure 1). Also because the 29 cm of width do not fit for standards of GRF, the 3 cm of vertical space between 1st and 2nd stair secured, that is, aligned and fixed correspondingly endpoint of GRF with endpoint of wooden box. All trials considered to be success when fore-foot area completely positioned on GRF plate.

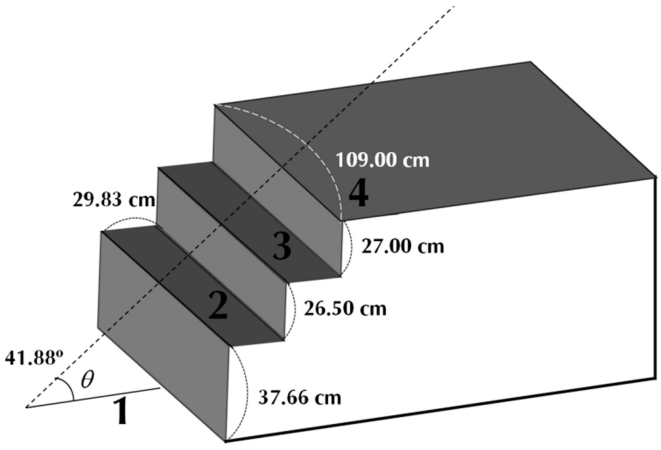

Figure 1. Structure of bus stair

It was required participants for self- paced gait & self-selected speed of stair due to repeated measurement of experimental situation (Hah, 2009; Perry & Burnfield, 2010), thus was not controlled between ground and 1 step of touch down during descending of stair. While Touch-down of left foot one's most preferring was required during descending of bus stair because mechanical difference of balance between right and left foot in common stair can be induced (Hah, 2009; Perry & Burnfield, 2010).

Successful GRF data from stair ascending & descending of 5 times (n=8×5 times×2 types) was selected as analysis trial. All participants wore half-sleeve & pants by considering influence to analysis results, and performed with bare foot to reduce a different effect of various shapes & kinds of shoe.

3. Analysis & process of data

Transfer time of body weight and parameters of GRF was analyzed with calculated with Kwon GRF 2.0 program (Visol., Korea) and Excel 2007 (Microsoft., USA), and calculated asymmetric index & coefficient of variation (CV) of GRF data for a point of time of analysis & phases (1, 2, 3, 4) Stüssi & Debrunner (1980), Stacoff et al. (2005) (Figure 2).

First of all, normalized value divided body weight (BW) by splitting of GRF (N) based on mid-line of Fz2 and Fz4. PVC consists of 1st initial peak (PVF1) of Fz2 phase transferring body weight after initial touch-down, and 2nd peak (PVF2) of Fz4 phase pushing body weight of 2 kinds of peak. Fz3 between Fz2 and Fz4 of 2 curves means no-loading phase as mid-stance, and here LR is loading rate, DR is decay rate respectively. These parameters means intensity of force occurring at take off & initial touch-down of foot (Stacoff et al., 2005), which increases in LR, and decreases in DR (Nigg & Morlock, 1987).

Particularly proper section between LR and DR is set for about 80% due to slowed gait speed with slope when evaluating of patients (Stüssi & Debrunner, 1980), the same of which applied to the studies as con-

