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Wpływ zróżnicowanego obciążenia zewnętrznego na rozkład nacisku stóp na podłoże i zdolność zachowania równowagi ciała w okresie późnego dzieciństwa i wczesnej adolescencji

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1. Rozprawa doktorska

1. Jaszczur-Nowicki Jarosław, Bukowska Joanna M., Kruczkowski Dariusz, Pieniążek Magdalena, Mańko Grzegorz, Spieszny Michał. ***Distribution of feet pressure on ground and maintaining body balance among 8–10-year-old children with and without external load application;*** Acta of Bioengineering and Biomechanics 2020; 22(4): 1-14. https://doi.org/10.37190/abb-01696-2020-02
   Impact Factor: 1.073, Punktacja MEiN: 100

2. Bukowska Joanna M., Jekiełek Małgorzata, Kruczkowski Dariusz, Ambroży Tadeusz, Rydzik Łukasz, Spieszny Michał, Jaszczur-Nowicki Jarosław. ***Podiatric and stabilographic examinations of the effects of school bag carrying in children aged 11 to 15 years;*** Applied Sciences-Basel 2021; 11(19), 1-11. https://doi.org/10.3390/app11199357
   Impact Factor 2.679, Punktacja MEiN: 100

3. Bukowska Joanna M., Jekiełek Małgorzata, Kruczkowski Dariusz, Ambroży Tadeusz, Jaszczur-Nowicki Jarosław. ***Biomechanical Aspects of the Foot Arch, Body Balance and Body Weight Composition of Boys Training Football;*** International Journal of Environmental Research and Public Health 2021; 18(9): 5017. https://doi.org/10.3390/ijerph18095017
   Impact Factor: 3.390, Punktacja MEiN: 140

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2. Wykaz skrótów

BFM – (ang. Body fat mass) – Masa tkanki tłuszczowej

BMI – (ang. Body mass index) – Indeks masy ciała

COP – (ang. Center of pressure) – Środek nacisku

cop-bars – (ang. Surface of deflections of the body's center of gravity) – Powierzchnia wychwiań środka ciężkości ciała

cop-dist – (ang. Distance between extreme deflections of the body's center of gravity) – Odległość COP

cop-lsf – (ang. Ratio of the distance between extreme deflections to the deflection surface) – Stosunek odległości między skrajnymi wychwianiami do powierzchni wychwiań)

cop-speed – (ang. Deflection's speed of body's center of gravity) – Szybkość wychwiań środka ciężkości ciała

FFM – (ang. Fat-free mass) – Beztłuszczowa masa ciała

L (LF) – (ang. Left foot) – Lewa stopa

l-bars – (ang. Left foot deflection area) – Powierzchnia wychwiań lewej stopy

O – (ang. measurement with a backpack) – Obciążenie plecakiem

PBF– (ang. Percentage of adipose tissue) – Procentowa zawartość tłuszczu w organizmie

R (RF) – (ang. Right foot) – Prawa stopa

r-bars – (ang. Right foot deflection area) – Powierzchnia wychwiań prawej stopy

S – (ang. Resting measurement) – Bez obciążenia

SMM – (ang. Skeletal muscle mass) – Masa mięśni szkieletowych

TBW – (ang. Total body water) – Całkowita objętość wody

VFL – (ang. Visceral fat) – Tłuszcz wisceralny

WHR – (ang. Waist–hip index) – Indeks talia-biodra

<u>Skróty dotyczące statystyki</u>

d – (ang. Effect size) – Wielkość efektu

M – (ang. The arithmetic mean of a sample) – Średnia wartość w próbie

Max. – (ang. Maximum value of a sample) – Maksymalna wartość w próbie

Me – (ang. The middle average of a sample) – Wartość mediany w próbie

Min. – (ang. Minimum value of a sample) – Minimalna wartość w próbie

p – (ang. Significance level) – Poziom istotności

Q1, Q3 – (ang. Extreme quartiles) – Kwartyle

SD – (ang. Standard deviation) – Odchylenie standardowe

3. Wprowadzenie

Stopa ludzka, jako istotna część statyczno-dynamiczna łańcucha biomechanicznego narządu ruchu, charakteryzuje się osobniczo zmiennym ukształtowaniem. Jej budowa i ustawienie mają duży wpływ na jakość chodu i stabilność postawy ciała. Prawidłowa funkcja stóp jest uwarunkowana przez ich morfologiczną budowę, a w szczególności przez prawidłowe ukształtowanie łuków podłużnych i łuku poprzecznego, czego efektem jest poprawne ukształtowanie stopy. Tworzące je sprężyste i mocno wysklepione łuki, spełniają funkcję ochronną i amortyzującą wobec innych układów ustrojowych, jednocześnie dźwigając całe ciało**.** Prawidłowe ukształtowanie stopy jest uwarunkowane odpowiednią sprawnością mięśni i więzadeł, a także prawidłową budową układu kostno-stawowego (Leszczak i wsp. 2014; Puszczałowska-Lizis i wsp. 2017; Łagan i Stopka 2017; Asghar i Naaz 2021).

Dzieci w wieku szkolnym to nastolatki, przeżywające okres szybkiego wzrostu i rozwoju tkanek kostnych i miękkich. Struktury kręgosłupa u dzieci są bardziej podatne na zaburzenia wywołane czynnikami zewnętrznymi, niż u dorosłych. Ponadto, siły zewnętrzne spowodowane przenoszeniem obciążeń mogą również wpływać na wzrost, rozwój i prawidłową postawę ciała (Wojtków i wsp. 2018).

Głównym aspektem rozważanego cyklu artykułów jest rozkład nacisku stóp na podłoże i jego związki z równowagą ciała. Interesujące jest w jaki sposób zmienne, takie jak: opór zewnętrzny lub oddziaływanie długotrwałym wysiłkiem fizycznym, mają wpływ na wymienione parametry.

Ontogenetyczne zmiany w postawie i równowadze ciała są coraz częściej odnotowywane w statystykach związanych z diagnostyką medyczną. Jest to spowodowane faktem, iż w dzisiejszych czasach wielu uczniów już we wczesnym okresie życia odczuwa bóle kręgosłupa, spowodowane dużym obciążeniem w postaci tornistra. Siły zewnętrzne w postaci obciążenia ciężarem tornistra, mogą wpływać na prawidłowy wzrost i rozwój dzieci oraz młodzieży, a także na utrzymanie fizjologicznych kierunków osi ciała, co może stanowić ogromne zagrożenie dla integralności postawy ciała pod wpływem obciążania zewnętrznego, np. podczas noszenia torby lub plecaka (Janakiraman i wsp. 2017). Coraz wnikliwiej obszar eksploracji naukowej dotyka skutków oddziaływania nadmiernego obciążania zewnętrznego w postaci plecaka szkolnego na postawę ciała dziecka. Istnieje wiele dowodów potwierdzających, że sposób noszenia plecaka szkolnego ma wpływ na stan zdrowia uczniów. Obciążenia te mogą zwiększać siły reakcji podłoża, co może prowadzić do kumulacji urazów w późniejszym okresie życia, z powodu biomechanicznych adaptacji w statyce i dynamice (Alami i wsp. 2018; Barbosa i wsp. 2019; Suresh i wsp. 2019; Rashid i wsp. 2021).

W swoich badaniach Alfageme-García i wsp. (2020), oceniając wpływ ciężaru plecaka szkolnego, w ciągu trzech lat obserwacji, na rozwój obrazu stopy u dzieci z neutralnym jej kształtem, stwierdzili wprost proporcjonalny związek ryzyka rozwoju stopy z nadmierną pronacją.

Niepokojące jest zróżnicowanie rozkładu obciążenia stóp w pozycji stojącej tyłostopia i przodostopia, zarówno w statyce, jak i dynamice. Zwiększanie ciężaru plecaka powoduje wzrost dysproporcji pomiędzy naciskiem strony podeszwowej prawej i lewej stopy, przy jednoczesnym obciążeniu przodostopia i tyłostopia (Szyszka i wsp., 2020). Dodatkowo, noszenie plecaka z różnym ciężarem ma znaczące oddziaływanie na strukturę morfologiczną stopy i rozkład sił w odniesieniu do podłoża. Stwierdzono wprost proporcjonalne oddziaływanie wielkości obciążenia plecakiem szkolnym, w stosunku do sił działających w różnych obszarach stopy, zwiększając zmiany struktury stopy w kierunku jej spłaszczenia. Dociekania naukowe potwierdzają, że na biomechanikę chodu dzieci, w tym rozkład sił nacisku stóp na podłoże, w sposób znaczący wpływa nadmierne obciążenie plecakiem szkolnym (Ahmad i Barbosa 2019). Podczas nauki, w Polsce, większość uczniów korzysta z podręczników papierowych. Każdy uczeń ma jeden komplet książek i nie ma możliwości pozostawienia podręczników w szkole z powodu prac domowych i konieczności nauki do testów. W wielu szkołach uczniowie nie mają dostępu do szafek, w których mogliby zostawić książki, niepotrzebne na następny dzień lub do nauki. Ciężar plecaka dodatkowo zwiększają noszone przez uczniów przedmioty osobiste, niezwiązane z zajęciami. W badaniach Pau i wsp. (2015), dotyczących oceny wpływu noszenia plecaka na rozkłady nacisku podeszwy stopy i czasowo-przestrzenne parametry chodu u dzieci, stwierdzono znaczny wzrost (do 25%) nacisku na stronę podeszwową stopy, zarówno podczas stania, jak i chodzenia, zwłaszcza w obszarze przodostopia. Podobne wyniki otrzymali Wojtków M. i wsp. (2018). Ich badania wykazały nieprawidłową postawę ciała u ok. 42% badanych dzieci, w tym u ok. 40% dziewczynek i ok. 44% chłopców. Odnotowano również zwiększenie asymetrii obciążenia kończyn dolnych u około 65% dzieci.

Plecak o dużym ciężarze ma również wpływ na równowagę ciała. Wykazały to między innymi badania Vieira i wsp. (2016), w których autorzy ocenili, w jaki sposób noszenie plecaka wpływa na proces inicjacji chodu u uczniów szkół średnich, którzy intensywnie korzystają z plecaków. Otrzymane wyniki wykazały, że antycypacyjne korekty postawy ciała były zmniejszone i szybsze w warunkach obciążenia, a przyśrodkowo-boczne wychylenia COP były mniejsze.

Noszenie nadmiernie obciążonego plecaka, może wywoływać efekty zmęczeniowe związane z niefizjologicznym ukształtowaniem krzywizn kręgosłupa, a w konsekwencji bóle pleców na skutek zmian czynnościowych, aż po zmiany utrwalone. To z kolei pozostawia negatywne zmiany w postawie ciała młodego człowieka. Podobnie jest w przypadku równowagi ciała, gdzie ciężar plecaka stwarza zagrożenie dla jej zachowania. Uczniowie radzą sobie w tej sytuacji, utrzymując kontrolę nad równowagą poprzez dostosowanie postawy podczas stania i w ruchu. Powoduje to przeniesienie środka ciężkości ciała (Zhou i wsp. 2018). Z badań wynika, że bezpieczną wartością ciężaru plecaka jest 15% masy ciała dziecka. Zwiększenie ciężaru plecaka ma znacząco negatywny wpływ na postawę ciała (Zhou i wsp. 2018; Mosaad i Abdel-Aziem 2020).

W prezentowanych badaniach i wyciąganych na podstawie ich analizy wniosków zawartych w cyklu publikacji wskazano, że zadane obciążenie wagą plecaka, jak również w postaci długotrwałego obciążenia wysiłkiem fizycznym, wykazało istotnie statystycznie zmiany zarówno w badaniu podologicznym (rozkład nacisku stóp na podłoże), jak również posturograficznym (zmiany w stabilizacji postawy ciała).

Varga i wsp. (2020) w swoich badaniach wykazali, że wraz z wiekiem wysklepienie łuku podłużnego zwiększa się. Fizjologiczne ukształtowanie stopy w wieku przedszkolnym, ze względów morfologicznych, posiada „poduszkę" tłuszczową i do osiągnięcia wczesnego wieku szkolnego, często daje obraz stopy płaskiej. Zmiany fizjologiczne, w kolejnych etapach wzrastania, zmierzają w kierunku normalizacji wysklepienia stopy. Uważa się, że związek kształtu stopy z masą ciała, wysokością ciała czy BMI jest minimalny (Martínez-Nova i wsp. 2018). Dotychczasowe badania, nad wpływem nadmiernej masy ciała na stopę, miały zwykle charakter przekrojowy, dlatego wciąż nie jest jasne, w jaki sposób funkcja stopy zmienia się wraz ze zwiększoną masą ciała, która wzrasta w ontogenezie w sposób fizjologiczny, a często również patologiczny (Li i wsp. 2021).

Celem badań Dulaj i wsp. (2021) było określenie ilościowe parametrów morfologicznych i funkcjonalnych stopy oraz scharakteryzowanie wzorca nacisku stopy na podłoże, u dzieci rozwijających się prawidłowo i porównanie ich z naciskiem u pełnosprawnych dorosłych. Wykazano, że nacisk na śródstopie był największy w najmłodszej grupie wiekowej. Wraz z wiekiem nacisk na śródstopie zmniejszał się. W porównaniu wyników nie wystąpiły znaczące różnice między dziećmi w wieku pomiędzy 15 - 17 lat a dorosłymi. Wskazuje to, że dojrzałość szkieletowa stopy w późnym okresie dojrzewania, daje cechy funkcjonalne obserwowane u dorosłych. Istnieje coraz więcej dowodów ilościowych, dotyczących związanych z wiekiem różnic w obciążeniu podeszwowym stopy, wielosegmentowej kinematyki stopy i aktywności mięśni (Deschamps i wsp. 2021).

Przegląd literatury, dotyczący rozkładu nacisku stóp na podłoże u piłkarzy i piłkarek nożnych, który na potrzebę swoich badań przeprowadzili Husain i wsp. (2020), wykazał, że obszarem, który najczęściej posiadał najwyższy nacisk było przodostopie, co sugeruje również zwiększone ryzyko złamań kości śródstopia.

Zależność pomiędzy wynikami sportowymi a reakcją na wytrącenie z równowagi (stabilizacją posturalną) – rozumianą, jako specyficzne wzorce aktywacji mięśni, ruchów stawów i/lub ruchów kończyn, które są wywołane przez zaburzenia równowagi w celu zapobieganiu upadkom i przywracaniu równowagi nie jest jednak systematyczna, gdyż wcześniej wspomniane reakcje są odległe od tych z praktyki sportowej. Co więcej, sportowcy osiągający największe sukcesy mają bardziej wytrenowaną stabilizację posturalną w odniesieniu do sportowców na niższych poziomach rywalizacji. Wysokokwalifikowani sportowcy wykazują również lepsze naturalne predyspozycje posturalne niż sportowi amatorzy. Obecnie wiadomo, że umiejętności motoryczne mogą w dużym stopniu być zależne od stabilizacji posturalnej, podczas gdy właściwości posturalne mogą również zależeć od umiejętności motorycznych. Obie umiejętności wpływają na siebie nawzajem, ale trudno jest dokładnie określić wpływ jednej na drugą, nawet jeśli obecne założenie jest takie, że wpływ umiejętności motorycznych na predyspozycje posturalne byłby prawdopodobnie silniejszy niż wpływ odwrotny (Paillard 2019).

W rozwoju filogenetycznym człowiek uwolnił swoje kończyny górne od konieczności podpierania ciała, stając się istotą dwunożną. W rezultacie jednak stale musi dążyć do utrzymania "bezpiecznej" postawy ciała w warunkach statycznych i dynamicznych (Kruczkowski i Jaszczur-Nowicki 2015). Równowagę ciała definiuje się, jako zdolność organizmu do utrzymania stabilnej postawy ciała bez pomocy innej osoby (Mańko i wsp. 2014; Golle i wsp. 2019).

