วารสารวิทยาศาสตร์และเทคโนโลยีการกีฬา ปีที่ 22 ฉบับที่ 1, กรกฎาคม 2565

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Original article

STUDY OF VERTICAL GROUND REACTION FORCE IN DIFFERENT VARIATIONS OF PUSH-UP IN HEALTHY MEN

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ABSTRACT

The aim of this study was to determine the kinetic variation analysis between both hands during different variation of push-ups (standard push-up, balance boards push-up, and suspension push-up). Methodology: Seventeen healthy, right handed males were the subjects of this study, whose mean age are 22.47± 0.87 years mean height ±SD= 173.82 ± 3.11 cm, and mean weight ±SD = 70.80 ± 8.55 kg. This research was a single group, repeated measures design. On the day of testing, researchers informed the participants about the general information of the research and consent forms were signed. The subjects were then asked to warm up for 10 minutes by (1) riding a bicycle and (2) doing general stretching for five minutes each, (3) subjects drew the push-up variation, then (4) familiarizes themselves with the push-up variation. Then (5) subject did the push-up three times consecutively within three seconds controlled by the metronome. After that (6) the ground reaction force in both hands was recorded. (7) Three trials with 10-minute rest between trial were conducted and drew another push-up variation for the next trial. After trial session, (8) subjects cooled down and stretched. Vertical ground reaction force was recorded by two force platforms for each hand. One-way ANOVA with repeated measure was used to calculate for means and standard deviation; and LSD *post hoc* test and Friedman test were used to analyze the data. The statistically significant was at $p < 0.05$ level. Results: No significant differences in peak ground reaction force between left hand, right hand and both hands were found among standard push-up, balance boards push-up and suspension push-up. Conclusion: The kinetic analysis resulted in the present study showing that the indicated ground reaction force was not related to the different push-up variation. However, the findings can be used for development and inventing new innovation for push-up training in the future research.

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นิพนธ์ต้นฉบับ

การศึกษาแรงปฏิกิริยาแนวดิ่งของการดันพื้นรูปแบบที่แตกต่างกันในผู้ชายสุขภาพดี

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บทคัดย่อ

วัตถุประสงค์ในศึกษาครั้งนี้ คือการศึกษาการวิเคราะห์ตัวแปรทางคิเนติคระหว่างมือทั้งสองข้างในขณะดันพื้นรูปแบบที่แตกต่างกันในผู้ชายสุขภาพดี ได้แก่ท่าที่ 1. standard push-up 2. Balance boards push-up 3. suspension push-up โดยมีกลุ่มตัวอย่าง 17 คน เพศชาย สุขภาพดีที่ถนัดมือขวาอายุ 22.47±0.87 ปี น้ำหนัก 70.80±8.55 กิโลกรัม และส่วนสูง 173.82±3.11 เซ็นติเมตร การวิจัยครั้งนี้เป็นการทดลองแบบกลุ่มเดียววัดซ้ำโดยใช้ท่าที่ต่างกัน 3 ท่า ผู้เข้าร่วมวิจัยรับทราบแล้วให้อ่านรายละเอียดและลงนามยินยอม ผู้วิจัยให้ผู้เข้าร่วมวิจัยทำการอบอุ่นร่างกาย 10 นาที ดังนี้ 1. ปั่นจักรยาน 5 นาที 2. ยืดเหยียดกล้ามเนื้อ 5 นาที 3.ผู้เข้าร่วมวิจัยจับฉลากสุ่มเลือกท่าดันพื้น 4.ทำความคุ้นเคยกับท่าดันพื้น 5. ดันพื้น 3 ครั้งต่อเนื่องกันเป็นจังหวะภายใน 3 วินาทีควบคุมจังหวะโดยเครื่องกำหนดสัญญาณเสียง (metronome) 6. บันทึกแรงปฏิกิริยาในแนวดิ่งของมือทั้งสองข้าง 7. นั่งพักเป็นเวลา 10 นาทีและจับฉลากท่าดันพื้นในท่าต่อไปจนครบ 8. คลายกล้ามเนื้อด้วยการยืดเหยียด ผู้วิจัยบันทึกข้อมูลแรงปฏิกิริยาในแนวดิ่งด้วย Force Platform 2 แผ่น ในการวิเคราะห์ข้อมูลโดยใช้ค่าเฉลี่ยและส่วนเบี่ยงเบนมาตรฐาน โดยวิเคราะห์ความแปรปรวนทางเดียวแบบวัดซ้ำ (One-way analysis of variant with repeated measures) เปรียบเทียบโดยใช้ LSD post hoc test ถ้าข้อมูลมีการแจกแจงไม่ปกติจะใช้การทดสอบโดยวิธี Friedman test โดยกำหนดค่าความเชื่อมั่นที่ $p < 0.05$ ผลการศึกษา พบว่าไม่มีความแตกต่างอย่างมีนัยสำคัญทางสถิติของค่าเฉลี่ยแรงปฏิกิริยาในแนวดิ่งระหว่างมือซ้าย มือขวา และมือทั้งสองข้างเมื่อวิดพื้นในท่าที่แตกต่างกันทั้งสามท่า สรุปได้ว่า การศึกษานี้ได้บ่งชี้ว่าแรงปฏิกิริยาที่เกิดขึ้นไม่แปรผันตรงกับท่าการดันพื้น อย่างไรก็ตามจากการศึกษานี้สามารถนำไปใช้ในการพัฒนาและผลิตอุปกรณ์เพื่อช่วยฝึกในท่าดันพื้นให้มีประสิทธิภาพสูงสุด