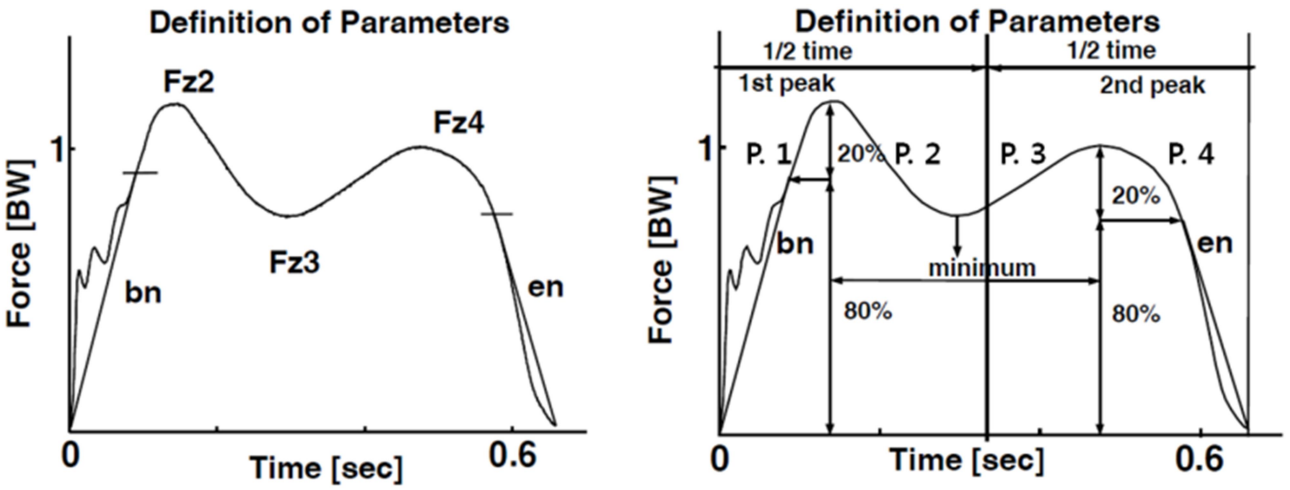

Figure 2. (left) Detection and (right) definition of selected parameters of the vertical GRF measured during level walking (Stüssi & Debrunner, 1980; Stacoff et al., 2005).

sidering height of bus stair. Also revelation time of Fz3 to be phase of non-weight loading at point of 1/2 of total time elapsed was calculated, then positive (+) means coming close value to Fz2 of Fz3, and negative (-) means coming close to Fz4 of Fz3 respectively.

AS these, symmetry coefficient & CV (coefficient of variation) after analysis of GRF variables was calculated (Formula 1) (Winter, 1983; Stacoff et al., 2005).

$$CV(\%) = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}\sigma^2{}_i}}{\sqrt{\frac{1}{n}\sum_{i=1}^{n}\overline{X}^2{}_i}} \times 100$$

Formula 1. Coefficient of variation

Then, n = number of sample, σ=SD of sample, $\overline{X}$=mean value of sample, when CV is 0, it means complete consistency, while more of CV value means its lowering. Calculation of AI (asymmetry index) was referred to (Formula 2) of Giakas & Baltzopoulos (1997), White, Agouris, Selbi, & Kirkpatrick (1999).

$$AI(\%) = \left| \frac{Fz2 - Fz4}{\frac{1}{2}(Fz2 + Fz4)} \right| \times 100$$

Formula 2. Asymmetry index

Also Fz2 means PVF1 (passive force), Fz4 means PVF2 (active force) during ascending & descending, and when AI (%) is 0, it means complete degree of symmetry, while more of AI value means its degree of asymmetry. LR (loading rate) & DR (decay rate) was calculated with force exerting to the body by unit time (Formula 3, 4) (Munro, Miller, & Fuglevand, 1987) respectively.

$$\text{Loading rate} = (P_1 - F50^+)/(T_1 - T50^+)$$

Formula 3. Loading rate

P1 means value of PVF1 occurred at touch-down of foot, $F50^+$ means value exceeded 50 N before occurrence of PVF1, T1 means a point of occurrence of P1, and T 50^+means a point of occurrence of $F50^+$.

$$\text{Decay rate} = (F50^- - P_2)/(T50^- - T_2)$$

Formula 4. Decay rate

P2 of DR (%) means value of PVF2 occurring during propulsive phase just before taking off of foot from GRF, $F50^-$ means 1st vertical GRF occurring less 50 N of PVF2, T_2 means a point of occurrence of P_2, and $T50^-$ means a point of occurrence of $F50^-$ respectively.

Two way analysis of variance with PASW 18.0 (IBM., USA) based on GRF variables processed were treated on the TT (transfer-time), PVF (peak vertical force), LR (loading rate), DR (decay rate), CV (coefficient of variation), and AI (asymmetry index) according a point of occurrence of vertical GRF (Fz 1, 2, 3, 4, 5) and AI (asymmetry index,%) between 1st and 2nd of peak value was compared by independent *t*-test (α=.05).

