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Movement and hardware content selection for exergame development

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Abstract

Introduction: A trend of spending leisure time in front of various screens is widespread among children and adolescents. Prolonged sitting, low level of local muscular endurance, and playing video games are some of the risk factors for low back pain among children and adolescents. In order to motivate children to be regularly active, exercise video games (exergames) have appeared on the market. The aim of this paper is to review the literature on movement content to increase spine stability and hardware options for effective motion tracking. In order to determine the game content more accurately, the second aim was to evaluate the correlation between maximum trunk strength (in the lateral and frontal planes) and the performance of the lumbar stability test. *Methods:* We focused on Pubmed database, where we searched for articles published since 2010. The correlation study included 9 subjects (age 20,4 ± 6,1, height 178,8 ± 6,1 cm, weight 70,8 ± 13,5 kg) who were physically active 3 times per week. We used Spearman coefficient for correlation analysis. *Results:* 40 articles were included in the analysis. Maximal trunk strength in sagittal and frontal planes did not significantly correlate with total CoP area ($r < 0{,}10$), $p > 0{,}79$). In general, researchers agreed that a successful preventive-curative approach to manage low back pain consists of several phases. In reviewing the hardware, the researchers stressed the importance of motion tracking with marker-less sensors, as their validity in performing simple movements is comparable to the gold standard.

Key words: physical activity, exergames, sedentary behaviour, low back pain, children

Introduction

A sedentary lifestyle and physical inactivity are well-known trends in developed countries. In 2011, a study including nearly 300,000 participants from 76 different countries showed that 1 out of 5 people did not meet the minimum level of physical activity (Dumith et al., 2011). Just four years later, in 2015, the World Health Organisation revealed that about one third of the world's population aged 15 years or less did not meet the minimum requirements of 1 hour of moderate to high intensity physical activity per day (WHO, 2020). The SARS-CoV-2 virus, responsible for COVID-19 disease, spread worldwide in 2020, causing a global pandemic. The population that has been particularly affected by the pandemic are children and adolescents. Reduction in physical activity during the pandemic could have adverse effects, as regular physical activity prevents the occurrence of several diseases such as obesity, cardiovascular disease and lower back pain (LBP) (Rubin, 2007).

LBP is a global health problem experienced by 50-80% of adults (Rubin, 2007). In approximately 20% of the population, pain develops into chronic LBP (Maher, etc., 2017). Unfortunately, LBP often starts in childhood and the prevalence in adolescents is similar to that in adults (Leboeuf-Yde and Kyvik, 1998). The trunk plays an important role in both elite sport and everyday life. The effectiveness of multi-joint movements depends on the efficiency of force transfer between the body segments. Kicking, throwing and lifting are examples of multi-joint movements in which an adequate level of stability of the spine is essential for the transfer of energy from the trunk to the arms or legs. Stability is the ability to control the joint position and depends on the effective interaction of the passive, active and nervous system (Panjabi, 1992). Exercise is an important factor in maintaining a healthy lifestyle and is important for treating several diseases, including LBP (Hurley et al., 2011). Several studies have shown improved muscle strength, local endurance and patterns of muscle activation after exercise intervention (Magnusson et al., 1996; Pedersen et al., 2004; Kocjan and Sarabon, 2020). For the treatment of LBP, exercise has been shown to be more effective than non-exercise-based interventions (Searle et al., 2015). Due to multifactorial nature of LBP the training content should include exercises that improve coordination, aerobic capacity, strength and local endurance (Owen et al., 2020; Gordon and Bloxham, 2016).

Video games with moving content (exergames) represent one way to improve movement activity among children and adolescents. Studies have shown the impact of playing such games on psychological abilities, physical activity in overweight people (Höchsmann et al., 2016; Andrade and Correia, 2019) and balance performance in older adults (Fang et al., 2020). Exergame systems such as Xbox and Kinect are becoming increasingly popular where a new type of entertainment could promote physical activity (Sween et al., 2014).

The aim of this paper is to review scientific literature on the field of motion tracking technology and exercise protocols to reduce the risk of LBP. The

second aim is to evaluate the relationship between maximum trunk strength and the performance of the stability test.

Methods

Subjects: The literature review included subjects between 10 and 65 years of age. The relationship study involved 9 subjects (20.4 ± 6.1 years, 178.8 ± 6.1 centimeters, 70.8 ± 13.5 kilograms). Subjects with LBP and/or musculoskeletal disorders were excluded from the study. Before the study all subjects signed the informed consent.

Article selection process: The review was carried out in the PubMed database. We focused on articles published since 2010. The search key relating to the hardware contained the following keywords: (*"motion" OR "movement" OR "exercise") AND ("capture" OR "video analysis" OR "tracking") AND ("system" OR "technology)*. The search key related to movement therapy contained the following keywords: (*"low back pain") AND ("exercise" OR "training" OR "kinesiotherapy") AND ("program" OR "intervention")*.