(วารสารวิทยาศาสตร์และเทคโนโลยีการกีฬา 2565; 22(1):25-36)

คำสำคัญ : คิเนติกต์/ การดันพื้น/ แรงสำหรับท่าดันพื้น/ แรงปฏิกิริยาในแนวดิ่ง

INTRODUCTION

In the present, exercising is playing an important role in contributing to good health for everyone. Also, it enhances physical fitness, including body muscles and cardiovascular strengths, and mental health[1]. There are various kinds of exercising, but push-ups are consistently the most familiar one. It promotes muscle strength with beneficial qualifications. Push-ups is an easily trained exercising pose, space-saving activity, zero expenses, and free of expensive equipment[2]. Moreover, push-ups are also a great physical fitness and muscle tolerant measurement[3]. There are several ways to do push-ups in which weight resistance will be orderly exercised from beginner to advanced levels. Becoming a training for physical improvement, push-ups have been developed into variations. A number of researches has been conducted to develop difficulty progression in push-ups. In the study of ground reaction force, Ebben et al. (2011) found that a person should place feet together on different levels to lift up the lower body. This will produce a tense resistance during the training, resulting in another level of hardship of the exercise[4]. Another study showed that when a person does plyometric push-ups[5] with both dominant and non-dominant hands, ground reaction force tends to occur in the dominant hand[6]. Moreover, other studies claimed that doing push-ups on an unstable surface causes electromyography more often than doing push-ups on a stable surface[7-9]

However, there is still lack of evidence to affirm whether varied push-up variations on an unstable surface can cause any difference in ground reaction force in hands or not. A proper measurement of ground reaction force during the push-ups leads to a proper and effective muscle gaining for each individual. An explicit result of ground reaction force measurement record during training would lead to the effective fitness plan design which is suitable for athletes of all levels ranging from beginner to advance or national athletes such as bodybuilders, rugby players, basketball players etc. This will help each athlete with different physiology, muscle mass and training experience, especially in the world class competition, to have a detailed and proper training program design or force calculation. Moreover, the analysis of the ground reaction force is the basic that most people ignore and careless. This would lead to muscle and joint injuries as well as delay the muscle growth. Therefore, this kind of data would help and enhance the push-up performances as well as the strong push-up foundation in order to have a sustainable muscle development.

Thus, the significant objective of this study is to examine the ground reaction force from three different push-up variations: 1) standard push-ups (SDP), 2) balance boards push-ups (BBP), and 3) suspension push-ups (SPP) as well as comparing force between dominant and nondominant arm. The hypotheses for this study are 1) the different push-up variations have the different vertical ground reaction force in both hands; 2) the average peak vertical ground reaction force of both hands differs in each push-up variation; and 3) the average peak vertical ground reaction force of the dominance hand (right) is higher than the force of the non-dominance hand (left) in each push-up variation. This study will help ones designing an effective fitness plan or a befitting push-up training program. In the future, this study will also bring new innovations that help people do push-ups

properly and practically. For instance, the company can utilize the research finding by inventing a push-up aid machine for the most effective push-up exercise.