Rozstawienie stóp i ich kształt ma istotny wpływ na utrzymanie fundamentalnej dla człowieka wyprostowanej postawy ciała (Zanevskyy i Nowak 2020). Szczepanowska-Wolowiec, i wsp. (2019), w swoich badaniach zwrócili uwagę, że nawet niewielkie zaburzenia kształtu stóp mogą wpływać na cały łańcuch bio-kinematyczny, wpływając również na motorykę stopy. Co za tym idzie, zmiany strukturalne w obrębie stopy mogą upośledzać równowagę ciała w pozycji stojącej. Z kolei Hyouk Hyong i Ho Kang (2016), w przeprowadzonych badaniach, nie stwierdzili istotnych różnic w zdolności do dynamicznego utrzymywania równowagi w zależności od kształtu stopy u zdrowych studentów uczelni wyższych ze stopami prawidłowymi, pronującymi i supinującymi.

Prawidłowy rozwój kontroli postawy ciała u dzieci, ma fundamentalne znaczenie dla zapewnienia osiągnięcia przez nie pełnych możliwości psychomotorycznych (García-Soidán i wsp. 2021). Badania Libardoni i wsp. (2018), potwierdziły, że wiek był zmienną, która najlepiej wyjaśniała różnice w wynikach równowagi u dzieci w wieku od 8 do 12 lat.

Na rozwój równowagi ciała mają wpływ takie czynniki jak: zakres ruchomości w stawach, zręczność i dokładność ruchów, tempo, dynamika wykonania, itp. Ważnym czynnikiem, zwiększającym zdolność do utrzymania równowagi ciała, jest nastrój psychiczny i stan emocjonalny. Badania wykazały, że zdolności koordynacyjne (w tym równowaga, jako rodzaj zdolności koordynacyjnych), są bardziej podatne na trening w pewnych okresach rozwojowych. Wrażliwym okresem dla najlepszego rozwoju zdolności koordynacyjnych u dzieci w wieku szkolnym jest wiek około 7-12 lat (Ergash i wsp. 2020). Zdolność utrzymania równowagi ciała jest sumarycznym efektem wielu zdolności koordynacyjnych (Michnik i wsp. 2016). Badania wykazują, że dzieci aktywne mają lepszą kontrolę posturalną niż dzieci siedzące. W związku z tym, aktywność fizyczna wydaje się sprzyjać sprawniejszemu rozwojowi kontroli postawy ciała (García-Soidán i wsp. 2020). Jedną z podstawowych składowych koordynacji ruchowej jest zdolność równowagi ciała. Ta ostatnia w warunkach dynamiki odgrywa ważną rolę podczas osiągania prędkości przy zmianie kierunku biegu, a zatem jest niezbędnym składnikiem wyników w sportach zespołowych (Menezes i wsp. 2021). W badaniach Islam i Kundu (2020), zdolności fizyczne oparte na zwinności okazały się silniej skorelowane z dryblingiem. Wynika z tego, że ustalenie i egzekwowanie odpowiedniego harmonogramu treningu w celu poprawy efektywności dryblingu, będzie się przyczyniać również do poprawy koordynacji a tym samym równowagi.

Zależności pomiędzy równowagą, siłą i mocą mogą zawierać ważne informacje na różnych etapach dojrzewania, pozwalające określić priorytety treningowe. Hammami i wsp. (2016) badali związki między równowagą a siłą mięśniową i mocą u młodych sportowców płci męskiej o różnym stopniu dojrzałości. Wyniki tych badań wykazały, że związki między badanymi parametrami, które wzrastają wraz z dojrzałością, u młodych sportowców, mogą oznaczać wzajemne oddziaływanie na siebie treningu siły i mocy oraz treningu równowagi. Wieloletni trening w sporcie wyczynowym, prowadzi do adaptacji organizmu człowieka do określonego rodzaju ćwiczeń. Przykładem są wyniki badań porównawczych, dotyczące zmian adaptacyjnych po maksymalnych wysiłkach beztlenowych wśród sportowców judo i osób nietrenujących. Zmęczenie po anaerobowym teście Wingate znacznie pogorszyło wskaźniki stabilności ciała, które we wszystkich punktach czasowych były istotnie lepsze u sportowców uprawiających judo. Wyniki te sugerują specyficzność adaptacyjną organizmu człowieka u osób trenujących, między innymi w zakresie równowagi ciała (Sterkowicz i wsp. 2016).

Badanie przeprowadzone przez Olchowik i Czwalik (2020), miało na celu określenie wpływu regularnych treningów piłkarskich na układ równowagi u młodych kobiet. Przedstawione przez autorki wyniki wykazały, że regularnie trenujące piłkarki nożne mają wyższy poziom równowagi niż ich nieaktywne rówieśniczki.

4. Cel badań i pytania badawcze

4.1. Cel badań

1. Wpływ zastosowanego obciążenia zewnętrznego o różnym charakterze oddziaływania fizycznego, tj.: wielkość ciężaru plecaka szkolnego i specyfika wysiłku fizycznego na wartości rozkładu nacisku stóp na podłoże u osobników w okresie późnego dzieciństwa i wczesnej adolescencji.
2. Wpływ zastosowanego obciążenia zewnętrznego o różnym charakterze oddziaływania fizycznego, tj.: wielkość ciężaru tornistra szkolnego i specyfika wysiłku fizycznego na poziom zdolności zachowania równowagi ciała u osobników w okresie późnego dzieciństwa i wczesnej adolescencji.

4.2. Pytania badawcze

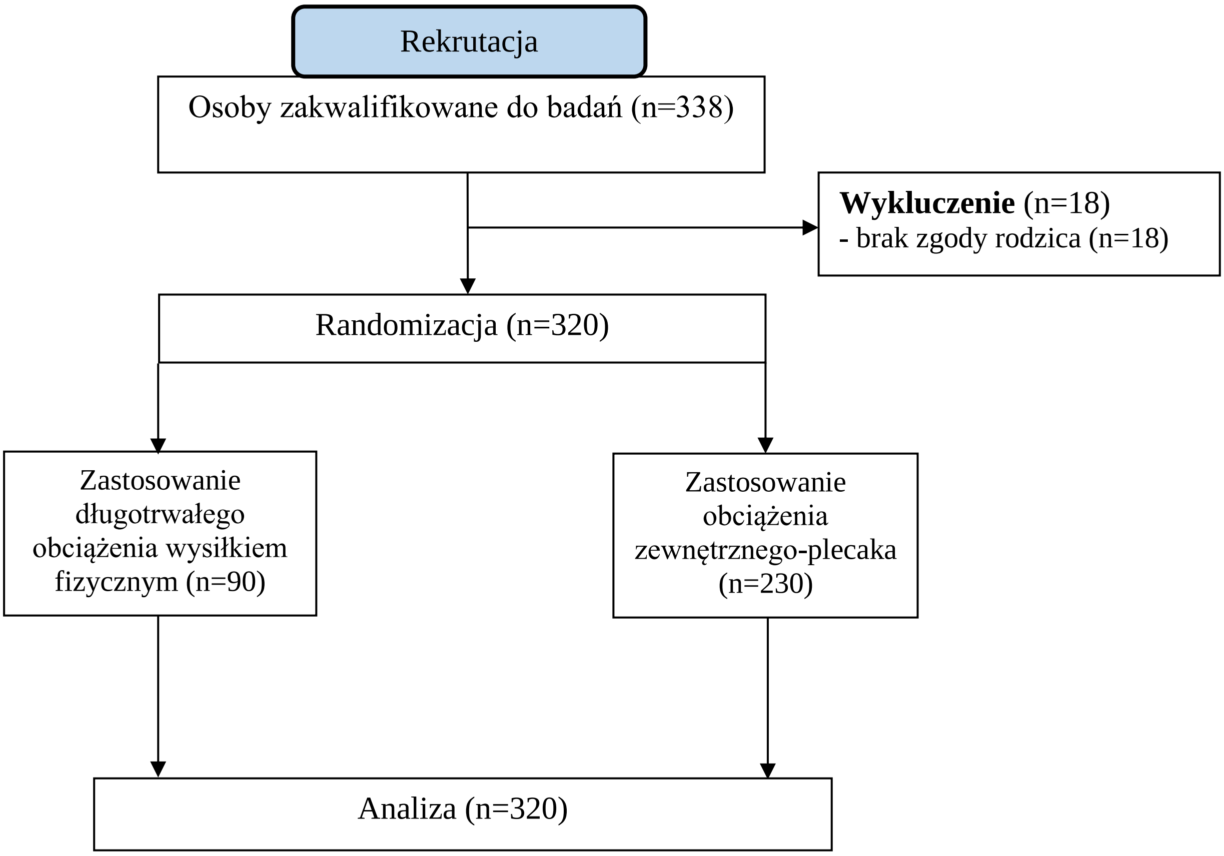
1. Jakie efekty somatyczne i motoryczne, zdiagnozowane w badaniu podologicznym w wysklepieniu łuków stopy i posturograficznym w zdolności zachowania równowagi ciała, wywołuje obciążenie zewnętrzne w postaci 5 kg plecaka szkolnego u badanych dzieci w okresie późnego dzieciństwa i wczesnej adolescencji?
2. Jakie efekty somatyczne i motoryczne, zdiagnozowane w badaniu podologicznym w wysklepieniu łuków stopy i posturograficznym w zdolności zachowania równowagi ciała, wywołuje obciążenie zwiększonym wysiłkiem fizycznym u chłopców w okresie późnego dzieciństwa i wczesnej adolescencji trenujących piłkę nożną?

5. Materiał i metody badań

Niniejsza rozprawa doktorska, została oparta o cykl powiązanych ze sobą tematycznie artykułów, opublikowanych w recenzowanych czasopismach naukowych. Wszystkie prace opisują wpływ zróżnicowanego obciążenia zewnętrznego na rozkład nacisku strony podeszwowej stopy na podłoże oraz na zdolność równowagi ciała. Badania przeprowadzono na podstawie zgody Komisji Etyki Badań Naukowych Uniwersytetu Warmińsko Mazurskiego w Olsztynie (decyzja nr 9/2018).

5.1. Osoby badane

W badaniach opublikowanych w prezentowanych pracach udział wzięło n=320, z czego n=198 to mężczyźni, a n=122 to kobiety. Badania zostały przeprowadzone wśród osób na różnym etapie rozwoju fizycznego, co zaprezentowane zostało na Rycina 1 oraz w Tabela 1.



Rycina 1. Proces rekrutacji oraz liczba uczestników badań.

Tabela 1. Charakterystyka uczestników badań

Charakterystyka	**n**	**%**
Płeć		
Kobiety	122	38
Mężczyźni	198	62
Wiek		
8-10	158	49,4
11-13	116	36,2
14-16	46	14,4
	Średnia±SD	
Wiek	10,82±2,14	
Masa ciała (kg)	38,9±13,2	
Wysokość ciała (cm)	140±13	

W badaniach do pracy ***"Distribution of feet pressure on ground and maintaining body balance among 8–10-year-old children with and without external load application"*** udział wzięło 130 losowo wybranych dzieci: 68 dziewcząt i 62 chłopców w wieku 8–10 lat. Uczestnikami badań byli uczniowie trzech gdańskich szkół publicznych. Wszyscy badani uczestniczyli w programie edukacyjno-profilaktycznym, w którym jednym z celów było kształtowanie prozdrowotnych postaw uczniów w dziedzinie prawidłowego rozwoju motoryki i postawy ciała. Średnia wieku całej grupy osób badanych wynosiła 8,9±0,8 lat, średni wiek chłopców to 9,2±0,7 lat, a dziewczynek 8,6±0,8 lat. Chłopcy byli cięższi i wyżsi niż dziewczynki, ich masa ciała wynosiła 31,13±6,5kg, a wysokość ciała 134,4±7,3cm, dziewczynek – odpowiednio: 27,8±6,0kg i 129,3±7,5cm.

W badaniach opublikowanych w pracy ***"Podiatric and stabilographic examinations of the effects of school bag carrying in children aged 11 to 15 years"*** udział wzięło 100 uczniów gdańskich szkół podstawowych, w wieku od 11 do 15 lat, w tym 54 dziewczynek i 46 chłopców. W grupie dziewcząt średnia wysokość ciała wynosiła 149cm (SD=9cm), przy średniej masie ciała 41kg (SD=8,4kg). U chłopców te parametry somatyczne wynosiły odpowiednio 152,6cm (SD=11,3cm) i 45,7kg (SD=13,2kg). Wszyscy zgłosili dobry stan zdrowia i brak kontuzji. Badania przeprowadzono na dzieciach o zwiększonej aktywności fizycznej, u których spójnym czynnikiem był wdrożony program edukacyjno-profilaktyczny, którego jednym z celów jest kształtowanie prawidłowej postawy ciała w okresie dynamicznego rozwoju motorycznego i posturalnego.

Uczestnikami badań w pracy ***“Biomechanical Aspects of the Foot Arch, Body Balance and Body Weight Composition of Boys Training Football”*** było 90 młodocianych piłkarzy z Olsztyna i Barczewa, w trzech grupach wiekowych: 8–10 lat (średni wiek 9±0,86 lat, masa ciała 33,66±8,51kg, wysokość ciała 136,03±10,31cm), 11–13 lat (średni wiek 12,55±0,63 lat, masa ciała 47,83±7,66kg, wysokość ciała 159,79±6,72cm) i 14–16 lat (średni wiek 14,30±0,46 lat, masa ciała 60,08±10,31kg, wysokość ciała 171,61±6,57cm). Wszyscy chłopcy w wieku 8–16 lat, trenujący w klubach w Olsztynie i Barczewie, którzy zostali włączeni do badań byli zawodnikami rozgrywek na szczeblu wojewódzkim lub centralnym, w ich kategorii wiekowej. Badani chłopcy brali udział w treningach trzy razy w tygodniu.

5.2. Metody badań

W pracy nr 3 do wykonania analizy składu ciała użyte zostało urządzenie InBody 270. Jest to urządzenie wykorzystuje impedancję elektryczną o częstotliwości 20, 100 kHz i natężenie prądu 200 µA. Wykonanie pomiarów możliwe jest dzięki 8-punktowemu tetrapolarnemu systemowi elektrod dotykowych (2 elektrody na lewą stopę, 2 dla prawej, 2 dla lewej ręki i 2 dla prawej). Przed rozpoczęciem badania osoba wykwalifikowana wprowadziła do programu dane osoby testowej, takie jak ID, data urodzenia i wysokość ciała, która została sprawdzona przez badacza przy pomocy wzrostomierza Soehnle (Soehnle, Gaildorfer Straße 6, 71522 Backnang, Niemcy). Następnie, każdy uczestnik, ubrany w strój sportowy (koszulka i spodenki) z nagimi stopami, wchodził na matę analizatora, tak aby stopy pokryły jak najwięcej elektrod. Urządzenie automatycznie uruchomiało pomiar masy ciała. Po zakończeniu pomiaru osoba badana chwytała rączki urządzenia w dłonie, z kciukiem dotykającym górnej elektrody, a pozostałe palce dolnej elektrody. Uczestnik był proszony o odsunięcie wyprostowanych rąk od ciała, aby nie dotykać tułowia, ponieważ mogłoby to wpłynąć na wyniki. Szczególną uwagę zwracano, aby stopy i dłonie przylegały podczas badania, do elektrod. W celu uniknięcia błędów, testy zostały przeprowadzone zgodnie z procedurą załączoną przez producenta w instrukcji urządzenia. Po zakończeniu testu dane były automatycznie wysyłane do programu Lookin'Body 120.

W pracach nr 1 i nr 2 wartości masy i wysokości ciała, zostały spisane z aktualnych badań lekarskich osób biorących udział w badaniach.