RESULTS

Transferred time of body weight and PVF by phases was normalized with dividing N value by BW (body weight) occurred during ascending & descending of bus stair (Table 2).

1. Transfer time of BW

As result of analysis with independent *t*-test on the point of a half time of total time elapsed (100%) from initial occurrence to the last point of time of PVF (Table 2), the case of descending showed significant difference as of more short than case of ascending (p<.001), and trans-

Table 2. Variation of Transfer time and PVF

Section	Direction	Vertical force					Total average	*Source*	*F*	Post-hoc
		Fz1	Fz2	Fz3	Fz4	Fz5				
		Phase1	Phase2	Phase3	Phase4	Total				
Transfer time (sec)	Ascending (A)	0.25±0.08	0.23±0.04	0.22±0.07	0.12±0.02	(100/50%) 0.84±0.49 0.42±0.07	0.21±0.07	*S*	35.345***	A>D
		29.73%	28.28%	27.23%	14.76%					
	Descending (D)	0.05±0.02	0.21±0.05	0.09±0.02	0.12±0.08	(100/50%) 0.49±0.25 0.24±0.01	0.12±0.07	*F*	9.126***	P2>P1, P3, P4
		11.88%	44.30%	19.62%	24.20%					
	Total average	0.15±0.11	0.22±0.04	0.16±0.08	0.12±0.05	(50%) *t*=6.435***	0.16±0.08	*S*×*F*	10.068***	F>S
PVF 100% (N/BW)	Ascending (A)	0.99±0.10	0.62±0.06	1.36±0.05			0.99±0.31	*S*	99.917***	A>D
	Descending (D)	3.96±0.40	0.67±0.36	0.80±0.40			1.81±1.59	*F*	183.608***	Fz2>Fz4>Fz3
	Total average	2.48±1.55	0.64±0.25	1.08±0.40			1.40±1.21	*S*×*F*	178.08***	F>S

NOTE: ***p<.001, S: main effect of stairs direction, F: main effect of vertical force, S×F: interaction

Table 3. Change in loading rate, decay rate, CV, and AI

Section	Direction	Intensity (%)		Total average	*Source*	*F*	Post-hoc
		Loading rate	Decay rate				
Rate 80% (N/BW·sec^{-1})	Ascending (A)	4.60±2.24	-11.33±1.78	-3.36±8.45	*S*	16.367***	A>D
	Descending (D)	88.52±61.77	-6.77±1.26	40.87±64.83	*I*	25.872***	LR>DR
	Total average	46.56±60.50	-9.05±2.78	18.75±50.72	*S*×*I*	13.173***	S>R
CV (%)	Ascending (A)	35.42±8.11	40.51±4.54	37.97±7.00	*S*	15.698***	A>D
	Descending (D)	55.65±10.56	44.31±9.61	49.98±11.37	*I*	1.063	n/a
	Total average	45.54±13.85	42.41±7.63	43.97±11.11	*S*×*I*	7.339*	S>R
AI (%)	Ascending (A)	17.37±9.64			–		
	Descending (D)	91.85±15.32			–		
	t	-11.635***			–		

NOTE: ***p<.001, *p<.05, n/a: not applicable, CV: coefficient of variation, AI: asymmetry index, S: main effect of stairs direction, I: main effect of intensity, S×R: interaction

fer time of BW showed significant difference by occurrence points of PVF according to locomotion direction of stair as result of main effects of interaction (p<.001). Also the 1st Phase showed the shortest transfer time of BW during descending1 as result of main effects of interaction (p<.001) (F=13.304, p<.001) (Table 2).

2. Variation of PVF (100%)

PVF1 (Fz2) showed significant difference according to locomotion direction of stair & occurrence points (p<.001), More influence in case of descending was given rather than case of ascending for PVF1 as result of main effects of interaction (F=164.661, p<.001).