METHODOLOGY

Participants

The number of participants was calculated by using G-power software 3.1.9.2 with 0.80 in power according to Cohen (1988). The sample size estimation is 12; however, the authors chose to collect data from 17 participants. All 17 participants are in healthy conditions and the characteristics participants are average of arm length: 74.33±1.91 centimeters (left) and 74.52±2.31 centimeters (right); upper arms triceps brachii muscle: 26.06±5.53 centimeters (left) and 26.49±5.80 centimeters (right); chest measurement 88.38±6.40 centimeters (when inhaled) and 85.26±5.53 centimeters (when exhaled). As for the inclusion criteria, every participant was right-handed without any injury on the medical record. Before going through the experiment, they were asked to answer personal information questions including age, gender, height, weight, dominance arm and medical history and complete a consent form regarding the American College of Sports Medicine guidelines. For the applicants who have bone and muscles injuries, inability to do the balance board push-up and suspension push-up, unable to follow the authors' instruction, overweight and open wounds were excluded from the study. Target subjects were considered and chosen according to the criteria, one month prior to the experiment. Participants must not have any injury record. Also, the American College of Sports Medicine guidelines form, referring to health condition and exercise routine must be completed by all participants before starting the experiment. Participants were asked to complete a health history and informed of their consent. Seeking valid participants, the project launched the recruitment one month prior to the data collecting process. The recruiting process was accomplished through advertisement and social networks.

Procedure

This experiment was a single group repeated measures design, meaning that each participant would be tested for 3 push-up variations over time. Starting the experiment, researchers declared the objectives of the experiment followed by benefits and possible effects that could have happened to the participant. The researchers also elaborated the participant on details and steps of the experiment. After reading through the paper and acknowledging all the details, the participant signed a consent form (HREC-TUSc 102/2561), which was referred to as a proper declaration. Then, the participant engaged in the general characteristics of subjects by measuring weight, height, and body fat. Anthropometrics data of subjects were also undertaken: the participant's both arm circumferences and chest expansion circumferences were measured. After doing warm-up for 10 minutes, including 5-minute-cycling and 5-minute-stretching, the participant randomly drew lots to pick 3 push-up variations. The leg height of each push-up position was set at 26 cm. high and the angle of the

elbows was monitored using high-speed camera together with Kinovea software 0.9.5 to ensure that the elbow bended at 90 degree (Figure1).

The data collection was done by using two Kistler's Force platforms (Kistler Insturmente AG, Winterthur, Switzerland) with 2,000 Hertz of sampling frequency and normalize the signal by calibrating the participants' weight in Newton force, then calculated into percentage (see figure1). The first calibrate was done at the force platform and weighed the body weight there, rested, recorded the data in the form provided and the data were analyzed by using Software Bioware (2812A1-3, Version: 3.2.6.104). Familiarizing himself with the selected variations for 3 trials, the participant was required to perform each variation a set of consecutive 3 push-ups by following the three-metronome rhythm of 60 bpm: the first rhythm was set up the pose, the second was to go down and the third was to push-up to the first position. The data collection was done at this stage. A metronome was used as a tool to control the speed of the push-ups. The ground reaction force from both hands was recorded when the participants had finished the first set of push-ups. Then, the participant was allowed to have a 10-minute-break and continued drawing lots for the next variation. After finishing all 3 variations, the researchers analyzed the results and assisted the participant to do stretching for pain prevention. The researchers used the same setting (equipment, space, and height) throughout the data collecting processes. Although the data collecting processes took a few days to finish, the confounding factors were controlled.