Głównym urządzeniem do wykonania badań do wszystkich prac przedstawionych w niniejszej pracy była mata pedobarograficzna E.P.S./R1 z 2304 czujnikami ciśnienia umieszczonymi na powierzchni aktywnej (Letsens Grupa Letsens S.R.L. Via Buozzi, CastelMaggiore, Bolonia, Włochy). Mata została użyta do pomiaru procentowego rozkład nacisku podeszwowej strony stopy na podłoże i równowagę ciała. W celu zebrania danych do analiz, każdy uczestnik został anonimowo zarejestrowany w oprogramowaniu Biomech Studio (Biomech Studio 2.0, Letsens Group, Letsens SRL Via Buozzi, CastelMaggiore, Bolonia, Włochy) wraz z następującymi danymi: kod uczestnika, data urodzenia, płeć, masa ciała i wysokość ciała, mierzone przez badacza za pomocą wzrostomierza Soehnle. Mata była umieszczona na podłodze i połączona za pomocą kabla USB do komputera. Rozmiar maty wynosi 700mm x 500mm x 5mm. Czujniki umieszczone w macie zbierały dane przez 20s i automatycznie przesyłały je do komputera za pomocą programu Biomech Studio. Badanie to polegało na wejściu ubranego w strój sportowy (koszulka i spodenki) z nagimi stopami uczestnika, na matę pedobarograficzną, tak aby stopy znajdowały się po obu stronach pionowej linii, narysowanej na macie. W ramach przygotowania do badania uczestnicy byli poproszeni o wykonanie kilku kroków, aby swobodnie ułożyć stopy na macie. Badany stał boso, wyprostowany, z rękami przy ciele, w naturalnej pozycji, patrząc prosto przed siebie, na ustalony punkt na wysokości oczu. W tym czasie dokonano pomiarów i przenoszono je do systemu komputerowego.

Formą obciążenia zewnętrznego w pracach ***"Distribution of feet pressure on ground and maintaining body balance among 8–10-year-old children with and without external load application"*** oraz ***"Podiatric and stabilographic examinations of the effects of school bag carrying in children aged 11 to 15 years"*** był 5 kilogramowy plecak. Jego waga została określona na podstawie średniej z 20 losowo wybranych plecaków. Ubrane w strój sportowy (koszulka i spodenki) i nagimi stopami, badane dziecko wchodziło na matę pedobarograficzną w celu wykonania pomiaru, bez obciążenia zewnętrznego. Po zakończeniu pierwszego badania dziecko zakładało plecak o wadze 5 kg, poluzowywano paski regulacyjne plecaka, a uczestników poproszono o wyregulowanie ich w taki sposób, w jaki zazwyczaj dobierają długość w swoich plecakach. Następnie powtórzono procedurę na macie pedobarograficznej.

Praca **"*Biomechanical Aspects of the Foot Arch, Body Balance and Body Weight Composition of Boys Training Football"*** skupiała się na ocenie zmian fizycznych aspektów układu mięśniowo-szkieletowego, związanych z budową stopy i zdolnością do utrzymania równowagi ciała, młodych piłkarzy nożnych, pod wpływem obciążenia wysiłkiem fizycznym, wynikającego z regularnego procesu treningowego. Po przeprowadzeniu analizy składu ciała, uczestnicy badania stawali na matę pedobarograficzną. W trakcie obu badań, każdy uczestnik ubrany był w strój sportowy (koszulka i spodenki) z nagimi stopami. Zmiany wysklepienia badane były w różnych grupach trenujących piłkarzy.

5.3. Metody analizy statystycznej

Procedurę statystyczną przeprowadzano w programie Statistica 13.0 (Statsoft, Kraków). Analizę każdorazowo rozpoczynano od sprawdzenia normalności rozkładu zmiennej losowej poprzez wykonanie Testu Shapiro-Wilka. We wszystkich badaniach dane miały charakter nieparametryczny, w związku z tym zastosowano odpowiednio:

- W pracy nr 1 - test Manna–Whitneya–Wilcoxona (również znany, jako test Manna-Whitneya lub czasami test sumy rang Wilcoxona dla dwóch próbek lub po prostu test Wilcoxona dla dwóch próbek).
- W pracy nr 2 - test Manna–Whitneya–Wilcoxona (również znany, jako test Manna-Whitneya lub czasami test sumy rang Wilcoxona dla dwóch próbek lub po prostu test Wilcoxona dla dwóch próbek). Dodatkowo obliczono wielkość efektu Cohena.
- W pracy nr 3 - test rang Kruskala-Wallisa oraz test dwustronny z poprawką Bonferroniego. Do analizy zależności wykorzystano test Chi-kwadrat oraz test korelacji rang Spearmana.

We wszystkich pracach dla charakterystyki statystyki opisowej, użyto średnie miary wartości, medianę i rozrzut pomiaru wartości (kwartyle). Poziom istotności w badaniach ustalono na $p<0.05$.

6. Wyniki

6.1. Wyniki analizy opublikowanej w pracy: "*Distribution of feet pressure on ground and maintaining body balance among 8–10-year-old children with and without external load application*"

Analizując różnice pomiędzy pomiarami stanu spoczynku a pomiarami obciążenia plecakiem, wśród ogółu badanej grupy dziewcząt i chłopców, stwierdzono istotne zróżnicowanie w zakresie wszystkich obszarów stopy lewej (przodostopie p=0.008, śródstopie p=0.000 i pięta p=0.002) oraz dla przodostopia (p=0.024) i śródstopia (p=0.000) stopy prawej. Badanie stabiliograficzne w badanej populacji wykazało różnice istotne statystycznie dla parametrów cop-bars - powierzchnia wychwiań ciężkości ciała (p=0.003), l-bars - wychwiania lewej stopy (p=0.034) oraz cop-lsf – stosunek odległości między skrajnymi wychwianiami do powierzchni wychwiań (p=0.000).

6.2. Wyniki analizy opublikowanej w pracy: "*Podiatric and stabilographic examinations of the effects of school bag carrying in children aged 11 to 15 years*"

Pomiary spoczynkowe badanej populacji dziewcząt i chłopców, uwzględniające parametry fizyczne obu stóp, wykazały w wartościach średnich znaczne wydrążenie łuku podłużnego stopy. Margines istotnego wysklepienia dla okolicy śródstopia wynosi od 0 do 7%. Średnia wartość całej populacji wyniosła 6,6% dla stopy lewej i 6,8% dla stopy prawej. Po obciążeniu plecakiem, o wadze 5 kg wzrósł i zmienił się zakres dla obu stóp, odpowiadający średniemu wysklepieniu podłużnego łuku stopy (od 7 do 14%). Mediana wynosiła 10,1% dla stopy lewej i 9,9% dla stopy prawej. Analiza istotności statystycznej różnic w wielkości wysklepienia podłużnego stóp, w badanej populacji dziewcząt i chłopców w wieku 11-15 lat, wykazała różnice statystycznie istotne w wysklepieniu łuku podłużnego zarówno w lewej, jak i w prawej stopie. W badaniu stabilograficznym istotne statystycznie na poziomie p=0.020, okazały się jedynie wartości wychwiań lewej stopy (l-bars) w populacji dziewcząt. Pozostałe parametry w badanych grupach nie wykazały różnic statystycznie istotnych.

6.3. Wyniki analizy opublikowanej w pracy: "*Biomechanical Aspects of the Foot Arch, Body Balance and Body Weight Composition of Boys Training Football*"

W trakcie analizy zauważono różnice w wielkości łuków stopy, dla każdej z badanych grup młodych piłkarzy. Średnie wartości nacisku na śródstopie w grupie chłopców w wieku 8-10 lat wskazywały na znaczne wydrążenie obu stóp. Dla stopy lewej wartość powierzchni nacisku na śródstopie wynosiła zaledwie 0,1%, a w stopie prawej 0,8%. Biorąc pod uwagę wartości średnie, dla grupy chłopców w wieku 11-13 lat, stopa lewa była istotnie wydrążona (0,4%), natomiast stopa prawa mieściła się w przedziale średniego wydrążenia (9,8%). Wyniki najstarszej grupy chłopców w wieku 14-16 lat, były najwyższe dla stopy lewej, lokując wartość w przedziale średniego wysklepienia (12,9%), a dla stopy prawej w przedziale znacznego wysklepienia (2,3%). Analizując wyniki badania stabilograficznego, stwierdzono istotne różnice w wielkości wszystkich parametrów określających pole wychwiań pozycji całego ciała oraz obszaru wychwiań dla stopy lewej i prawej. Biorąc pod uwagę sumaryczny parametr, centrum nacisku całego ciała (cop-bars), w grupie najmłodszych piłkarzy w wieku 8-10 lat (360,62mm^2) wykazał najmniejszą stabilność. W kolejnych grupach chłopców obserwowano wzrost stabilizacji postawy ciała, gdzie w grupie chłopców w wieku 11-13 lat, wielkość powierzchni dla całego ciała (cop-bars) wynosiła 197,84mm^2, natomiast w grupie najstarszej, w wieku 14-16 lat, średnia wartość wynosiła 37,76mm^2. Uzyskane wyniki poddano ocenie statystycznej. W badaniu podologicznym pomiędzy grupami chłopców, zakwalifikowanych do poszczególnych grup wiekowych, nie stwierdzono różnic istotnych statystycznie, jedynie w obszarze przodostopia stopy lewej. Najbardziej istotne różnice zaobserwowano dla śródstopia (p=0.000) i pięty (p=0.001) w stopie lewej. W zakresie śródstopia, odnotowano istotne różnice pomiędzy wszystkimi badanymi grupami młodych piłkarzy. Odnosząc się do wyników oceny różnic statystycznych w badaniu stabilograficznym, istotne różnice odnotowano dla wszystkich parametrów (p=0.000).

7. Wnioski

1. Intensyfikacja wzrastania morfo-funkcjonalnego dziewcząt i chłopców na etapie rozwoju wieku szkolnego i wczesnej adolescencji jest szczególnie wrażliwa na zewnętrzne obciążenia fizyczne. Takim obciążeniem jest nadmierny ciężar plecaka szkolnego noszonego przez uczniów. Jak wynikało z przeprowadzonych badań, możliwy przeciążeniowy wzorzec ruchu, przejawiający się w statycznych efektach postawy ciała, może być czynnikiem sprzyjającym nabywaniu i utrwalaniu nieprawidłowości wad postawy ciała w obrębie stopy w kierunku jej spłaszczenia. Zapewnienie im bezpiecznego i zdrowego środowiska może zmniejszyć ich podatność na urazy, przewlekłe schorzenia i ich powikłania. Plecaki i przybory szkolne są noszone przez dzieci w różny sposób, dlatego ich ciężar i sposób noszenia przez uczniów, powinny być traktowane, jako ważne zagadnienie do dalszego wnioskowania ergonomicznego.
2. Najbardziej istotnym spostrzeżeniem na podstawie analizy wyników przeprowadzonych badań było ujawnienie istotnego zmniejszenia wysklepienia podłużnego stopy w badanej populacji dziewcząt i chłopców po obciążeniu pięciokilogramowym plecakiem. Różnice istotne statystycznie w ocenie wysklepienia stopy lewej charakteryzowały całość badanej populacji oraz oddzielnie w grupie badanych dziewcząt i chłopców. Zastosowane obciążenie plecakiem szkolnym uczniów poddanych badaniu, ujawniło u nich zwiększenie wartości pomiarowych obszaru śródstopia w kierunku jego spłaszczenia. Powyższe spostrzeżenie sprowadza się do stwierdzenia znacząco negatywnego wpływu codziennego obciążania plecakiem dzieci w wieku szkolnym przez co rekomenduje się zmianę proporcji środków dydaktycznych analogowych w kierunku korzystania z technologii informatycznej.
3. Ocena zdolności stabilizacyjnych postawy ciała nie wykazała tak jednoznacznych i jednorodnych wartości dla populacji badanych dziewcząt i chłopców, jak w przypadku morfo-funkcjonalnych zmian w obrębie wysklepienia stopy. Jedynym wskaźnikiem, który ujawnił różnice istotne statystycznie pomiędzy wartościami pomiarowymi w warunkach spoczynkowych i po obciążeniu pięciokilogramowym plecakiem szkolnym, była wielkość pola powierzchni wychwiań (r-bars) w przypadku kończyny dolnej prawej w populacji badanych dziewcząt. Ponownie, dalszych dociekań badawczych, należałoby poszukiwać w stronności ciała, w tym kończyny dolnej w aspekcie funkcjonalnym, przyjętej roli podporowej lub określonej funkcji powiązanej z jej użytecznością.
4. Efekty oddziaływania zwiększonej aktywności fizycznej związaniem z treningiem piłkarskim ukazała znaczący wpływ na wielkość wydrążenia stopy w kierunku jej spłaszczenia, wprost

proporcjonalnie do wieku badanych. Różnice uwidaczniają się rozpatrując wysklepienie rozłącznie dla stopy lewej i prawej. Jeżeli w stopie lewej tendencja ta jest utrzymana, to w stopie prawej nie przyjmuje tak zdecydowanego kierunku. W kolejnych badaniach należałoby włączyć kryterium stronności, które być może leży u podstaw ujawnionej różnicy.

5. Człowiek w wieku szkolnym i wczesnej adolescencji podlega dynamicznym zmianom morfo-funkcjonalnym w tym związanym ze zdolnością do zachowania równowagi ciała. Badani chłopcy, poddani rygorom treningu piłkarskiego w sposób znaczący zwiększali zdolność stabilizacji ciała wprost proporcjonalnie do wieku. Jednocześnie zaobserwowano stopniowe zmniejszanie dyspersji wyników pomiarowych w kolejnych grupach co może świadczyć o indywidualnym tempie rozwoju w zakresie zdolności równowagi ciała bez względu na oddziaływanie środowiska.

8. Wnioski aplikacyjne

1. Organizacja kształcenia w szkole nie może pozostawać i nie pozostaje obojętna na zapewnienie bezpiecznego i zdrowego środowiska uczniom. Istnieje konieczność przestrzegania korzystania z możliwości przechowywania podręczników i przyborów w szkole. Istnieje możliwość i konieczność powszechnego korzystania z podręczników w formie on-line. Wszystko to pozwoli na likwidację nadmiernego obciążania plecaka szkolnego a w konsekwencji na zmniejszenie podatności na urazy, przewlekłe schorzenia i ich powikłania. Ergonomiczność noszenia plecaków szkolnych to wartość dodana w dążeniu do rozwoju zdrowej postawy ciała dzieci i młodzieży
2. Ujawniona stronność dominacji kończyny podporowej w badaniu podologicznym dla lewej kończyny dolnej i badaniu stabilograficznym dla prawej kończyny dolnej, mogą wyjaśniać patogenezę zmian skoliotycznych w postawie ciała badanych dzieci. W związku z powyższym istotnym aspektem w działaniach korekcyjno-kompensacyjnych jest konieczność oddziaływania asymetrycznego w ćwiczeniach z obciążeniem zewnętrznym, jak również podczas stosowania ćwiczeń kształtujących koordynacyjną stronę motoryczności w aspekcie globalnym.

9. Piśmiennictwo

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10.Streszczenie

Wprowadzenie: Mając na uwadze prawidłowy rozwój młodego człowieka w okresie późnego dzieciństwa i wczesnej adolescencji, zagadnienie wielkości i kierunku zmian somatycznych w ukształtowaniu stopy i motorycznych w równowadze ciała pod wpływem zewnętrznego obciążenia i aktywności sportowej pozostaje wciąż aktualne. Dostrzegając coraz bardziej sedenteryjny styl życia współczesnego człowieka, dodatkowe obciążenia układu kostno-stawowego i mięśniowego, mogą zwiększać ryzyko zmian patologicznych.

Cel badań: Wpływ zastosowanego obciążenia zewnętrznego o różnym charakterze oddziaływania fizycznego, tj.: wielkość ciężaru plecaka szkolnego i specyfika wysiłku fizycznego na wartości rozkładu nacisku stóp na podłoże i równowagę ciała u osobników w okresie późnego dzieciństwa i wczesnej adolescencji.

Materiał badawczy: W opublikowanych, prezentowanych pracach udział wzięło 320 osobników (mężczyźni n=198, kobiety n=122).

