Biomechanical analysis on human gait and posture for development of floating backpack

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Abstract. Floating backpack system or also known as suspended-load backpack has been known as a new type of backpack which able to reduce the effect of impact force from the loads carried in the backpack while walking or running. Particularly on the application for military or rescue team, this new backpack design claimed to improve the comfort and reduce the burden on the skeletal muscle as well as the risk of injury. In this research, we try to assess the biomechanics performance of our novel floating backpack design on reducing the impact force on the wearer by firstly analyzing the human gait cycle and posture adjustment. This analysis conducted by motion analysis method which able to track the change of position of certain points while walking and running. We tracked several points on the volunteer’s lower extremity and analyze its kinematics information throughout the walk and running cycle with a different pace and velocity. From this data, we try to get the standard gait model as a mechanical input force for the floating backpack system. Furthermore, with this 3D analysis we can also analyze the posture adjustment as the balancing mechanism of human body to compensate the different forces from the different state of walking-running cycle. A sinusoidal pattern with a frequency of 2-3 Hz are measured on the transition phase of walking and running, while the maximum amplitude was varying on throughout each cycle phase

1. Introduction
Floating backpack or also known as suspended-load backpack is a special backpack with additional mechanical components consists of spring-damper systems. Several previous researches claimed that floating backpack is able to reduce the effect of backpack’s loads while the user move dynamically. As investigated by many prior studies, the effect of loads carried on the backpack has bring a great concern as it may be causing a serious harm to the user balance capability and body posture [1,2]. Moreover, for the special applications such as military backpack, the loads may be exceeding 20 kgs during combat and marching [3,4]. Therefore, this heavy loads may be causing a negative effect for the wearer since it may improve the risk of muscle injury and increase the metabolic cost.

As from 2018, our novel design of floating backpack has been patented in Indonesia (Patent no IDP000049297, Ministry of Law and Human Rights, The Republic of Indonesia), further design improvement needs to be conducted especially for the confirmation of its performance. Therefore, we try to conduct the complete investigations on the floating backpack system both from its ergonomical
factor and performance on reducing the physical burden of the wearer. As the first step, in this article we tried to assess the physical parameter from human gait while walking and running. This gait parameter acquired by a three dimensional (3-D) motion analysis method. Afterwards the data acquired will be analyzed to extract its physical parameters of frequency and amplitude which furtherly will be used as the basic parameters for further design analysis and improvement.

Focusing on walking and running activity, gait analysis research has been performed by many researches previously although the gait analysis data for Indonesian has not been yet completed [5,6]. Therefore, in this research we try to analyze the pattern and characteristic of human walking activity and assess the compatibility of our motion analyzer system.

2. Method

2.1. Data acquisitions method
The motion analysis conducted in this research has been performed at the Ergonomic Laboratory, Department of Product Design, Faculty of Art and Design, Institut Teknologi Bandung. This motion analysis system (Qualysis Motion Capture System, Qalsis AB, Göteborg, Sweden) consist of eight infra-red (IR) cameras and one video camera that work together to track the object in motion. The system work inside a special conditioned 5m×5m chamber, recorded and monitored through the software system from Qualysis. On this trial we perform the gait experiment of two volunteer with the age of 20 and 49, with normal body weight to height ratio. The volunteer subject can hear the instructions and performed the walk and run activity on the treadmill as the set velocity increase (5 – 10 km/hour) throughout the activity cycle. Markers has been placed at several points of the volunteer’s feet to track the 3D positional change during the activity and tracked by the camera system. Motion capture data output was obtained as 3D coordinate data information which can be furtherly processed to investigate the motion pattern and analyze its relation to the body posture.

![Figure 1](image.png)

**Figure 1.** Motion capture system and its output information as 3D kinematical coordinate data from the motion activity measured.

2.2. Data processing
All data obtained from our motion capture system was exported as text file which was later processed on data processing software. The 3D coordinate data was extracted from the measurement point at the left and right hips and furtherly projected as 2D data for x and z axis, since we were focused on the analysis of change of the amplitude and frequency during walking and running phase.
3. Results and discussion
From the motion tracking measurement, we obtained the whole plot of location change of both left and right hips as shown by figure 2.

![Tracking data from walking to running phase.](image1)

**Figure 2.** Tracking data from walking to running phase.

![Tracking data of the running phase.](image2)

**Figure 3.** Tracking data of the running phase.

From this data, the variations of gait patterns throughout walking to running phase has been well obtained. During walking phase, the gait amplitude was observed at a relatively low range of change. When the phase was progressing change by the increment of velocity, transition phase was detected as the amplitude and frequency of the tracked point start to change into wider amplitude and higher frequency. Gait frequency observed with 2-3 Hz, maximum amplitude at 3.5 cm, 8 cm and 9 cm during
walk, transition and running phase respectively. As one of our objective is to measure the vibration-related parameters for designing our new vibration simulator, the aforementioned data gave the insight of which working range of our motor system and mechanism for the simulator.

Apart from that, further investigation on how the relations between the behavior of left and right hip is interesting to be analyzed further. Many previous research has been utilized the simple inverted pendulum model as the mechanical model of gait activity which produce the simple sinusoidal wave if the we project the change of tracked point on the 2D plane [7-9]. However, from this analysis we found from our motion tracking results that the movement projection was not a perfect sinusoidal as the amplitude of each wave has a different maximum amplitude (Figure 3). Thus, from those behaviors we try to investigate further about the relations between left and right hips which may reflect the tendency of phase different. This analysis has been performed by measuring the coordinate change of right and left hips instead of measuring the change of the center of mass’s positions directly which is difficulty to conduct. From the comparison, the phase difference can prove that the inverted pendulum model is a simplification of the gait movement from the position change of center of mass inside the body. However, from our investigation we found that a small phase difference is exist between the right and left hip points. From this finding, we conclude that the movement of left and right hips are on the similar phase due since the position center of body mass itself changed during the walking and running phase. This change happens due to the body posture adaptation when person walk and run.

4. Conclusion
This research shows that the motion capture system can be used efficiently to obtain the human gait data while walking and running. From the data obtained, the work frequency during walk and running ranged between 2-3 Hz with amplitude 3.5 cm, 8 cm and 9 cm during walk, transition and running phase respectively. In this research, we also try to assess the inverted pendulum model as the simplification of gait movement. However, further investigations are needed to confirm about the posture change and mechanism to adapt the movement of center of mass during walking and running.

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