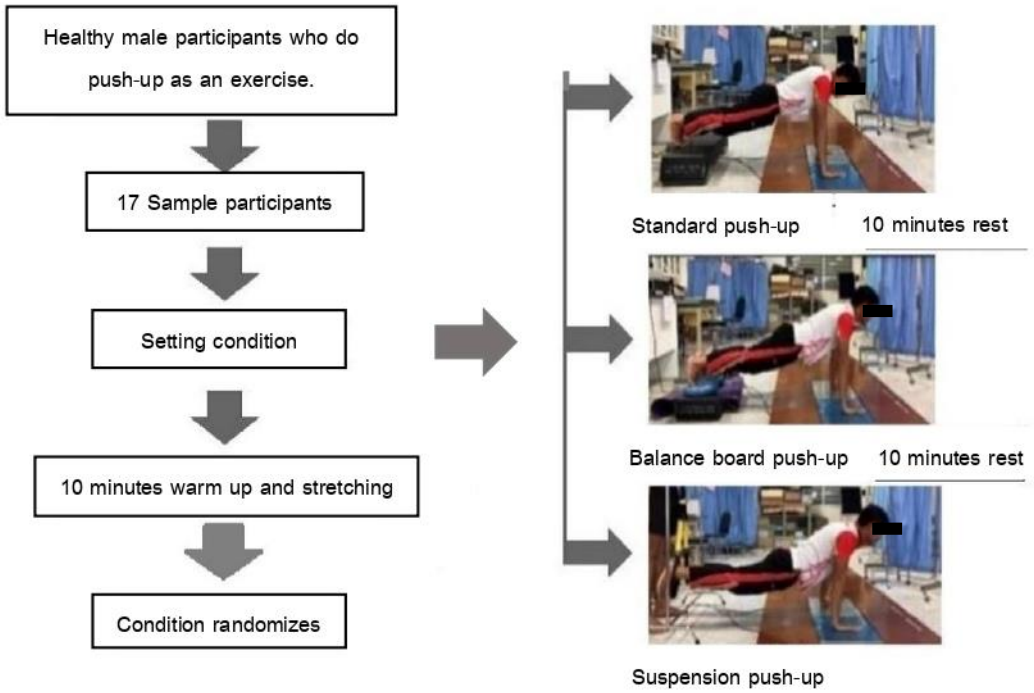

Figure 1. Diagram illustrates data collecting procedures.

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Statistical Analysis

In this part, one-way repeated measures ANOVA model is applied to the one independent variables with three levels (standard push-up, balance boards push-up and suspension push-up), and to the three Dependent Variables (an average of peak ground reaction force: right hand, left hand and both hands, which was derived and averaged from the peak force used during the push phase of each variation). To analyze the data, SPSS/PASW Statistics version SPSS (version 26, Chicago, IL, USA) is used. One-way repeated measures ANOVA model is also used in the part of ground reaction force (N) analysis. Standard deviations and Means are brought into the calculation in order to understand characteristics of subjects, Anthropometrics data of subjects, and ground reaction force (N) and its result. To study the normality of distribution, Kolmogorov-Smirnov Test is used due to the number of data was over 50, which was recommended by scholars and analyze using Shapiro- Wilk; and then test of homogeneity of variances is conducted. However, Friedman Test is conducted when the result does not illustrate the normal distribution.

RESULTS

General characteristic of subjects

There were 17 participants (male) who participated in this experiment. Each participant's characteristics were illustrated as follows:

General characteristics	Average measurement ± SD (n = 17)
Age (years)	22.47±0.87
Weight (kilograms)	70.80±8.55
Height (centimeters)	173.82±3.11
Body fat (percent)	20.27±4.29

Table 1. General characteristic of subjects and its standard deviation (average ± SD)

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Data of subjects on ground reaction force

This part showed the data of actions in average peak ground reaction force, focusing on participants' hand forces.

Action	Part of the body	Average peak vGRF (N)	± SD
SDP	Left hand	32.96	19.31
	Right hand	33.17	19.64
	Both hands	66.13	38.17
BBP	Left hand	35.39	17.37
	Right hand	35.28	17.47
	Both hands	70.67	34.10
SPP	Left hand	35.39	17.37
	Right hand	34.70	16.23
	Both hands	70.09	27.77

Table 2. Average peak vertical ground reaction force and its standard deviation (average ± SD)

The high range of standard deviation was resulted from the wide range of the means from the data collected.