Wyniki: Dla oceny wielkości zmian w ukształtowaniu stopy i poziomu przejawiania zdolności równowagi ciała zastosowano nowoczesną aparaturę pomiarową używaną dla celów diagnostycznych w badaniach ortopedycznych. Rozkład nacisku stóp na podłoże i równowagę ciała oceniano przy pomocy maty pedobarograficznej E.P.S./R1 z 2304 czujnikami ciśnienia umieszczonymi na powierzchni aktywnej. W wyniku analizy zebranego materiału badawczego obciążenie ciężarem plecaka szkolnego badanych uczniów ujawniło istotne zmniejszenie wysklepienia podłużnego stopy. Różnice istotne statystycznie w ocenie wysklepienia stopy lewej charakteryzowały całość badanej populacji oraz oddzielnie w grupie badanych dziewcząt i chłopców. Ocena zdolności stabilizacyjnych postawy ciała nie wykazała tak jednoznacznych i jednorodnych wartości, jak w przypadku morfo-funkcjonalnych zmian w obrębie wysklepienia stopy. Efekty oddziaływania zwiększonej aktywności fizycznej związane z treningiem piłkarskim ukazały znaczący wpływ na wielkość wydrążenia stopy w kierunku jej spłaszczenia, wprost proporcjonalnie do wieku badanych. Różnice uwidaczniają się rozpatrując wysklepienie rozłącznie dla stopy lewej i prawej. Badani chłopcy, poddani rygorom treningu piłkarskiego w sposób znaczący zwiększali zdolność stabilizacji ciała wprost proporcjonalnie do wieku. Jednocześnie zaobserwowano stopniowe zmniejszanie dyspersji wyników pomiarowych w kolejnych grupach co może świadczyć o indywidualnym tempie rozwoju w zakresie zdolności równowagi ciała bez względu na oddziaływanie środowiska.

Wnioski: Wyniki badań wskazują ergonomię noszenia plecaków szkolnych, jako wartość dodaną w dążeniu do rozwoju zdrowej postawy ciała dzieci i młodzieży. Jednocześnie ujawniona stronność dominacji kończyny podporowej w badaniu podologicznym dla lewej kończyny dolnej i badaniu stabilograficznym dla prawej kończyny dolnej, mogą wyjaśniać patogenezę zmian skoliotycznych w postawie ciała badanych dzieci.
Słowa kluczowe: wysklepienie stopy, opór zewnętrzny, równowaga ciała, aktywność sportowa, późne dzieciństwo, adolescencja

11.Summary

Introduction: The magnitude and direction of somatic changes in foot shape and motor changes in postural balance under the influence of external load and sports activity are very important considerations that affect healthy growth and development in late childhood and early adolescence. Due to an increasingly sedentary lifestyle of the modern population, additional external load on the musculoskeletal system can increase the risk of pathological changes.

Objective: The study was undertaken to analyze the effect of various external loads (weight of the school backpack) and physical activity on plantar force distribution and postural balance in school students during late childhood and early adolescence.

Materials and Methods: The study was performed in a group of 320 individuals (male n=198, female n=122).

Results: The magnitude of changes in foot shape and postural stability was analyzed with the use of modern measuring equipment used for diagnostic purposes in orthopedic examinations. Plantar force distribution and postural balance were evaluated with the EPS/R1 baropodometric plate with 2304 pressure sensors placed on the active surface. The results of the study indicate that the load exerted by the school backpack led to significant flattening of the longitudinal arch of the foot in the examined children. Significant differences in the arch of the left foot were observed in the entire population as well as in the groups of the examined female and male students. An evaluation of postural stability did not reveal equally definitive and unambiguous changes to those noted in the analysis of morphofunctional changes in the arch of the foot. Higher levels of physical activity associated with soccer training significantly contributed to the flattening of the foot arch, and the observed changes were directly proportional to the subjects' age. Differences in foot arch deformation were found when the right foot and the left foot were analyzed separately. In boys who played soccer, postural stability improved directly proportionally to age. At the same time, the dispersion of the measured values decreased gradually in successive age groups, which could suggest that postural stability develops independently of environmental impacts.

Conclusions: The study demonstrated that school backpack ergonomics is an added value that promotes healthy postural development in children and adolescents. Left-sided lower limb preference in the podological examination and right-sided lower limb preference in the posturography test could explain the pathogenesis of scoliosis in the analyzed population.

Keywords: foot arch, external resistance, postural balance, sports activity, late childhood, adolescence

12. Załączniki

- Oświadczenia autorów
- Praca nr 1: "Distribution of feet pressure on ground and maintaining body balance among 8–10-year-old children with and without external load application"
- Praca nr 2: "Podiatric and stabilographic examinations of the effects of school bag carrying in children aged 11 to 15 years"
- Praca nr 3: "Biomechanical Aspects of the Foot Arch, Body Balance and Body Weight Composition of Boys Training Football"

Oświadczenie współautorów publikacji

Jaszczur-Nowicki J., Bukowska J., M., Kruczkowski D., Pieniążek M., Mańko G., Spieszny M., (2020). Distribution of feet pressure on ground and maintaining body balance among 8–10-year-old children with and without external load application. *Acta of Bioengineering and Biomechanics*, 22(4): 1-14 https://doi.org/10.37190/abb-01696-2020-02

Niniejszym oświadczamy, że indywidualny wkład w powstanie ww publikacji jest następujący:

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* **A** – przygotowanie projektu badania, **B** – przeprowadzanie badań, **C** – analiza statystyczna, **D** – interpretacja wyników, **E** – przygotowanie publikacji, **F** – opracowanie piśmiennictwa, **G** – pozyskanie funduszy

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Bukowska J., M., Jekiełek M., Kruczkowski D., Ambroży T., Jaszczur-Nowicki J., (2021). Biomechanical Aspects of the Foot Arch, Body Balance and Body Weight Composition of Boys Training Football**.** *International Journal of Environmental Research and Public Health*, 18(9): 5017. https://doi.org/10.3390/ijerph18095017

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Distribution of feet pressure on ground and maintaining body balance among 8–10-year-old children with and without external load application

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Purpose: The aim of this study was to analyse the impact of applying an external load on the distribution of pressure on the plantar side of the foot and maintaining body balance, using the podobarographic platform. *Methods*: The study was conducted on 130 school children aged 8–10: girls (n = 68, body mass = 22.8 ± 6.0 kg, body height = 129.3 ± 7.5 cm) and boys (n = 62, body mass = 31.1 ± 6.5 kg, body height 134.4 ± 7.3 cm). The study involved 2 trials. At first, children stood on the platform assuming a natural position. Then, they put on a 5-kg backpack and stood on the platform once more. *Results*: The results indicate that after backpack loading, for the total research group of girls and boys, statistically significant differences were found in the distribution of foot force on the ground in the left forefoot (p = 0.008), metatarsus (p = 0.000) and heel areas (p = 0.002). While in the right foot, these differences were noted for the forefoot (p = 0.024) and metatarsus (p = 0.000). The results of balance testing were also statistically significant. They concerned measurements of the body barycentre area (cop-bars p = 0.003), the barycentre area of the left foot (l-bars p = 0.034) and the parameter comparing distance to surface ratio (cop-lsf p = 0.000). *Conclusions*: It may be concluded that prolonged overloading with backpacks affects movement patterns, which may further lead to the acquisition and consolidation of postural defects.

Key words: *foot, ground pressure, body balance, children, backpack*

1. Introduction

School is an important social institution that covers about 20% of active members of society. Many authors indicate that overloaded backpacks can lead to the development of back pain and other injuries of the musculoskeletal system among children and adolescents [7]. School children are teenagers who experience a period of accelerated growth and development of the skeletal and soft tissues. Their spinal structures are therefore different than adults', they are more susceptible to disorders resulting from external factors. Moreover, external forces, such as load transfer, can also affect the growth, development and maintenance of positioning the human body [22]. The non-standard weight of a backpack increases the frequency of lowering the arms, which further leads to kyphosis and lordosis in primary school students. This is a threat to the physical health of our future society. Therefore, parents, teachers and health care professionals should provide students with the training necessary to safely carry bags and backpacks [24].

In the existing subject-literature, studies based on epidemiological, physiological and biomechanical approaches, in which it is confirmed that backpacks

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weighing 10–15% of body mass constitute a justified upper limit, can be found. The very development of improper posture and its control is associated with abnormal sensory sensations, lack of proper postural tension or correct posture and movement patterns, as well as with incorrect mutual innervation. It disrupts the central stabilisation of a child's body and their posture structure [4]. The child's dimensions, mass and proportions change during ontogenesis, shaping of muscles and movement pattern. Locomotion is the result of coordinated actions of about 10 muscles involving various joints. The lower limbs and other parts of the body, through constant repetition of specific coordination patterns between them, cause gait to be a cyclical physical activity [5].

The human foot is an significant static-dynamic part of the musculoskeletal system. On the one hand, it is a supporting element, and in static conditions, it allows the body to maintain balance in space, while on the other, it is a driving mechanism that provides the body with propulsion during movement. Therefore, the foot, thanks to its specific design, absorbs shocks arising during locomotive movements, protecting the nervous system, spine and internal organs against micro-injuries resulting from everyday activities. Analysis of the existing literature shows that already at the end of the 1st year of life, when the child begins to load their feet, dynamic development of the longitudinal arch occurs [12].

In stabiliographic research from 2010 [21], significant relationships were demonstrated between postural defects found in the sagittal plane and the average foot load point. Stabilography is one of the most common methods for assessing posture stability, defined as the ability to maintain balance. It involves analysing the resulting ground reaction forces caused by feet pressure while standing. The way of maintaining balance is evidence of the ability to maintain motor coordination [11]. Balance may be shaped according to age because there is a strong correlation between this variable and balance results. In older children, body mass and height may partially affect balance. Age-related changes in balance control may be associated with the development of the visual, vestibular and somatosensory systems [10].

In foot diagnostics, traditional methods can be distinguished: orthopaedic – based on foot examination and foot fitness tests, anthropometric methods – based on length, height, width and circumference measurements, and plantoconturographic methods – most frequently based on ink prints. Computed tomography and magnetic resonance imaging are also used in foot examinations, however, the most common electronic print is the plantar surface of the foot, but more and more often, various types of podobarographic platforms are being used to conduct this type of testing [8]. Balance evaluation can be performed by static stabilisation, which deals with the registration of involuntary changes in the location of the resultant pressure forces on the posture plane of a person standing freely on a stabilographic platform. As a result of registration, the trajectory of this point is obtained (in the literature, this point is called COP – centre of pressure). Modern technologies make it possible to examine the distribution of forces on the plantar side of the foot and stabilographic examination in 1 trial using a podobarographic mat [9]. Such a mat was used in this study.

The aim of the study was to determine the impact of external load on foot force distribution on the ground among 8–10-year-old girls and boys. Assessment of the maintenance of body balance by the subjects was also the objective of the study. Conducting such an analysis was possible by identifying the differences in the distribution of forces in the various areas of the foot affecting the surface and maintaining the balance of the body in children with and without a school backpack load.

2. Materials and methods

The research included 130 randomly selected kids: 68 girls and 62 boys aged 8–10. The children participating in the research were students of three Gdańsk public schools and they participated in an educational and preventive program, in which one of the goals was to shape pro-health attitudes of students in the field of proper development of motor skills and body posture. The average age of the entire group being surveyed is 8.9 ± 0.8 years, the average age of boys is 9.2 ± 0.7 years and the girls – 8.6 ± 0.8 years. The boys were heavier and taller than the girls, their weight was 31.13 ± 6.5 kg and body height was 134.4 ± 7.3 cm, girls – respectively: 27.8 ± 6.0 kg and 129.3 ± 7.5 cm. Parents and the school management gave their written consent to the participation of children in the study. The research was conducted on the basis of the consent of the Commission for Ethics of Scientific Research of the University of Warmia and Mazury in Olsztyn (*Decision No. 9/2018*).

For testing, the E.P.S. R1 podobarorographic mat (Letsens Group, Letsens S.R.L. Via Buozzi, Castel-Maggiore; Italy) was used. This is a diagnostic device used for assessing foot defects in static and dynamic conditions. It enables the researchers to examine the distribution of foot forces on the surface and body balance. The mat is equipped with sensors that collect measurements for 20 seconds and transfer them to a computer using the Biomech Studio program (Biomech Studio 2.0 manual).

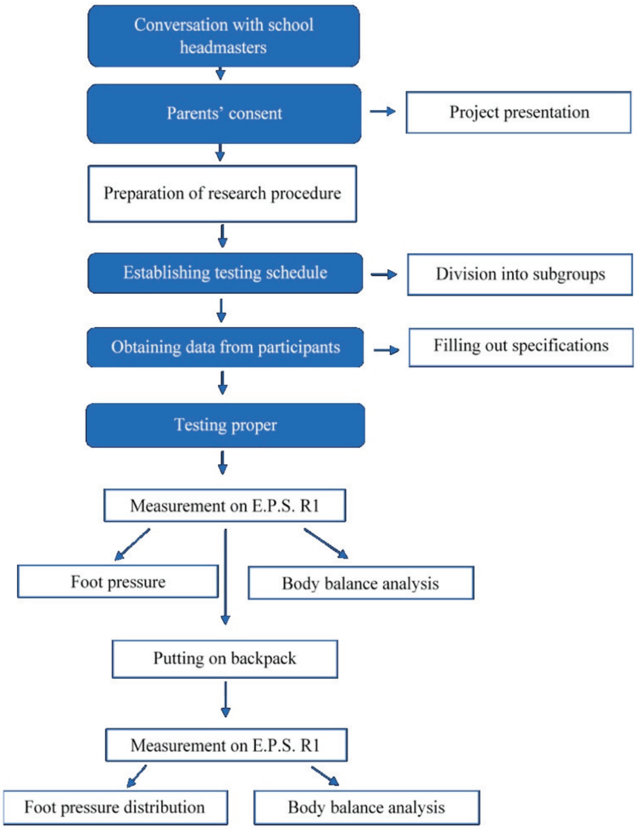

Fig. 1. Schematic of research procedure

The analyses were carried out in May 2019 in Gdańsk. Measurements were taken in the morning hours (10.00–12.00). The test pattern is illustrated in detail in Fig. 1.

Statistical Analysis

The Statistica 13.0 program was used for statistical calculations. The Mann–Whitney–Wilcoxon test (also known as the Mann–Whitney test or sometimes the Wilcoxon Rank Sum Test for two samples, or simply the Wilcoxon test for two samples). Due to the absence of normal distribution of the measurement results in the research group, the non-parametric test function was used. Therefore, non-parametric statistical functions were used in further analysis and inference. The median was applied as the main measure of average study sample value, and quartile 1 and 3 for threshold dispersion. For the purposes of analysing the statistical significance of differences between the results of measurements during rest and after loading with a 5-kg backpack for girls and boys, the Wilcoxon test was used, while for differences in the results of observation between both study sample, the Mann–Whitney *U*-test was applied.

3. Results

Descriptive statistics of foot parameters in resting conditions for girls and boys indicate a similar load on the forefoot and heel within 43–47% (Table 1). The average value in both samples allows to notice a slightly

Table 1. Significance of differences between measurements at rest and with backpack load for podological test for both study samples

Foot area [%]	Left foot						Right foot					
	Forefoot rest	Forefoot load	Metatarsus rest	Metatarsus load	Heel rest	Heel load	Forefoot rest	Forefoot load	Metatarsus rest	Metatarsus load	Heel rest	Heel load
girls (n = 68)												
Me	45.8	44.5	4.5	9.3	44.4	41.6	49.5	47.3	8.1	13.5	39.3	38.2
Q_1	40.2	40.3	1.7	2.9	38.7	38.1	45.3	42.1	1.8	3.4	34.3	33.7
Q_3	51.5	50.7	13.9	20.7	51.3	47.5	56.2	53.1	19.2	22.7	43.1	44.3
p	0.040		0.000		0.060		0.007		0.002		0.917	
boys (n = 62)												
Me	47.3	46.1	5.6	11.1	43.4	42.3	50.2	49.9	6.6	9.8	39.6	38.1
Q_1	42.6	41.5	2.1	4.1	38.3	36.8	44.9	44.7	2.2	4.4	36.0	34.5
Q_3	53.0	52.0	17.8	19.6	49.3	46.0	54.9	55.9	17.2	17.9	43.8	41.2
p	0.081		0.001		0.014		0.842		0.019		0.049	

Legend: Me – the middle average of a sample, Q_1, Q_3 – extreme quartiles, p – statistical significance.

higher load on the forefoot by approx. 4% in boys and 1.5% in girls. The average pressure on the metatarsus in both research groups, depending on the left or right foot, was about 4.5–8.0%.