Trunk strength and stability assessment: Postural control was evaluated with unstable sitting test, where we measured the center of pressure (CoP) area. Participants sat on an unstable hemi-sphere (radius = 22 cm; height = 18 cm) with arms crossed over their chest and their feet rested on a surface that was a part of the hemi-sphere. The hemi-sphere was placed on the force plate (Kistler, 9286B, Switzerland). Subjects performed 3 repetitions of 30 seconds with an intermediate 30 second break.

Maximal trunk strength was measured with multi-functional dynamometer (S2P d.o.o., Ljubljana, Slovenia). Each subject performed 3 maximal isometric contractions in direction of trunk extension and lateral flexion to the right.

Statistical analysis: Maximal force was evaluated as the peak value within one second time interval. An average of three repetitions was included into the further statistical analysis. The normality of the data distribution was verified with Shapiro–Wilk tests. Spearman coefficient was used to analyse the correlation between the variables. The level of statistical significance was set to $p < 0.05$. Statistical analyses were done in SPSS (SPSS statistics 19, IBM, New York, USA).

Results

The final review included 15 (hardware) and 25 (movement therapy) articles (Figure 1). Overall, the researchers agree that a successful LBP program consists of several phases (Mcgill, 2007). It seems that local muscle endurance plays a key role in LBP prevention and is superior to maximal strength. Our study did not show a significant association between the maximal strength in sagittal plane, frontal plane (Figure 2) and the CoP area ($\rho = 0.100$; $p = 0{,}789$, $\rho = 0{,}033$-; $p = 0.932$, respectively).

Regarding the motion tracking sensor, Microsoft Kinect V2 is an affordable, valid and reliable tool and it provides a solution which tracks gross body movements.

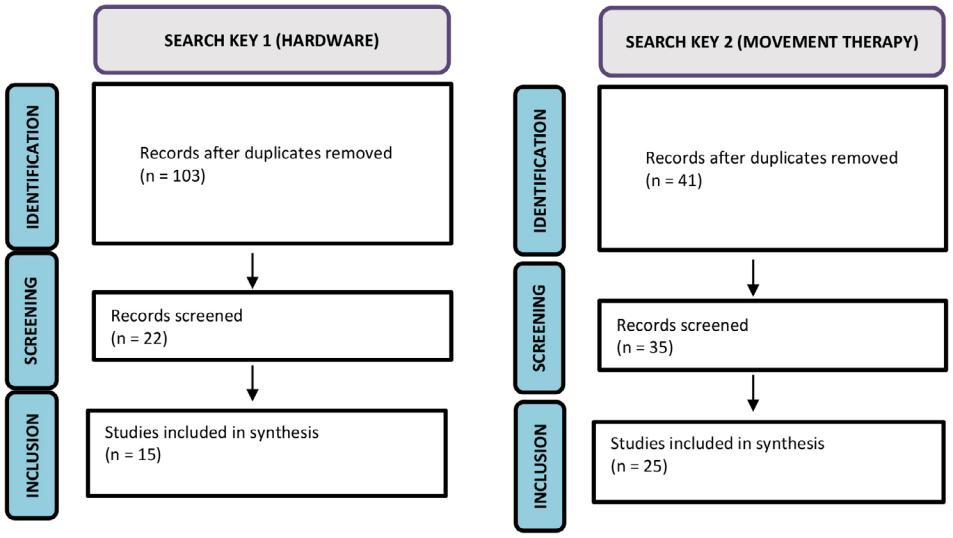

Figure 1: Diagram of selecting systematic reviews for the study

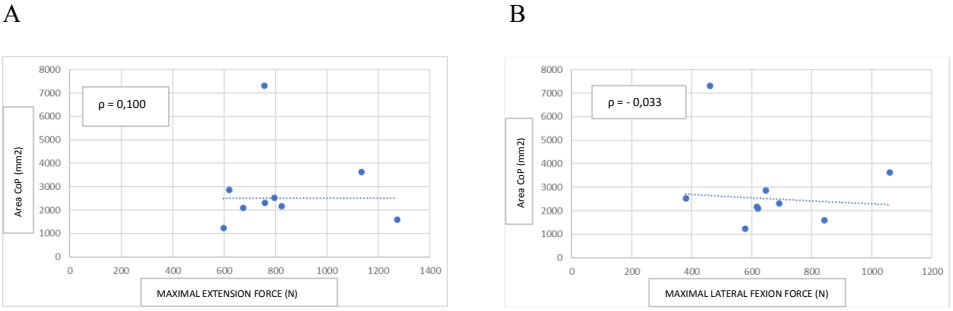

Figure 2: Relationship between trunk strength (sagittal plane (A), frontal pane (B)) and the center of pressure area during unstable sitting on a wobble board

Discussion

The literature review of managing LBP with movement therapy highlights the importance of a multi-stage approach, with education and the development of local muscle endurance at the forefront. Motion capture sensors without markers are an easy and affordable alternative to more expensive and complex systems.