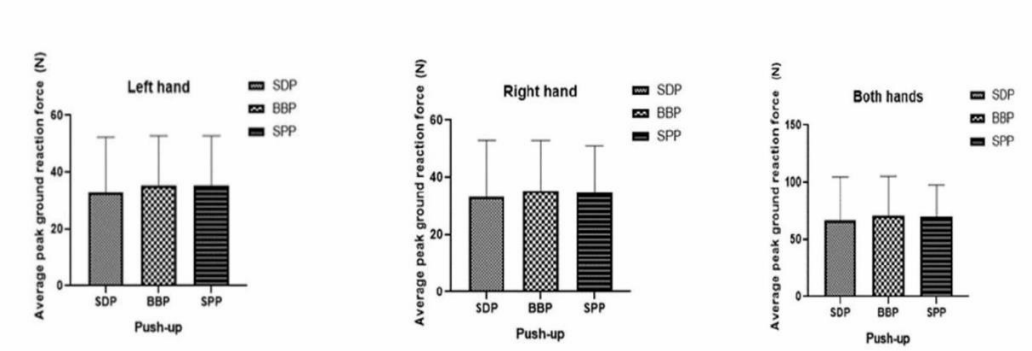

Figure 2. Graphs show the comparison of average peak ground reaction force using left hand, right hand and both hands push-up force, from left to right respectively.

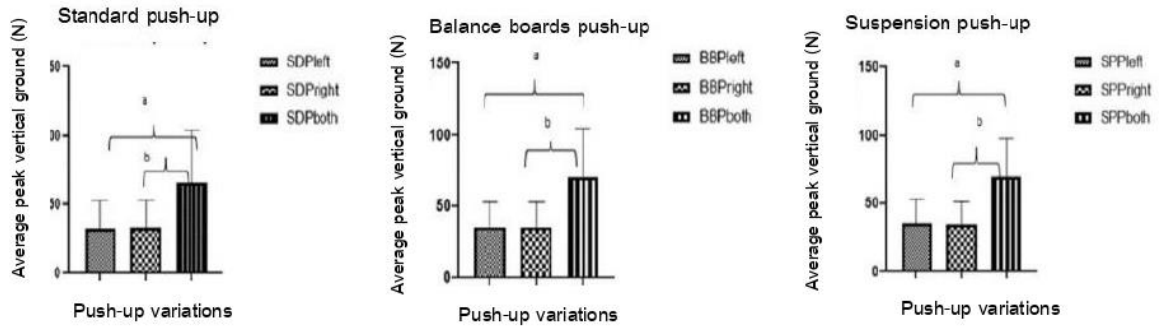

Figure 3. Graphs show the comparison of ground reaction by doing standard push-up, balance boards push-up and suspension push-up, from left to right respectively. (NB: SDP refers to Standard Push-up; BBP refers to Balance boards push-up; and SPP refers to Suspension push-up)

DISCUSSION

The significant objective of this study is to examine the ground reaction force from three different push-up variations: 1) standard push-ups (SDP), 2) balance boards push-ups (BBP), and 3) suspension push-ups (SPP). The hypothesizes for this study are hypothesis#1: the different push-up variations have the different vertical ground reaction force in both hands; hypothesis#2: the average peak vertical ground reaction force of both hands differ in each push-up variation; hypothesis#3: the average peak vertical ground reaction force of the dominance hand (right) is higher than the force of the non-dominance hand (left) in each push-up variation.