Analysing the differences between resting state and backpack load measurements among the total group of girls and boys being studied, significant differentiation was noted regarding all areas of the left foot (forefoot, metatarsus and heel) and for the forefoot and metatarsus of the right foot (Table 1). When analysing statistical differences between the values for the groups of girls and boys, no significant results were recorded both at rest or after loading ($p \geq 0.05$). Subjecting the differences between resting measurements and after backpack loading to statistical analysis, a number significant differences were noted (Table 1). In the research group of girls, significant differences were noted for the forefoot and metatarsus in both feet, while among the examined boys, for the metatarsal and heel areas.

Similarly as in the case of podological examination, subjecting the results of posturographic examination to mathematical analysis, significant dispersion of the measured values was noted. The values of dispersion measures ranged from a several dozen to 340% as in the case of the left foot deflection area (l-bars). No features of normal distribution were found for selected parameters, therefore, nonparametric functions were used in statistical proceedings.

When assessing the average values of posturographic test parameters in resting conditions and after loading, for the group of girls, differences were found allowing to state the existence of load impact on the values of body posture deflection (Table 2).

A particular increase in the measured values was observed for the parameters specifying the values of deflection areas for cop-bars – total posture, r-bars – left foot and l-bars – right foot (by 96, 132 and 211 mm^2, respectively). A similar analysis was conducted in the group of boys (Table 3). In this case, the differences in the average measured values of all parameters were not significant. For the parameters of deflection surface areas, they totalled: cop-bars = 4.7, r-bars = 4.7 and l-bars = 11.8. The average value of the parameter, which is the ratio of the extreme deflection distances to the total area in both groups, showed differences of 72–75%.

Conducting statistical assessment of the differences between values of posturographic examination parameters at rest and after loading among the group of girls, significant differences were noted for the majority (Table 3). These regarded cop-bars, r-bars and l-bars as well as the parameter of the distance to surface area (cop-lsf). Similar assessment in the boys' group revealed significant differences only for the cop-lsf parameter. When comparing both examined research group of girls and boys, significant differences were confirmed for cop-bars, l-bars and cop-lsf. An attempt to evaluate the statistical differences in resting conditions and after backpack loading between the group of examined girls and boys did not reveal any significant differences.

Table 2. Descriptive statistic of the posturographic test among the examined research group at rest and after loading with backpack (5 kg)

Parameter	Measurement at rest						Measurement after loading					
	cop-bars [mm^2]	r-bars [mm^2]	l-bars [mm^2]	cop-dist [mm]	cop-speed [mm/sec]	cop-lsf	cop-bars [mm^2]	r-bars [mm^2]	l-bars [mm^2]	cop-dist [mm]	cop-speed [mm/sec]	cop-lsf
Population of girls (n = 68)												
Me	152.8	41.5	21.0	170.3	8.6	1.1	190.9	38.1	27.3	178.1	8.9	0.9
Q_1	93.9	22.0	11.7	145.4	7.4	0.8	111.3	25.9	15.7	154.4	7.7	0.5
Q_3	241.1	71.4	41.5	205.8	10.3	1.7	380.1	108.6	63.9	219.4	11.2	1.6
Population of boys (n = 62)												
Me	131.8	32.4	25.3	170.5	8.6	1.3	154.7	41.1	25.9	167.4	8.4	1.1
Q_1	65.5	14.1	9.7	137.4	6.9	0.7	91.9	15.5	15.3	138.9	7.0	0.7
Q_3	238.3	86.6	64.2	201.8	9.9	2.2	270.3	92.2	63.2	191.7	9.6	1.5

Legend: Me – the middle average of a sample, Q_1, Q_3 – extreme quartiles, cop-bars – total surface area of deflections from body's centre of gravity, l-bars – surface area of left foot, r-bars – surface area of right foot, cop-dist – distance between extreme deflections, cop-speed – mean speed of deflections, cop-lsf – ratio of distance between extreme deflection to deflection area.

Table 3. Significance of differences between measurement at rest and loading with backpack for the parameters of posturographic testing for both study samples

	Population of girls (n = 68) and boys (n = 62)		
Parameter	T	Z	p
cop-bars [mm^2]	2994.000	2.936	0.003
r-bars [mm^2]	3514.500	1.727	0.084
l-bars [mm^2]	3346.000	2.118	0.034
cop-dist [mm]	3868.000	0.763	0.446
cop-speed [mm/sec]	3426.000	1.260	0.208
cop-lsf	2284.000	3.638	0.000
Population of girls (n = 68)			
cop-bars [mm^2]	704.000	2.866	0.004
r-bars [mm^2]	846.500	1.995	0.046
l-bars [mm^2]	820.000	2.157	0.031
cop-dist [mm]	895.000	1.699	0.089
cop-speed [mm/sec]	833.500	1.908	0.056
cop-lsf	609.500	2.573	0.010
Population of boys (n = 62)			
cop-bars [mm^2]	804.000	1.209	0.227
r-bars [mm^2]	912.000	0.452	0.651
l-bars [mm^2]	861.000	0.810	0.418
cop-dist [mm]	856.500	0.639	0.523
cop-speed [mm/sec]	830.500	0.194	0.847
cop-lsf	542.000	2.589	0.010

Legend: cop-bars – total surface area of deflections from body's centre of gravity, l-bars – surface area of left foot, r-bars – surface area of right foot, cop-dist – distance between extreme deflections, cop-speed – mean speed of deflections, cop-lsf – ratio of distance between extreme deflection to deflection area

4. Discussion

According to Yamato et al. [23], there is no convincing evidence that the use of school backpacks increases the risk of back pain. There is some evidence that feeling the weight of an object is associated with back pain. Children aged 11–14 report back pain, most of whom attribute their pain to wearing a school backpack [15]. When the load of a backpack is greater than the load capacity of muscle groups, the spine is overloaded, which can cause changes in posture, pain or dysfunctions. Since wearing a backpack with school supplies is a daily routine that is repeated over the years, special care should be devoted to avoiding postural changes that could become permanent in the mid- to long-term and thus, endanger health [17].

The results presented in this paper confirm the above thesis also assumed by other authors. Just putting on a 5-kg backpack changes a child's posture, including the distribution of plantar forces on the ground. Prolonged periods of carrying a heavy backpack leads to consolidation of these changes. Other authors have also dealt with the issue of pressure on the plantar surface with the application of an external load. In their study, Pau et al. [16] analysed maps of plantar pressure in static conditions among 359 primary school children (6–10 years of age). Statistically significant differences depended on the presence of the backpack ($p < 0.01$). The largest modifications were noted in the metatarsal area (with an increase of about 16% for the highest load), followed by the forefoot (+ 9%), the rear part of the foot remained practically constant regardless of the assumed load size. Statistical analysis showed significant impact of the backpack only on the metatarsal and forefoot areas ($p < 0.01$ in both cases). In research carried out on a general research group for the purposes of this study, a statistically significant difference for the metatarsal area, both in the right and left foot, was recorded at $p = 0.000$. However, for the forefoot area, these values were $p = 0.024$ and $p = 0.008$ for the right and left legs, respectively.

Children, both girls and boys, from London schools aged 7–11 took part in a study by Cousins et al. [6]. Only the students who did not have orthopaedic, neurological and/or musculoskeletal problems were included in the study. Participants were classified according to body mass: 22 obese, 22 overweight and 56 children within the norm. During the experiment, students had to walk a 5-meter section, in the middle of which a podobarographic platform was placed. Subjects covered the marked section of the route barefoot, asssuming a natural gait pattern and with the speed of their choice. Analysis of the results showed that children with excessive body mass demonstrated significantly ($p < 0.05$) higher metatarsal load. These results indicate that not only the applied load used in the experiment carried out by the authors of this work, but also excessive body mass cause the largest statistically significant differences to be noticeable in the metatarsal area.

The cited examples confirm the thesis indicated by Moslemi et al. [13] stating that the incidence of posture structure disorders is quite high among primary school children and is closely related to some ergonomic parameters, such as weight and type of backpack. Bibro et al. [3] dealt with the issue of the impact of strength training on the distribution of plantar pressure. The research was conducted among 60 students. The males were divided into 2 equal groups of 30. Group 1, subjected to training, completed the exercise at a gym within 60 minutes, including lower limb exercises. The training consisted of 7 complex exercises performed in accordance with the principles of strength training. The weight selection was individual, the repetition range was from 8 to 12 maximum repetitions, performed in 3 or 4 series. The intervals between the series lasted about 3–4 minutes. Group 2 – the control – spent the time between consecutive tests passively, in a seated position. In both groups, there was a tendency towards increasing forefoot load in the 2nd trial. After the training session, the examined males demonstrated significantly increased load on the lateral forefoot of the left foot and the load on the medial forefoot of both feet. Strength training of the lower limbs caused a significant reduction in both lateral load as well as on the medial side of the right hindfoot.

In the research by Varga et al. [19], it was shown that with age, the longitudinal arch changes, which increases surface and concavity. Compared with the results presented in this paper and the above-mentioned results obtained by other authors, it may be indicated that the application of external load in various forms, regardless of age and foot convexity, significantly affects load on the forefoot area. Alghadier [1] showed that wearing a backpack significantly affects foot load patterns (peak plantar pressure, peak plantar strength and contact area). The difference (SD) in maximal support pressure was 11.2 (12.5) kPa, peak plantar strength 3.7 (3.5) N and contact surface, 1.6 (2.9) cm^2. The same conclusions as those reached in this study were found by Vieira et al. [20], who conducted dynamic research among 117 high school students. The cited results showed that the values regarding both the displacement of the COP and its average speed were higher when using an external load in the form of a backpack than without its use. The issue of backpack weight among students in Chennai was dealt with by Suresh et al. [18]. The results of their research showed that the backpack load should be reduced to 5% of body mass.

Barbosa et al. [2] also dealt with the problem of surface reaction, examining 21 children (12 from grade 9 and 9 from grade 5). The backpacks of the younger children weighed 5 kg and for those from higher grades, 4.5 kg. In both cases, during walking and running, the use of the backpack significantly affected all of the analysed variables. Zhou et al. [25] examining 100 healthy primary school students (aged 7–12) when walking with a backpack load of 5, 10, 15, 20 and 25% of body mass, came to the conclusion that the increase in backpack weight has a limited effect on COP, and students can cope with the risk of balance loss resulting from increased load. They noticed that to maintain balance control, students adjust their posture by eliminating risk factors for balance loss due to load. When increasing the load had huge impact on body posture, a load of 15% body mass may be considered a safe value. The results presented above are in contradiction with the analysis conducted by the authors of this work, who noted statistically significant differences regarding cop-bars.

Analysing the literature and the results of the authors' research on the impact of using an external load in the form of a school backpack, statistically significant differences were expected. In comparative assessment, a negative change in the convexity of the foot was undeniably noted, as well as worse postural stability among the examined girls and boys, resulting from the applied load.

5. Conclusions

Considering a child's physical development, it is not advisable for students to wear overloaded backpacks on their way to and back from school or going to and from classes. As resulted from the tests conducted, a possible overloaded pattern of movement, manifested in the static effects of body posture, may be a factor in the acquisition and consolidation of body posture irregularities and defects within the foot towards a flat foot. School children and teenagers spend a lot of time at school. Moving from home to school and back also takes a certain amount of time. Providing them with a safe and healthy environment can reduce their susceptibility to injury, chronic health conditions and their complications. Backpacks and school supplies are worn by children in different ways, therefore, the weight and the way they are taken over by the students should be considered as an important issue.

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Podiatric and Stabilographic Examinations of the Effects of School Bag Carrying in Children Aged 11 to 15 Years

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Abstract: Background: The issues raised in this study were inspired by the concern for the musculoskeletal status of school children. Carrying excess weight in the form of a school bag in this period of life affects the correct body posture of school children. The aim of the study was to analyze the influence of school bags on the feet force distribution on the ground and postural balance in children of both sexes between 11 and 15 years of age. Methods: The study investigated the distribution of pressure forces on the sole of the foot and its arch. The center of pressure for both feet and the whole body was also examined. The participants were 100 students from primary schools in Gdańsk, aged 11 to 15, including 54 girls and 46 boys. The research used a podobarographic platform that measures the distribution of foot pressure to the ground. The examinations included two measurements: in the first, the children stood on the platform in a natural position. Then, a 5 kg backpack was put on and they stood on the platform again. Results: Statistically significant differences were found in the distribution of the foot pressure on the ground in the left metatarsus (p = 0.000) and heel (p = 0.000) after putting on the backpack in both girls and boys. However, in the right foot, these differences concerned the metatarsal area (p = 0.001). The results of the balance tests were only statistically significant in the group of girls in the right foot sway area (p = 0.020). Conclusions: The school backpack load led to an increase in the values of the heel and metatarsal area measured in the students, causing its flattening.

Keywords: adolescent; teenagers; backpack; stability; overload; school

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1. Introduction

School children are teenagers who experience a period of rapid growth and development of bone and soft tissues. Spinal structures in children are more susceptible to disturbances caused by external factors compared to those in adults. Furthermore, external forces caused by load transmission may also influence growth, development, and correct posture [1]. Increased body weight in children is associated with increased pressure on the plantar side of the developing foot. Child obesity can weaken the structure and function of the foot, exposing children to pain and discomfort in the feet [2,3]. An external load in the form of a school backpack, often used by children during the school period, may also have a negative impact on joints, bone health, and body posture [4]. According to reports in the literature, the prevention of backpack-related musculoskeletal problems in primary school students is a serious problem [5]. Research by Hu H et al., carried out on four age groups, showed that despite different loads, there are statistically significant differences in the body posture in each group between the tests with and without loads [6]. There is ample evidence that wearing a backpack affects students' health. Research shows that the relationship between the student's body weight and the weight of his or her backpack is very often incorrect. It is not rare that the child's backpack is heavier than 10% of their body weight, which is the value recommended in the literature [5,7–9]. As the load to the body increases, especially after exceeding the recommended backpack weight, significant kinematic changes in the ankle, knee, and hip joints are observed, both in children and adults. They affect both gait and pressure on the plantar side of the foot [10,11]. The human foot is an important part of the musculoskeletal system that transfers both static and dynamic load. Its shape is different in every human being. Its structure and positioning have a great effect on gait quality and postural stability. A properly arched foot is flexible and prevents micro-injuries and shocks during locomotion. The correct shape of the foot depends on the efficiency of the muscles and ligaments and the structure of the osteoarticular system [12]. Wearing too heavy a backpack may cause increased strain on joints and problems with maintaining dynamic stability and balance [13]. Body balance is defined as the ability of the human body to maintain its position. Body balance is genetically determined and, at some stage of development, the ability to maintain balance is hampered by the fact that the brain already has a fully formed set of neurological connections. Similarly, motor skills are already shaped [14], for example, by developed movement patterns and habits developed in everyday life. The aim of this study was to analyze the influence of the backpack on the distribution of foot forces on the ground and body balance in children (boys and girls) aged 11 to 15 years.

2. Materials and Methods

2.1. Participants

The criterion of purposeful selection was used in the study. The inclusion criterion was the consent of parents or legal guardians to participate in the study. Only 15% of the recruited participants refused to participate in the study. At the beginning of the recruitment, participants were verbally informed about the purpose and nature of the study and its benefits. The only coherent factor for the selection was the implementation of the educational and prevention program, with one of the goals being to develop healthy attitudes of students in the field of proper motor development and body posture. The research was conducted on children with increased physical activity. The study included 100 children aged 11 to 15, including 54 girls and 46 boys. In the group of girls, the mean body height was 149 cm (SD = 9 cm), with an average body weight of 41 kg (SD = 8.4 kg). In boys, these somatic parameters were 152.6 cm (SD = 11.3 cm) and 45.7 kg (SD = 13.2 kg), respectively. All respondents were students of Gdańsk primary schools and reported a good health status and no injuries. The headmasters and parents/legal guardians agreed to the participation of the children in the research. Both the guardians and the children were familiarized with the research procedure that was carried out in accordance with the International Charter of Ethical Research in Children. The research was also conducted based on the approval of the Scientific Research Ethics Committee of the University of Warmia and Mazury in Olsztyn (Decision No. 9/2018).