The most important factor in the development of an exergame is the need to make the game attractive to players and at the same time effective as an exercise. The introductory part of the treatment program consists of a patient's education, where she/he learns functional anatomy (Figure 3), harmful movements, protective techniques during handling loads and relieving positions. In the second part, patients learn to perform movements in lumbar spine and in hip joint. The aim of the third part is to learn the mechanism for increasing spine stability. In the fourth part, patients improve key motor abilities that increase spine stability. The fifth part represents the integration of the earlier parts, with great emphasis on improving neuromuscular coordination in conditions of instability.

Figure 3: Animation of functional anatomy in the educational part of a novel exergame

All parts of the exercise program aim to improve the stability of the spine which is influenced by three systems. The most important role of the passive system is to limit the extreme ranges of motion. The sitting position usually increases lumbar spine flexion and stretches the passive tissues at the back of the vertebrae. Prolonged sitting caused by the pandemic is a risk factor for the de-

velopment of LBP (Gupta et al., 2015). In the education part of the exergame, we inform the patient of the correct sitting postures and load handling techniques.

Trunk movements cannot be performed without the presence of the active system. The stability is first provided by deep trunk muscles, while the superficial muscles are primarily engaged during large movements of the spine. Several studies have shown changes in muscle activation of trunk muscles in people with LBP compared to healthy subjects (Cholewicki et al., 2005; Carpes et al., 2008). There are little prospective studies regarding the effect of maximal trunk strength on the incidence of LBP and their findings are contradictory (Lee et al., 1999; Cho et al., 2014). Literature highlights that the maximum hip strength is superior to the maximum trunk strength for LBP prevention (Coyle et al., 2021; Alsufiany et al., 2020). Furthermore, decreased local endurance of trunk muscles and impaired trunk strength ratio in sagittal plane represents a risk factor for future LBP (Biering-Sorensen, 1984; Lee et al., 1999). The latter suggests that local muscle endurance has a significant impact on the spine health which is in line with recent studies (Pilz et al. 2020). In addition, the exergame content regarding the volume/intensity of trunk flexors and extensors should be well balanced. Isolated maximal trunk strength and endurance of trunk muscles (assessed by the Biering-Sorensen test) are not significantly correlated (Conway et al., 2016). The latter indicates the importance of pelvic muscles in controlling the pelvic position and consequently the lumbar region of the spine. In a novel exergame it will be important to include exercises to strengthen the entire kinetic chain and not just individual muscle groups. The third subsystem, the nervous system, controls muscle activity. In cases where perturbations affect the spine, the human body automatically ensures spine stability. Reflex postural adjustments are the reactions of trunk muscles, which are important to maintain the correct position of vertebrae during unexpected trunk loading (Santos et al., 2010; Cholewicki et al., 2005). Koch and Hansel (2019) found out significant difference between healthy participants and LBP patients in the CoP sway during upright standing in situations with higher postural demands. This indicates that exercises should be performed in conditions of instability.

In order to successfully carry out an exercise intervention by playing an exergame, it is essential that information received by the therapist/coach from the device is valid and reliable. The current gold standard for non-invasive motion capture is radiography, which measures bone movement via X-rays (Kessler et al., 2019). Systems that track human motion with markers placed on specific anatomical locations are the best approximation to the gold standard. Movement tracking based on markers is risky due to errors in the setting of markers, and their installation is time-consuming, which is an important obstacle in clinical or sporting environments (Gorton and Hebert 2009; Whittle, 1996). On the other hand, systems without markers such as Microsoft Kinect, Intel Realsense and StereoLabs Zed have been developed, which are supposed to accurately detect body segments during movement. Investigators performed

validation studies mainly in the field of walking and body posture, while fewer studies have assessed accuracy during more complex multi-joint movements (Ma et al.., 2018). Although the time-spatial variables of motion capture systems without markers appear to be equivalent to systems with markers, the movement accuracy of some joints is not good enough (Wade et al., 2022). After we reviewed several possibilities, we decided to use Kinect V2 sensor to track movement in our exergame. The Kinect V2 proved to be a valid and reliable sensor for motion tracking in an exergame (Ma et al., 2018).

Our study has some limitations. Since the stability is influenced by several factors, the interpretation of results based on one test is questionable. In addition, the sample of subjects in the correlation study does not allow generalisation to the general population.

Conclusion

The COVID-19 pandemic and a sedentary lifestyle have caused a decrease in regular physical activity in children and adolescents, which increases the risk of LBP. Since children and adolescents spend several hours in front of various screens, a well-designed exergame represents a new motivational approach to regular physical activity. The content of a novel exergame should improve patients' education and local muscle endurance, and gross body movements should be tracked by a reliable markerless system (Microsoft Kinect V2).

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