The study demonstrated a correlation between push-up variations and ground reaction force in both hands. The results, when participants performing three push-up variation regardless of hand used left hand, right hand or both hands, suggested that the ground reaction force of three push-up variations (leg position and usage of hands) differed; however, the overall result of ground reaction force and the push-up variation are correlated. This study proved the correlation between average peak ground reaction force in dominant and non-dominant hands, right and left hands orderly in every variation scenario. The result showed that when they were compared in each variation, there was no statistically significant difference, whether using right or left hands. Based on kinetic analysis, when healthy men perform push-up variations with one and both hands, there is no statistically significant difference. Notably, at the same height from the floor, balance boards push-ups and suspension push-ups tend to ignite the reaction more than standard push-ups because of the different support of distal part of extremity as presented in table 2. Furthermore, the study and discussion prove that the law of reaction in pushing hands with a closed chain kinetic manner is neither a direct variation nor relates to electrical activities in muscles. To be exact, as long as the extremity fully touches the floor, the reaction occurring from push-ups will not intensify muscular activities. Otherwise, push-ups in an open kinetic chain manner, the extremity is free and away from the floor, will escalate the reaction and electrical activities in muscles rather than the former manner. It can be concluded that when hands contact the floor, doing push-ups with balance boards and suspension ropes stimulates the reaction more than doing standard push-ups. Even though each variation insignificantly produces the reaction in both hands, the knowledge from this study can still beneficially design fitness training programs. It suggests that a person should do push-ups with the reaction in hands and with an open kinetic chain manner by letting one part of extremity free from the floor. This knowledge will effectively help the training and further expand other relevant academic research and studies.

According to research hypothesis#1, the different push-up variants effect in the ground reaction force of both hands was studied by normalizing ground reaction force percentage, which was calculated in the Newton unit. The researchers determined the same height of leg position for every participant while doing different push-up variants, which does not affect the ground reaction force. The research finding is consistent with Moore L.H. (2012)'s[5] research reported that while doing the plyometric push-up by elevating the body and clapping the

hand, which is called clapping push-up, has more ground reaction force than another position in which the body is elevated lower. Regarding the case study, hands and legs are of the same height; therefore, there were no significant differences in the ground reaction force in both hands. Interestingly, the study is close to the study by Ebben WB. (2011)[10] studying Kinetic analysis of several variation of push-ups in which the height of leg position is different. It was found that the higher leg position while doing push-ups provides more ground reaction force than other push-up variants. Gender and height of participants does not affect the ground reaction force. Moore L.H. (2012) and Ebben W.B. (2011) provided a great idea about research methodology and data collecting plan. Although the research methodology and data collecting plans were not exact, the authors can apply and adjust the trends from these researches in the future research or training. In research hypothesis#2, the average peak ground reaction force of both hands differs by different push-up variants. In this study, each participant performed three different push-up variants in random order, then researchers calculated the average ground reaction force. It was found that there were no significant differences which is inconsistent with the research hypothesis. According to the finding, there are no significant differences, as a result of the unstable points of legs causing an unstable pose of participants, which deviated participant's focus from hands to legs and didn't properly distribute weight on hands. The research finding, indicating that there are no significant differences is consistent with the theory of Mayer F. (2003)[11] on closed kinetic chain and open kinetic chain which is one of the factors affecting the upper and lower extremity to the ground. The closed kinetic chain was used in standard push-up and balance board push-up while the open kinetic chain was used in suspension push-up, in which participants had to place their legs on the rope. To the aforementioned, the concept, when the upper and lower extremity do not touch the ground or are in open kinetic chain manner, joints and muscles work harder, is supported. The concept is consistent with Snarr R. L. (2013)'s[7] study on electromyography which reported that when doing suspension push-ups, a lot of electric waves were found in muscle. Moreover, the finding is also consistent with Youdas J. (2010)'s[12] study on push-ups using other push-up tools, which indicated that joints and muscles when pushing-up in open kinetic chain manner are more intense than when pushing in closed kinetic chain manner, which is unrelated to the ground reaction force. In addition, García-Massó X. (2011)[13] studied myoelectric differences between 3 types of plyometric push-ups (FPU = fall push-ups; JPU = jump push-ups; CPU = countermovement push-ups). It was found that the maximum force (N) in CPU is the highest while the impact force in FPU is the highest. In research hypothesis#3 stated that the average peak ground reaction force of the dominant hand is higher than the non-dominant hand when doing the different variant push-ups. The researchers determined that participants should be right-handed. The finding shows that there were no significant differences. When considering about the Kran J.L.'s theory on muscle contraction, it was expected that the dominant hand has a better muscle contraction and has an impact on a higher accumulated force on ground reaction force; however, according to the experiment, it was found that force contribution on points of hand contacting the ground is inconsistent with the muscle