2.2. Instruments

The participant's body height was measured with a Soehnle electronic ultrasonic height measuring device (Soehnle, Gaildorfer Straße 6, 71522 Backnang, Germany), which features an ultrasound system, and the built-in tilt sensor allows for precise measurement. The E.P.S./R1 mat with 2304 pressure sensors located on the active surface (Letsens Group, Letsens S.R.L. Via Buozzi, CastelMaggiore, Bologna, Italy) was used to measure the percentage distribution of foot forces on the ground and body balance. The mat size is 700 mm $\times$ 500 mm $\times$ 5 mm. Sensors placed in the mat collect the measurements for 20 s and automatically transfer them to a computer using the Biomech Studio program

(Biomech Studio 2.0 Manual, Letsens Group, Letsens SRL Via Buozzi, CastelMaggiore, Bologna, Italy). The following parameters can be tested using the mat:

Load on the right and left feet (%);
Pressure on the forefoot, metatarsal area, and heel (expressed in %);
COP-bars—the area of the body's center of gravity (mm^2);
l-bars—left foot imbalance area, (mm^2);
r-bars—right foot imbalance area, (mm^2).

2.3. Procedure

The examination was preceded by a diagnosis. The tests were conducted at rest, without load, and with the load of a 5 kg backpack. This weight was the mean weight of 20 randomly selected backpacks. Random sampling was used to select children for the study. Children participating in the study were students from Gdańsk schools aged from 11 to 15 years old with normal weight and normal weight indices ($n = 100$). The test procedure consisted of several steps. In the initial stages, consultations with headmasters and parents were conducted regarding the planned study. The study schedule was also drawn up and parental consent was obtained for the examination. All parents gave their written consent for their children to participate in the study. A specially developed parental informed consent form was used for this purpose. The experimental sessions were held in gyms to correct postural defects. Natural light was used in the room and the participants were offered privacy to avoid external influences. Each participant was examined in a single session so all the tasks could be performed in the same conditions (ambient temperature: 22 °C). The research was conducted in May 2019. In order to collect data for gait analysis, each subject was anonymously registered in the Biomech software (Biomech Studio 2.0 Manual) along with the following data: participant's code, date of birth, sex, and body weight and height measured by the researcher using a height-measuring device while maintaining an upright posture. The platform was placed on the floor and connected with a USB cable to a computer that saved the data from the analysis to the Biomech program.

2.4. Measurement Protocol

After undressing to underwear, the examined child went to the podographic mat so that his or her feet were on both sides of the vertical line drawn on the mat. In preparation for the study, participants were asked to take a few steps to place their feet freely on the mat. The child stood barefoot, upright, with his or her arms against the body, in a natural position looking straight ahead at a fixed point at eye level. The participant remained stationary for 20 s. At that time, the measurements were made and transferred to a computer system using the Biomech Studio software. Then, the child put on a 5 kg backpack, the backpack adjustment straps were loosened, and the participants were asked to adjust them as they usually do with their backpacks. Then, the procedure was repeated on the stabilographic mat. The study design is shown in Figure 1.

The Biomech Studio program allows data regarding the foot type, longitudinal arch, percentage distribution of forces on the sole of the foot (Figure 2) to be read, as well as data from the stabilometric evaluation, such as the area of the body's center of gravity, left foot imbalance area, and right foot imbalance area (Figure 3).

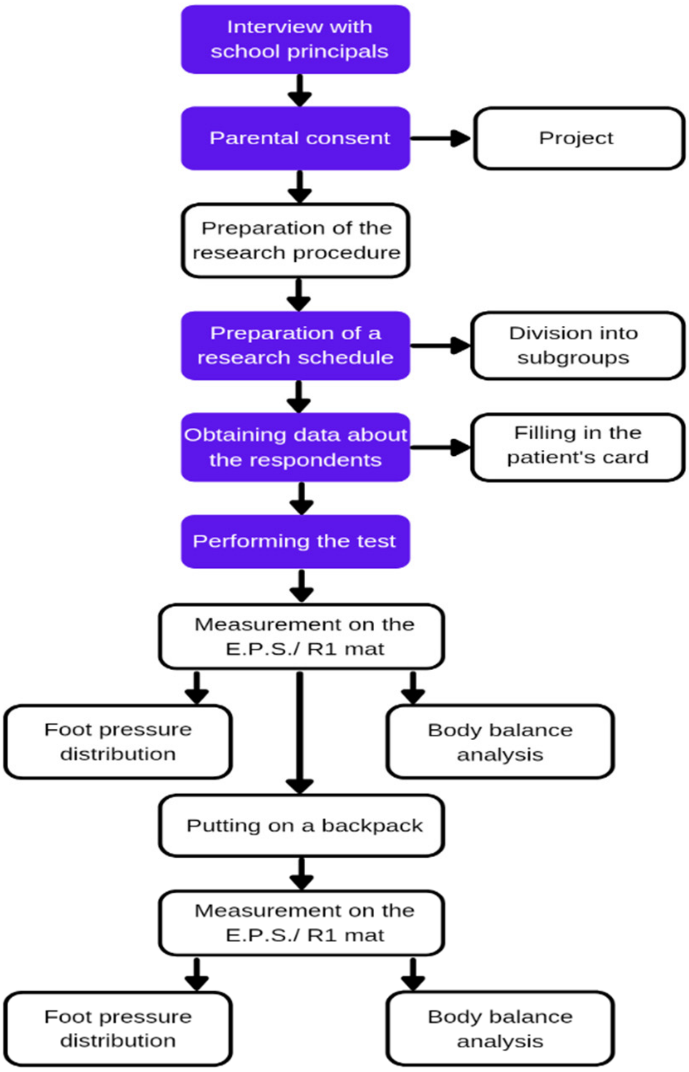

Figure 1. Scheme of the test procedure.

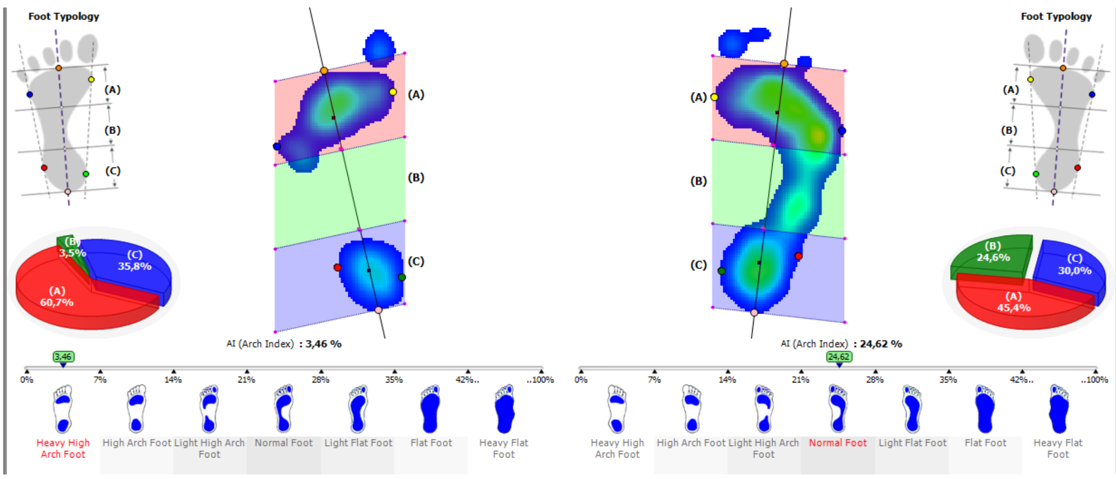

Figure 2. An example image with the results of pressure distribution on the sole of the foot from the Biomech Studio software.

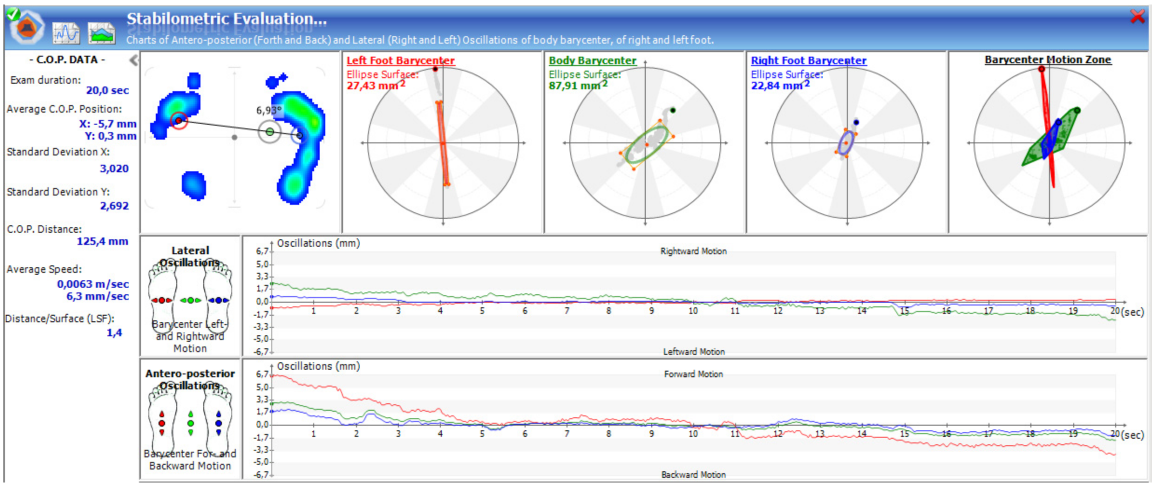

Figure 3. Sample image with the balance results from the Biomech Studio program.

2.5. Data Analysis

The size of the longitudinal arch of the foot in the population of children in early adolescence and adolescence should have a normal distribution. However, in the foot load study design, it can be assumed that data distribution does not follow the normal distribution; therefore, it was decided to verify the appropriate statistical treatment in relation to the sample size. The Shapiro–Wilk test used for the analysis showed inconsistency with the normal distribution for all measurement parameters. Therefore, in further analysis, a statistical non-parametric method (the Wilcoxon pairwise test) was employed. Additionally, the Cohen effect size was calculated. For the characteristics of descriptive statistics, the measure of the median was used: the median and the dispersion of the measurement values (quartiles). The significance level in the study was set at $p < 0.05$. Statistical analyzes were performed using the Statistica program (StatSoft Polska, Kraków, Poland, version 13.3).

3. Results

Measurements of the studied population of girls and boys at rest for both feet recorded the median corresponding to a significant hollow of the longitudinal arch of the foot. The margin of a significant cavity for the metatarsal area is 0 to 7%. The median of the total population in the authors' research was 6.6% for the left foot and 6.8% for the right foot (Table 1). After loading with a 5 kg backpack, the median increased and changed the range for both feet corresponding to the mean hollow of the foot arch (from 7 to 14% of the metatarsal cavity). The median was 10.1% for the left foot and 9.9% for the right foot. Comparison of the mean measurement results between the populations of girls and boys revealed differences in the size of the longitudinal arch of the foot both in the examinations at rest and after loading with a 5 kg backpack (Table 1). In both tests, the mean result in the population of girls indicated a hollow foot, with the medians of S = 6% and O = 8.8% for the left foot and S = 5.2% and O = 9.6% for the right foot. In the case of the male population, the mean result characterized an average hollow foot, with S = 11.2% and O = 13.2% for the left foot, and S = 12.4% and O = 13.4% for the right foot. Under load conditions, in both studied populations, the medians for both feet were recorded, reducing their longitudinal arch. In the population of girls, the values increased by 2.8 pp in the left foot and 4.4 pp in the right foot. Furthermore, in the population of boys, the medians increased by 2 and 1 pp, respectively. In both populations, the values were classified as an average hollow. Analysis of the statistical significance of the differences in the magnitude of the longitudinal arch of the feet in the studied population of girls and boys aged 11–15 years revealed significant differences in the longitudinal arch for the left and right feet (Table 1). Similar differences, significant for both feet, were found in the populations of girls and boys for the left foot.

There was also a homogeneous trend of changes for the populations studied in the load on the heel area of both feet (Table 1). These differences were not statistically significant in the right foot, with a mean reduction in the load by 0.8% for the entire study population (0.6% for girls and 1.7% for boys). In the case of the left foot, they were statistically significant, with the load being decreased by 2.7% (3.4%, and 1.6%, respectively). In all analyzed parameters of the studied populations, the Cohen effect size was small (Table 1).

Table 1. Distribution of the results of the tests for the pressure of the foot on the ground at rest and after loading with a backpack in the study group; the Wilcoxon Matched Pairs Test.

Foot Area (%)	**L Forefoot**		**L Metatarsus**		**L Heel**		**R Forefoot**		**R Metatarsus**		**R Heel**	
	S	**O**	**S**	**O**	**S**	**O**	**S**	**O**	**S**	**O**	**S**	**O**
boys and girls (*n* = 100)												
$\underline{X}$	47.85	47.72	10.31	12.72	41.84	39.77	53.39	53.21	10.92	12.29	35.69	34.50
SD	8.96	8.72	9.86	10.23	9.11	8.12	9.33	9.67	10.42	10.55	8.14	8.46
Me	47.5	46.8	6.6	10.1	41.0	38.3	52.0	54.2	6.8	9.9	35.5	34.7
Q_1	43.3	43.4	1.3	3.4	34.8	34.0	47.7	47.1	1.2	2.1	30.9	29.0
Q_3	54.2	53.4	19.9	22.2	46.5	45.2	61.4	58.6	20.1	21.7	40.6	40.0
p	0.836		0.000 *		0.000 *		0.549		0.001 *		0.115	
d	0.01		0.24		0.32		0.02		0.14		0.13	
girls (*n* = 54)												
$\underline{X}$	47.17	47.16	9.54	12.35	43.28	40.88	53.66	52.80	9.69	11.33	36.65	35.87
SD	9.75	9.50	9.48	10.42	9.53	8.20	9.69	8.93	9.91	9.79	8.47	7.60
Me	47.3	47.0	6.0	8.8	42.5	39.1	52.4	54.4	5.2	9.6	36.4	35.8
Q_1	42.9	42.6	2.0	3.0	36.3	35.4	48.7	47.0	1.1	2.1	32.1	31.3
Q_3	54.3	52.5	18.2	22.3	46.5	46.7	62.2	58.2	19.0	20.5	41.8	41.8
p	0.757		0.001 *		0.013 *		0.270		0.004 *		0.408	
d	0.00		0.30		0.24		0.10		0.17		0.09	
boys (*n* = 46)												
$\underline{X}$	48.64	48.38	11.22	13.16	40.14	38.45	53.08	53.70	12.35	13.42	34.56	32.88
SD	7.95	7.77	10.31	10.09	8.39	7.91	8.99	10.56	10.92	11.39	7.67	9.19
Me	48.6	48.4	11.2	13.2	40.1	38.5	53.1	53.7	12.4	13.4	34.6	32.9
Q_1	8.0	7.8	10.3	10.1	8.4	7.9	9.0	10.6	10.9	11.4	7.7	9.2
Q_3	27.3	27.3	0.0	0.0	27.1	25.9	28.4	26.5	0.0	0.0	19.3	10.6
p	0.901		0.002 *		0.011 *		0.831		0.055		0.194	
d	0.03		0.21		0.18		0.07		0.10		0.18	

L—left foot, P—right foot, $\underline{X}$—average, SD—standard deviation, Me—median, Q_1, Q_3—quartiles 1 and 3, S—resting measurement, O—measurement with a backpack, p—significance level of Wilcoxon Matched Pairs Test, *—statistical significance, d—effect size.

The analysis of the posturographic examination showed differences between the measurement at rest and the measurement with a backpack in the examined girls and boys (Table 2). The mean measurement values for the population of girls and boys are different. Taking into account the parameter of total changes in the area of the center of gravity, an increase of approximately 35 mm^2 in the population of girls and a decrease in the median by nearly 30 mm^2 in the population of boys was observed. Statistically significant differences in the body balance at rest and after loading with a backpack were shown only for the population of the examined girls in the case of the left leg, with an increase in balance disturbance observed as slightly more than 4.84 pp. The effect size in the population of both girls and boys in the area of the left forefoot was moderate. The other parameters, on the other hand, showed a small effect size (Table 2).