3. Variation of Intensity, CV (coefficient of variation), AI (asymmetry index)

The CV on the LR (loading rate), DR (decay rate) was analyzed on the range of 80% considering incline & height of bus stair (Stüssi & Debrunner, 1980), and showed significant difference according to locomotion direction & intensity (p<.001) (Table 3). More influence in case of descending was given rather than case of ascending for LR as result of main effects of interaction (F=164.661, p<.001) (F=18.470, p<.001).

Variation of CV showed significant difference according to locomotion direction (p<.001), more influence of LR in case of descending was given rather than case of ascending for CV as result of main effects of interaction (F=8.033, p<.001). As results of independent t-test after

analysis on the AI (asymmetry index) between PVF1 (Fz2) and PVF2 (Fz4) occurred during ascending & descending of bus stair, AI showed significant difference as of higher during descending than that of ascending ($p < .05$).

DISCUSSION

It should be no inconvenience during ascending & descending as means of public transportation as long as many demands of utilization. But vertical height of bus stair was manufactured to a higher degree than that of such various cases as walking road, outside & inside of building, tracking & climb course, vehicles. In order to investigate & solve an inconvenience of incumbent height of bus stair, this study undertaken to investigate & solve an inconvenience factors of improper height of bus stair and thus analyzed variables of TT (transfer time), CV (coefficient of variation) and AI (asymmetry index) of PVF (peak vertical force) using GRF during ascending and descending.

Pattern of VRF (vertical reaction force) occurred during ascending & descending on the basis of Stüssi & Debrunner (1980), Stacoff et al. (2005) during ascending & descending did not show apparent figuration of "M" appearing on level gait during supporting phase of left foot, but showed similar peak figuration of 2 times (PVF2 and PVF4).

The 1st of PVF1 during descending on common stair showed 1.40± 0.20 N/BW (Christina & Cavanagh, 2002), 2.06 N/BW (Lobo da Costa & Amadio, 1995), 1.26 N/BW at 24 deg. of incline, 1.32 N/BW at 30 deg (Riener, Rabuffetti & Frigo, 2002), 1.56B N/BW on 17.1 cm and 1.57 N/BW on 20 cm of stair height (Stacoff et al., 2005) respectively, but this study showed larger figuration of 3.96 N/BW during descending than the former.

CV between P1-P2 and P3-P4 showed largest figuration of CV of PVF1 during descending, but AI between PVF2 and PVF4 of vertical GRF more asymmetry figuration during descending. CV, which means ratio (%) on mean value divided by standard deviation (SD) of vertical force occurred, and considered to be related highly with increase of PVF & Loading rate during descending. These characteristics may be factors influencing to variation of TT (transfer time), and transfer time ratio (%) from 1st to 4th phase and during ascending showed portion of time 29.73%, 28.28%, 27.23%, 14.76% but showed portion of time 11.88%, 44.30%, 19.62%, 24.20% respectively.

Thus TT of body weight was occurred in shorter time during descending than that of ascending of stair, and it was considered to be abrupt occurrence of vertical force & higher CV. Asymmetric degree due to AI between PVF2 and PVF4 showed similar figuration & sine curve during ascending, but different figuration each other during descending.

That is, because of being transferred with the largest impact force on body at instant of PVF occurrence, too excessive occurrence of GRF can result in increase of risk possibility of injuries due to limit of carrying out of load on articulation & muscle at touch-down (Cerulli, Benoit, Lamontagne, Caraffa, & Liti, 2003; Miyama & Nosaka, 2004). Thus in case of non-stopage exactly at designated site, increase of touch down height between stair and ground, or in case of forcible downward speed from stair due to traffic congestion, It may be considered muscular skeletal system was transferred with excessive impact force temporarily.

Transfer time (TT) at 1st phase during ascending of stair showed longest time elapsed, and the higher of vertical height, the more delayed ascending time of stair. Then 100% of PVF1 (Fz2) corresponded to 0.99% of N/BW, It showed less value than 1.2 times of BW in case of level gait (Whittle, 2007; White et al., 1999), particularly showed less value than that of 1.17±0.10 times of N/BW of (Yoon, 2008) and 1.12 times of N/BW of (Stacoff et al., 2005) meets the standard of stair height of architecture. Also 100% of PVF2 (Fz4) again corresponded 1.36 times of N/BW.