contraction theory. According to Koch J. (2012)[6] studying the ground reaction force variation in plyometric push-ups focusing on vertical ground reaction force (vGRF) characteristics between the clap push-ups and box drop push-ups among limbs (dominant and non-dominant), it was reported that the push-up on the different height of boxes (3.8, 7.6 and 11.4 cm) has no significant difference ($P < 0.05$). It was well-observed that the contraction of muscle and joints of the dominant hand cannot indicate the higher ground reaction force; furthermore, the perimeter and length of dominant arm, which is more likely to be bigger and longer than the non-dominant one, is not an indicator to the higher ground reaction force during push-up. According to Suprak D. (2010)'s[14] research about 'The Effect of Position on the Percentage of Body Mass Supported During Traditional and Modified Push-up Variants', it was found that "a result of differing moment arms between the support surface contact point (knees or feet) and the hands helps strengthening and/or rehabilitation for both the prime movers and stabilizers of the upper extremity. On the contrary, range of motion may need to be altered to accommodate strength differences in beginners and clients rehabilitating from injury." In addition, there is also Smith J.P. (2011)'s[15] research studying kinematic and kinetic variations among three depth jump conditions in male NCAA division III athletes whose question was 'depth jumping over a hurdle and depth jumping while touching as high as possible using an overhead goal'. It was found that "Few differences were found to exist between the Vertec and control conditions. Hurdle jumping in particular may be superior for the development of short ground contact time (0.3 s) sport movements requiring brief but powerful lower extremity power production." As the muscle mechanism while doing the depth jump and push-up are similar; therefore, with an appropriate training, the muscle will be improved effectively. According to Mier C. (2014)[16] studying 'the Differences between Men and Women in Percentage of Body Weight Supported during Push-up Exercise', it was found that "women perform the push-up with less relative load and ROM, likely due to gender differences in movement patterns which can be altered by fatigue." Moreover, according to Hinshaw T. (2017)[17] studying about effect of external loading from force and power production during plyometric push-ups it was found that "there were no significant differences were observed for peak power among the push-ups with or without external loading. Although peak power is similar with or without external loading, push-ups without external loading may be more beneficial for a quick movement, and push-ups with external loading may be more beneficial for a greater force production." This could lead to the point studying about ground reaction force when performing push-ups. Although there were many studies about push-up, there were no study emphasizing the relation between ground reaction force and the dominance and non-dominance arm. Those studies provided ideas and examples leading to in-depth study on push-up variation in relation to the ground force reaction. Although there are no significant differences in each push-up variation and force in dominance hand as previously discussed, the importance of this study for the general public to learn and understand about the push-up variations, where there are different levels of difficulty, force used and vertical ground reaction force. Therefore, the result of this study can maximize the push-up exercise by providing guidelines and ideas for

general public to choose the most appropriation push-up variations that conform to their physical fitness and purpose of exercise.

CONCLUSION

The study showed that the balance board push-up and suspension push-up variants tend to have more reaction force than standard push-up despite the same height of different leg-rests, the differences of which was the result of the distal parts of extremity were supported differently. To clarify, feet were placed in the foot cradles on suspension ropes while doing the suspension push-up, while feet were placed on the unsteady balance board when completing the balance push-up resulting in an increase of reaction force. The study also demonstrated that balance board push-ups and suspension push-ups are likely to produce more reaction force on the touching point over hands than standard push-ups. Even if each push-up variation insignificantly produces a similar reaction, the knowledge from this research may be integrated into physical fitness program designing. It is recommended to do push-up variations that highly produce the reaction in hands and in an open kinetic chain manner, namely, one part of extremity does not touch the floor. Although there is a minimal important different in statistic of peak vertical ground reaction force, between standard push-up vs balance boards push-up and standard push-up and suspension push-up, this finding provides a fitness program designer a push-up alternative which can be choice upon the trainee's skills and appropriateness. The knowledge does not only benefit push-up training, but also be implemented to other future research and studies by using different unstable equipment or using gaming/virtual technology in push-up exercise. According to the research findings, researchers are inspired and recognized the necessity in inventing an innovation such as a low-cost ground reaction force measurement machine. This machine will be used during training aiming to record a proper and accurate force record. Moreover, the development and invention of a digital push-up machine for individual's training measurement result is recommended.

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