Table 2. Distribution of the results of the stabilographic tests at rest and after loading with a backpack in the study group and the statistical significance of differences measured with the Wilcoxon Matched Pairs Test.

Parameter	Cop-Bars (mm^2)		l-Bars (mm^2)		r-Bars (mm^2)	
	S	O	S	O	S	O
boys and girls (n = 100)						
X	198.74	187.30	57.10	55.16	76.65	74.49
SD	179.01	163.48	108.78	77.99	134.06	101.04
Me	142.29	135.23	26.54	31.38	30.08	41.294
Q_1	76,84	84.10	15.15	14.65	15.34	19.31
Q_3	230.78	227.34	64.60	60.96	82.06	93.43
p	0.907		0.364		0.618	
d	0.12		0.01		0.02	
girls (n = 54)						
X	170.46	204.23	53.34	56.29	74.41	76.54
SD	147.14	183.31	119.26	68.99	134.98	116.70
Me	115.50	150.55	23.42	34.48	26.94	31.88
Q_1	74.94	93.47	14.19	16.61	14.69	19.57
Q_3	196.91	228.03	46.52	73.48	76.96	90.48
p	0.204		0.020 *		0.341	
d	0.36		0.02		0.02	
boys (n = 46)						
X	231.93	167.42	61.52	53.82	79.28	72.09
SD	207.16	135.91	96.16	88.16	134.42	80.06
Me	154.44	124.84	36.75	25.80	40.23	44.93
Q_1	81.75	75.65	17.90	13.41	18.30	18.90
Q_3	308.78	210.78	68.05	47.48	86.14	102.30
p	0.097		0.222		0.880	
d	0.40		0.07		0.06	

X—average, SD—standard deviation, Me—median, Q_1, Q_3—quartiles 1 and 3, S—resting measurement, O—measurement with a backpack, p—significance level of Wilcoxon Matched Pairs Test, cop-bars—the total surface area of the body's center of gravity, l-bars—the surface area of the left foot, r-bars—the surface area of the right foot, *—statistical significance, d—effect size.

4. Discussion

During their education in Poland, the majority of students use paper textbooks. Each student has one set of books, and it is impossible to leave textbooks at school due to homework and the need to study for tests. Additionally, in many schools, there are no lockers for pupils where they could leave books that are not needed for the next day or studying at home. The weight of the backpack is additionally increased by personal items carried by students not related to classes.

The longitudinal arch of the foot in humans was formed in phylogenetic development, along with the verticalization of the body posture. The longitudinal arch in vertebrates is only observed in humans. Furthermore, its structure is subject to factors influencing the course of ontogenetic development. Significant changes in the size of the foot arch are attributable to the individual's body weight [15–17].

During this cross-sectional study, the authors investigated the relationship between the use of a backpack and changes in the distribution of forces on the plantar side of the foot and body balance in a group of children aged 11 to 14 years. Analysis of the results showed that wearing a backpack affects the arches of the foot and body balance. The main changes in the parameters tested after the application of external load were observed in the entire study population. These changes included the magnitude of pressure forces on the metatarsus and heel of the left foot and the metatarsus of the right foot. The same parameters were statistically significant in the population of girls, but only for the metatarsus and heel area of the left foot in boys. The stabiliographic study only showed statistically significant differences in the population of the girls for the body surface area in the right leg.

The problems of the effect of external load on the distribution of forces on the plantar side of the foot and the level of body balance are increasingly common in scientific considerations. In their study conducted on college students, Jaszczur-Nowicki et al. examined physical exercise during the Harvard test used as a load. The comparative assessment unquestionably showed negative changes in the arch of the feet and the stability of the lower body posture in the women and men studied caused by the physical exercise used [18].

A different approach to the problem was used by Zawadka et al. in a pilot study that investigated the effect of a light, asymmetrical, hand-held load on posture and pressure distribution on the plantar side of the foot in adults with a mean age of 21.5 years [19]. School children very often wear a backpack the wrong way, which, in addition to the issue discussed in the above work, may result in an asymmetric load on the whole body, especially in adolescence. Incorrect loading with a backpack may also result in postural defects in the spine, lower limbs, and individual feet, which is closely related to the distribution of forces on the plantar side of the foot. Incorrect loading increases the effect caused by the backpack's weight itself.

In addition to overloading the body of a young person with a backpack, Bieniek andi-enieg Wilczyński pointed to the relationships between the parameters of body posture and its stability. They also drew attention to the need for exercises to correct body posture [20]. Interpretation of the above research via comparison with our results shows that the mere wearing of a properly fitted backpack with a certain weight causes changes in posture and the distribution of forces on the plantar side of the foot and balance.

Studies have also analyzed the effects of backpacks on the ground reaction forces acting on children when walking, running, and jumping. An example confirming the results obtained in this study is the research conducted by Barbosa et al. in groups of children aged 10 to 11 and 14 to 15 years. The results showed that the load caused by the backpack influences the ground reaction forces during walking and running [4]. Similar results were obtained by Ahmad and Barbosa after conducting a study on 48 primary school students performing four trials (carrying backpacks weighing 0%, 10%, and 15% of their body weight) over a distance of 10 m. The children walked slower and with a lower number of steps per minute than in the other three conditions. There was no significant effect on stride length. Wearing a backpack with different loads had a significant impact on the distribution of forces on the sole of the foot. It was found that the load mainly had an effect on the contact surface under the metatarsus and heel [21]. The authors of this study made the same observations. In addition, the analysis of the results of this study showed that the flattening of the longitudinal arch of the foot under the load is observed. Similar results were obtained by Alfageme-García et al. in their research on the impact of carrying a backpack on the shape of the feet in children with normal longitudinal arches. During the three-year follow-up, 50 examined children developed supination (n = 18) or pronation (n = 32) of the foot. A significant relationship was found between wearing a backpack and the risk of developing pronation. Wearing a backpack every day did not change the physiological shape of the foot arch towards supination [22].

The problem similar to that discussed in our study was also addressed by Szyszka et al. The aim of their study was to assess the variability of selected stabilographic parameters caused by increasing external load of a school backpack in children aged 10 years. The same backpack was used for the measurements, with its design allowing for a symmetrical distribution of the weight. The school backpack in the subsequent tests accounted for 0%, 5%, 10%, and 15% of the body weight of the examined person. The mean variability of the static analysis indices in the studied group of students ranged from 16.5% for the COP path length to 55.6% for the difference in the load distribution between the right and left feet. The mean variability of the parameters of dynamic gait analysis ranged from 4.7% for the left limb stride length to 39% for lateral symmetry. The authors found differences in load distribution in the standing position for the heel and forefoot areas, both in static and dynamic conditions. Increasing the load led to the differentiation of the arch parameters of the right and left feet with increasing pressure on the area of the forefoot and heel [23]. Similar results were obtained by Pau et al., who analyzed the effect of backpack load on the magnitude of ground reaction force in children aged 6 to 13 years. The analysis also showed that after applying a backpack weight of 5.2 kg, the load on the forefoot area increased [24]. The examinations discussed in the present study showed that after loading with a backpack weighing 5 kg, the impact on the forefoot and toes area decreased. Another example of research dealing with the backpack effect is the study by Hell et al., who analyzed the effect of a 4 kg backpack load on the gait pattern and postural sway. They examined a group of 12 children aged 7–10 years without any neurological or orthopedic problems. The load of the backpack, averaging 15% of the body weight, led to a decreased walking speed, shortened walking speed, shortened stride length, and an extended double-support phase. School backpacks weighing 4 kg caused changes in children's gait, muscle activity, posture, and stability. Due to the weight of the backpack, the center of mass shifted back, and the children's posture became less stable [9]. Similar results were also obtained by Mosaad and Abdelaziem. These scholars found that carrying a backpack weighing 15% of the child's body weight changes the position of the head and increases the normalized value of the anterior–posterior shear force. Increasing this force may lead to the development of postural disorders and defects [25]. In addition to heavy books and notebooks, students carry different personal items in their backpacks that increase the backpack's weight. Excess weight in the form of a schoolbag during this period of life changes the body posture of school-age children. A partial solution to the problem of too heavy a backpack may be the introduction of digital textbooks by schools.

In their 3-year research, Martínez-Nova et al. showed that the arch of the feet in children shifts towards the physiological norm with age, and the relationship with body weight and height and the weight–height index (BMI) is minimal [26]. Similar results were obtained by Bukowska et al., who analyzed the differences in the arch of the foot and body balance in three age groups of boys training football. It was observed that the total length of the longitudinal arch of both feet in the boys studied tended to flatten in direct proportion to their age. There was also a statistically significant increase in body balance with age [27]. The above results are consistent with the results contained in this paper and another work by Jaszczur-Nowicki, in which the same research methodology was used in a group of children aged 8 to 10 years [28]. Comparison of both papers shows that there are fewer statistically significant differences observed with age, both in the parameters related to the load on the plantar side of the foot and body balance. Based on the previously mentioned studies by Martínez-Nova et al. and Bukowska et al., it can be assumed that the strength of the lower limb muscle groups increases with age, thus increasing body stability. Furthermore, in older school-age children, the external load did not have such a significant impact on the sub-league and stabiliographic parameters. Some of the studies cited in the discussion were carried out on a small group of respondents, and therefore, the results are inconclusive. However, the results obtained in the studies conducted on larger populations coincided with the results and conclusions of the authors of the present study.

Limitations of the Study

The main limitation of the study was its cross-sectional nature. The risk factor (carrying a backpack) was assessed in a strictly defined group. Our research did not examine cause-and-effect relationships but clearly indicated the need to continue the diagnosis on a larger population. Only children with physiologically normal growth and weight indices participated in the study. In addition, the distribution of forces on the plantar side of the foot during walking was not verified, which could reflect the nature of the study in more detail. In the future, the authors plan to extend the research presented in this paper by taking into account the types of feet of the participants or the physical activity in both static and dynamic tests.

5. Conclusions

1. Podological examinations before and after carrying the backpack showed a change in the distribution of forces in the study group. A significant change occurred on the left side, which may indicate a difference in a functionally dominant limb that affects the body balance in children.
2. In the study population, a significant reduction in the longitudinal arch of the foot was found after wearing a backpack.
3. Wearing a backpack caused flattening of the metatarsal area in the study group.

Practical Implication

The above conclusions may suggest a negative impact of the daily use of a heavy backpack in the study group of school children. Therefore, it can be suggested that the proportion of traditional teaching resources should be changed to increase the use of information technology. However, the final determination of the usefulness of such changes requires further experimental research. Based on the results of our research, attention should be drawn to the need for symmetrical loading of both lower limbs by appropriately putting the backpack on both shoulders in order to properly distribute its weight and avoid scoliosis in children.

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Article

Biomechanical Aspects of the Foot Arch, Body Balance and Body Weight Composition of Boys Training Football

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Abstract: *Background:* The aim of the study is to assess the body balance and podological parameters and body composition of young footballers in the context of the control of football training. *Methods:* The study examined the distribution of the pressure of the part of the foot on the ground, the arch of the foot, and the analysis of the body composition of the boys. The pressure center for both feet and the whole body was also examined. The study involved 90 youth footballers from Olsztyn and Barczewo in three age groups: 8–10 years, 11–13 years old, and 14–16 years. The study used the Inbody 270 body composition analyzer and the EPSR1, a mat that measures the pressure distribution of the feet on the ground. *Results:* The results showed statistically significant differences in almost every case for each area of the foot between the groups of the examined boys. The most significant differences were observed for the metatarsal area and the left heel. In the case of stabilization of the whole body, statistically significant differences were noted between all study groups. In the case of the body composition parameters, in the examined boys, a coherent direction of changes was noticed for most of them. The relationships and correlations between the examined parameters were also investigated. The significance level in the study was set at $p < 0.05$. *Conclusions:* Under the training rigor, a statistically significant increase in stability was observed with age. The total length of the longitudinal arch of both feet of the examined boys showed a tendency to flatten in direct proportion to the age of the examined boys. Mean values of the body composition parameters reflect changes with the ontogenetic development, basic somatic parameters (body height and weight) and training experience, and thus with the intensity and volume of training. This indicates a correct training process that does not interfere with the proper development of the body in terms of tissue and biochemical composition.

Keywords: foot; ground pressure; body composition; body balance; football players

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1. Introduction

The attempt to achieve the championship forced the coaches to pay more attention to training children and adolescents. This procedure seems to be fundamental, but in practice it very often causes many errors, deformations or even degenerations [1,2]. Most often, in the case of talented youth, there is a quick entry into sport for adults, often with temporary successes of young players. However, they are unprepared physically, mentally, technically and tactically. It is often accompanied by the exhaustion of a young athlete, both physically (injuries, permanent damage to the musculoskeletal system, problems in the field of motor coordination, lack of progress in the field of physical preparation) and mentally [3]. Coordination abilities can be a diagnostic tool for monitoring the dynamics of their development and on the basis of them, conclusions can be drawn about the dynamics of physical health [4]. The current knowledge and many years of training experience, not only in football, clearly show that properly selected methods and forms of training are the key to success. Perfectly matched training loads at individual stages of a player's development may bring in the future the result of an optimally prepared footballer for a world-class sport fight [3]. Football is a team game in which the players should represent a sufficiently high level of speed, strength and coordination motor skills. The level of these abilities may depend on the task performed on the pitch as well as on the sport advancement [5,6]. Coordination is one of the factors indicating a significant improvement in physical performance. This is confirmed by the directly proportional relationship between muscle strength and neuromuscular coordination [7,8]. The aim of general coordination training is to develop, improve, stabilize and restore coordination skills or performance requirements in order to be able to successfully cope with all motor tasks in sport and everyday life [9]. One of the coordination skills is balance, which is the ability to concentrate on one's own body [10]. Balance has a direct and significant influence on the ability to dribble [11]. A better balance of the body allows for better results in sports [12]. As a result of the literature review, it can be stated that people from various sports disciplines training at a higher level have better balance than people who are just starting their training [13–15]. The cause of problems and at the same time a greater risk of lower limb injuries is overweight. One of the effects of excessive fat mass in the torso reduces the degree of mobility, balance control and a decrease in postural stability [16]. The foot is an important part of the musculoskeletal system. Its function is to support the conditioning of human movement. The foot is influenced by a number of factors that have a positive effect on it or contribute to the formation of defects [17]. The use of the foot as a basic element in practicing football causes it to carry out more work than during everyday activities. Biomechanical loads that the foot is subjected to while kicking a ball, the use of special and specific footwear and the varied terrain of various sports fields (compacted earth, grass, etc.) activate a number of muscles and joints that do not function with the same intensity and mobility in everyday life [18]. Soccer players are exposed to injuries due to overload, discomfort and decreased performance due to shoe design and repetitive plantar loads [19]. The specificity of the sport discipline causes players to have different morphological profiles [17]. Laterality is also a factor that can affect foot function. Khudik, Chikurov, Voynich et al. believe that asymmetry manifests itself in the human body. Cultural factors and genetics influence the asymmetry of a given individual, and Guilherme J. et al. in their research show that training influences the functional asymmetry of the lower limbs in young football players. [20]. During the research, the following hypothesis and purpose of the research was formulated: sports activity related to football training allows for the biological development of a human being in accordance with the norms in the field of body posture and its composition. The aim of the study is to assess the physical aspects of the musculoskeletal system, related to the structure of the foot and the ability to maintain body balance, as well as to analyze the body composition of young football players in the context of football training control.

2. Materials and Methods

2.1. Participants

The study included 90 youth footballers from Olsztyn and Barczewo in three age groups: 8–10 years (mean age 9 ± 0.86 years, body weight 33.66 ± 8.51 kg, body height 136.03 ± 10.31 cm), 11–13 years (mean age 12.55 ± 0.63 years, body weight 47.83 ± 7.66 kg, height 159.79 ± 6.72 cm) and 14–16 years (mean age 14.30 ± 0.46 years, body weight 60.08 ± 10.31 kg, height 171.61 ± 6.57 cm). All boys aged 8–16, training in clubs in Olsztyn and Barczewo, who were entered into the games at the province or central level in their age categories, participated in the research. Boys under examination took part in training three times a week. Each training session consisted of a warm-up, improving football skills, shaping motor skills with or without the ball, improving individual and team behavior in specific parts of the game, playing ball, and stretching at the end of training. The research was conducted during the competition period. All respondents are players of the same league games in different age categories. The construction of the training unit between the teams was very similar and adapted to their age. All players declared their right upper and lower limbs as dominant and had no visible dysfunctions in the musculoskeletal system. Parents and trainers gave their written consent to the study. All examined boys were players of the same class of games, at different levels of classification depending on age. All coaches of the studied players have the same game goals: victory in individual matches and, as a result, obtaining the best possible place in the league. The research was conducted on the basis of the consent of the Scientific Research Ethics Committee of the University of Warmia and Mazury in Olsztyn (Decision No. 9/2018).