From a point of view, It is necessary to produce more positive force for ascent to the next stair than increasing of impulsive force at initial touch down on escalated height of bus stair, and to perform instant motion of pushing-off strongly. Because combination between knee extensors and plantar flexors of foot propels the next step of foot forwardly (McFadyen & Winter, 1988), it should maintain stable & symmetric function between lower. But it was considered not to be consecutive motion of pushing-off, and sufficient force was exerted only from initial touch-down to supporting phase of opposite leg.

Each LR (%) (loading rate) & DR (%) (decay rate) occurring at initial touch down and take off on ground corresponds to intensity of force per unit time (Munro et al., 1987; Stacoff et al., 2005). As a result of analysis within range of 80% of LR & DR according to variations of incline height, LR during descending showed 11.81 N/BW·sec^{-1} of 19.0°, 12.79 N/BW·sec^{-1} of 30.4°, and 13.64 N/BW·sec^{-1} of 410° over incline stair respectively and DR was considered not to be occurred due to consecutive descending.

LR (%) of this study showed more intensity of 88.52 N/BW·sec^{-1} than the former's studies, which means stair incline can influence to increase of LR (%), but result of PVF2 occurred within less time than touch-down of foot on ground as increase of vertical height as during descending, thus was considered higher intensity of force absorbing on body could be increased. This study showed -6.77±1.26 N/BW·sec^{-1} of DR (%), which showed difference with the former's in the course of level gait after touch down on ground in situation of experiment. This is, DR (%) was not influenced significantly in the course of locomotion horizontally & downwardly of COG during descending of bus stair.

While LR (%) according to increase of incline angle as of 19.8° on 13.3 cm, 30.4° on 17.1 cm, and 41.0° on 20 cm of vertical height during ascending of stair showed decrease of 6.09 N/BW·sec^{-1}, 5.79 N/BW·sec^{-1}, and 5.34 N/BW·sec^{-1}, and showed increase of -10.16 BW/N·sec^{-1}, -11.12 BW/N·sec^{-1}, and -11.44 BW/N·sec^{-1} respectively.

LR (%) during ascending of stair showed less value of 4.60 BW/N·sec^{-1}, but DR (%) showed more higher of -11.33 BW/N·sec^{-1}, which meant breaking force at initial touch-down for locomotion of COG upwardly was not act sufficiently due to inclined angle of stair and vertical height on heighten bus stair, thus considered as a result of fast take-off just later pushing-off of heel was not act sufficiently.

Therefore DR (%) during ascending was occurred as more of 2 times compared to descending of bus stair, which considered to be completed fast take-off without consecutive pushing motion of supporting leg differing from level gait & descending of common stair.

Therefore Public bus should be lined up at designated bus stopage exactly to solve problems of inconvenience, reduce impulsive force and

secure a stability of passenger's COG during ascending & descending of stair. Also because motion of pushing-off may not be performed easily during ascending in case of bus of congested-passengers, passengers should put up with various difficulties. It is necessary to develop fitted design of bus stair available control & absorb efficiently the vertical GRF during ascending & descending of bus stair.

For Because Introduction of lowered bus stair has various realistic problems, if lined up at designated bus stopage exactly, rather can solve problems of inconvenience, reduce impulsive force and secure a stability of COG during ascending & descending of stair.

CONCLUSION

The aim of the study was to compare & analyze variation of GRF variables during ascending & descending of bus stair. Analysis variables with participants (n=8) was consisted of TT (transfer-time), PVF (peak vertical force), LR (loading rate), DR (decay rate), CV (coefficient of variation) and AI (asymmetry index).

Variation of TT showed shortest at 1st during ascending, but longest at 1st phase at descending. PVF1 (Fz2, 100%) showed larger figuration during descending, but larger figuration during ascending. Variation of CV (%) did not show significant difference, and showed higher index during descending than ascending. Also AI (%) showed higher ratio during ascending rather than descending. Further studies related with bus stair should be studied considering variables of age, body height, body weight etc. of passengers during ascending & descending of bus stair focusing on service quality of public transportation.

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