2.2. Instruments

The body composition analyzer Inbody 270 (Inbody Co. Ltd, Soul, Korea) was used for the research. It is a specialized medical device that uses the bioelectric impedance method to measure body composition using a quantitative method. This method is based on the ability to electrically conduct muscle tissue. Body height was measured with a Soehnle (Soehnle, Gaildorfer Straße 6, 71522 Backnang, Germany) electronic ultrasonic height measuring device. (The height measuring device performs the ultrasound measurement and the built-in tilt sensor helps to measure it precisely. The device transmits data to the computer program Lookin'Body 120 (Included in the package with the Inbody 270 device). For the measurement of foot pressure distribution and balance, the EPSR1 mat (Letsens Group, Letsens S.R.L. Via Buozzi, CastelMaggiore; Bologna, Italy) was used. The 700 × 500 × 5 mm mat is equipped with 2304 pressure sensors located on the active surface. It is a diagnostic device used to evaluate the feet in static and dynamic conditions. The mat is equipped with sensors that collect the measurements for 20 seconds and transfers them to the computer using the Biomech Studio program (Biomech Studio 2.0 Manual, (Letsens Group, Letsens S.R.L. Via Buozzi, CastelMaggiore; Bologna, Italy). The following stabilometric parameters can be measured with the mat:

- COP LF—area of left foot imbalances,
- COP RF—right foot imbalances area,
- body COP—the surface of the body's center of gravity.

2.3. Procedure

The research was conducted on 5 March 2020, 11 March 2020 and 30 July 2020. The test procedure consisted of several steps. In the initial stages, consultations with trainers and parents were conducted regarding the planned study. The study schedule was also drawn up and parental consent was obtained for the study of boys. Before starting the study, a qualified person entered the data of the test person into the program, such as ID, date of birth and height. The height of the body was checked by the researcher with the help of a measuring rod, keeping an upright posture. Then, after undressing to underwear, removing jewelry and glasses, the erect participant climbed the analyzer platform so that the feet covered as much of the electrodes as possible. The device automatically started measuring the body weight. After completing the measurement, the examined person took the handles of the device in their hands with their thumb touching the upper electrode and the other fingers of the lower electrode. The subject was asked to remove the extended arms from the body so as not to touch the torso, as this could affect the reliability of the results. The feet and hands adhered to the electrodes throughout the examination, and special attention was paid to it. During the composition analysis, the boys' standards were checked by precisely referring to the body parameters generated by the program for each of them. In order to avoid errors, the tests were carried out in accordance with the procedure enclosed by the manufacturer in the device manual. The examined boys were either fasting or at least 2–3 h after a meal, and also after defecation. In order to optimize the obtained results, the test was performed in the morning, before exercise, approximately

2–3 min after changing from sitting to standing. Earlier bathing was a contraindication to the study, as it accelerates blood flow in the body, which the respondents were aware of. After the end of the test, the data were automatically sent to the Lookin'Body 120 program and the subject put down the handles of the device and left it. Then, the examined boy went to the podographic mat so that his feet were on both sides of the vertical line drawn on the mat. They were then asked to take a few steps to place their feet freely on the mat. The boy stood upright with his arms against his body, staring straight ahead. The signal remained stationary for 20 seconds. At that time, the measurements were made and transferred to a computer system using the Biomech Studio software (Biomech Studio 2.0 Manual). The diagram of the test procedure is shown in Figure 1.

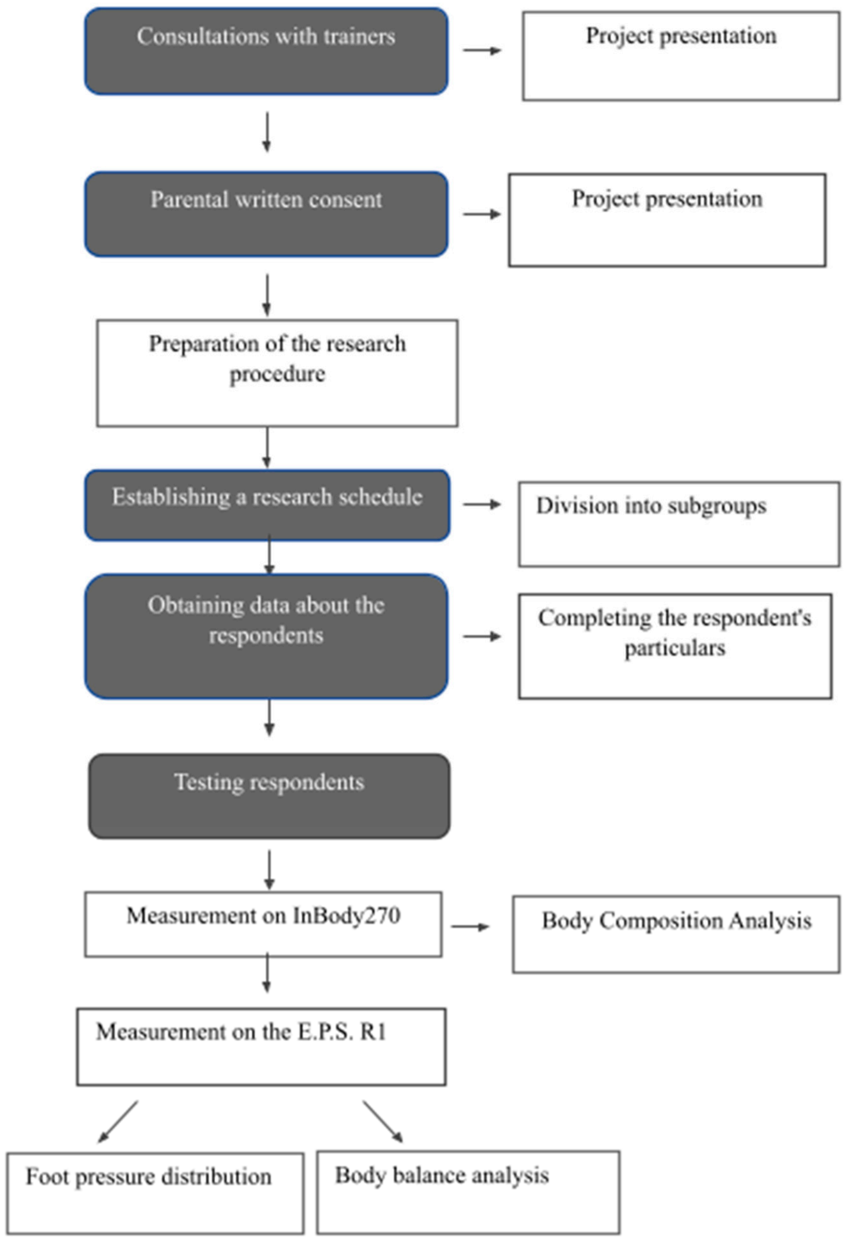

Figure 1. Scheme of the test procedure.

2.4. Statistical Analysis

The Shapiro–Wilk test was used to analyze the studied groups of boys categorized according to their age, which indicated non-compliance with the normal distribution for all measurement parameters. Therefore, in further analysis, a statistical nonparametric function was used, which is the rank test of Kruskal–Wallis. In the case of podological and stabilographic measurements, the two-tailed test with Bonferroni's correction was used due to the mean differences between the groups of boys under study. In the whole work for the characteristics of descriptive statistics, the measures of mean value, median and dispersion of quartile measurement values were used. During the statistical analysis, the Chi square test and the Spearman correlation test were also used to analyze the dependence and correlation between the obtained results. The significance level in the study was set at $p < 0.05$. Statistical analyses were performed using the Statistica program (StatSoft Polska, Kraków, Poland version 13.3).

3. Results

During the analysis, differences in the size of the foot arches were noticed for each of the studied groups of young footballers. The mean values of the pressure of the metatarsal area in the group of boys aged 8–10 years indicated significant hollowing of both feet. For the left foot, the value of the pressure area on the metatarsus was only 0.1%, and in the right foot, 0.8%. Taking into account the mean values for the group of boys aged 11–13 years, the left foot was significantly hollow (0.4%), while the right foot was in the range of the average hollow (9.8%). The results for the oldest group of boys aged 14–16 were the highest for the left foot, placing the value in the range of mean arching (12.9%) and the right foot in the range of significant arching (2.3%). The detailed results of the podiatry examination in the studied age groups are presented in Table 1.

Table 1. Characteristics of the distribution of pressure forces of the foot in the age groups of the studied boys.

	Forefoot LF (%)	Metatarsus LF (%)	Heel LF (%)	Forefoot RF (%)	Metatarsus RF (%)	Heel RF (%)
			Footballers aged 8–10 (n = 28)			
Me	38.40	0.10	56.70	57.30	0.80	37.95
Q_1	27.45	0.00	44.70	53.38	0.00	27.15
Q_3	49.93	2.70	71.80	65.23	6.65	43.65
			Footballers aged 11–13 (n = 29)			
Me	47.80	0.40	44.80	58.40	9.80	29.20
Q_1	36.50	0.00	38.10	44.50	2.30	17.60
Q_3	55.20	11.20	5510	69.40	20.50	49.50
			Footballers aged 14–16 (n = 33)			
Me	43.70	12.90	40.00	45.30	2.30	49.30
Q_1	39.00	7.00	37.30	37.30	0.50	43.90
Q_3	49.20	21.30	45.50	49.70	11.10	56.60

LF—left foot, RF—right foot, Me—median, Q—quartile.

Analyzing the results of the stabilographic examination, significant differences were noticed in the size of all parameters defining the field of changes in the position of the entire body, as well as the area for the left and right feet. Taking into account the total parameter of the pressure center of the whole body, the group of the youngest footballers aged 8–10 (360.62 mm^2) showed the least stability. In the following groups of boys, an increase in the stabilization of body posture was noticed, where in the group of boys aged 11–13 years, the size of the area for the whole body was 197.84 mm^2, while for the oldest group, aged 14–16, the mean value was 37.76 mm^2. The results of the stabilographic examination are presented in Table 2.

Table 2. Characteristics of the changes in the position of the center of gravity examination in the age‘groups.

	Body COP (mm^2)	COP LF (mm^2)	COP RF (mm^2)
Footballers aged 8–10 (n = 28)			
Me	360.62	40.96	73.62
Q_1	195.05	20.25	25.38
Q_3	792.63	109.44	245.89
Footballers aged 11–13 (n = 29)			
Me	197.84	20.36	33.65
Q_1	60.96	12.25	12.54
Q_3	512.23	49.52	123.17
Footballers aged 14–16 (n = 33)			
Me	37.76	4.33	7.30
Q_1	20.71	2.20	2.84
Q_3	72.57	9.05	14.75

COP—center of pressure, LF—left foot, RF—right foot, Me—median, Q—quartile.

The obtained results were statistically evaluated. In the podiatry study, statistically significant differences were noticed between the groups of boys, categorized in specific age groups, in almost every case for each area of the foot. The most significant differences were observed for the metatarsal area and the heel in the left foot. In the metatarsal area, significant differences were noted between all the studied groups of young footballers. Referring to the results of the evaluation of the statistical differences in the stabilographic study, significant differences were noted for all parameters. In the case of the summary parameter constituting the stabilization of the whole body, statistically significant differences were noted between all groups of the studied footballers. The results of the analysis of the statistical significance of differences in individual parameters and age groups are presented in Tables 3–5.

Table 3. Significance of differences in parameters of the distribution of pressure forces in the left foot between the studied age groups.

Variable		Forefoot LF			Metatarsus LF			Heel LF		
Kruskal–Wallis test (p)		0.100			0.000			0.001		
Age		8–10	11–13	14–16	8–10	11–13	14–16	8–10	11–13	14–16
Test post hoc with the amendment Bonferroni	8–10	X	0.100	0.546	X	1.000	0.000	X	0.122	0.001
	11–13	0.100	X	1.000	1.000	X	0.000	0.122	X	0.321
	14–16	0.546	1.000	X	0.000	0.000	X	0.001	0.321	X

LF—left foot, RF—right foot.

In the statistical analysis, differences between the groups of boys were noticed in the size of their body composition parameters. For most of them, there was a homogeneous direction of changes. A total of 80–95% of the examined boys, divided into groups, had measurement values within the normal range (TBW, proteins, FFM, WHR). In the case of the parameters related to total body water (TBW), lean body mass (FFM), skeletal muscle mass (SMM), body mass index (BMI), but also in the case of protein and mineral content in the body, the mean measurement values increased directly proportional to the age of the respondents. The differences in the mean values of the above-mentioned parameters for each group of boys were statistically significant. In the case of the percentage of adipose tissue (PBF) and the degree of obesity (obesity degree), the mean values for the subsequent study groups were inversely proportional. In their case, statistically significant differences were also noted between the boys' groups. By comparing the mean values of the parameters: total body fat mass (BFM) and the waist–hip index (WHR) and visceral fat (VFL) related to the analysis of the abdominal area, no statistically significant differences were found and the mean values for each group were almost equal. Taking into account the specificity of physical effort, football players require a high ratio of muscle mass to body fat mass, where excess fat mass leads to a significant reduction in exercise capacity. The general body mass index BMI for boys of the youngest age group remained at the lower limit of the normal range (BMI = 17.5), while in the other two groups it was at the lower limits of the normal range: BMI = 18.30 and BMI = 20.20. The gradual increase in the value of the index is closely related to the mass of skeletal muscles, where successively in the age groups of the studied footballers there is an average higher skeletal muscle mass in the body, respectively: SMM: 12.65; 20.80; 28.40. This relationship translates into mean values of lean body mass (FFM). Additionally, in the case of this parameter, the mean value increases in the subsequent age groups, respectively: FFM: 24.75; 38.40; 51.30. The analysis of body composition in terms of water content (TBW), proteins and minerals also follow the principle of a directly proportional increase in mean values in relation to the age of the studied group of boys. The mean values of the percentage of adipose tissue in the subsequent age groups of the boys under study are inversely proportional to the analyzed indicators, respectively: PBF: 22.15; 16.50; 11.30. The characteristics of body composition parameters (InBody) presented in Table 6.

Table 4. Significance of differences in parameters of the distribution of pressure forces in the right foot between the studied age groups.

Variable		**Forefoot RF**			**Metatarsus RF**			**Heel RF**		
Kruskal–Wallis test (p)		0.000			0.032			0.000		
Age		8–10	11–13	14–16	8–10	11–13	14–16	8–10	11–13	14–16
Test post hoc with the amendment Bonferroni	8–10	X	0.869	0.000	X	0.029	0.776	X	1.000	0.000
	11–13	0.869	X	0.003	0.029	X	0.361	1.000	X	0.000
	14–16	0.000	0.003	X	0.776	0.361	X	0.000	0.000	X

LF—left foot, RF—right foot.

Table 5. Significance of the changes in the position of the center of gravity between the studied age groups.

Variable		**Body COP**			**LF COP**			**RF COP**		
Kruskal–Wallis test (p)		0.000			0.000			0.000		
Age		8–10	11–13	14–16	8–10	11–13	14–16	8–10	11–13	14–16
Test post hoc with the amendment Bonferroni	8–10	X	0.013	0.000	X	0.155	0.000	X	0.012	0.000
	11–13	0.013	X	0.001	0.155	X	0.000	0.012	X	0.016
	14–16	0.000	0.001	X	0.000	0.000	X	0.000	0.000	X

COP—center of pressure, LF—left foot, RF—right foot.

During the statistical analysis, the relationships between the examined parameters were also examined. Both the relationships between the examined features and the correlation between them were analyzed. For this purpose, the Chi^2 test and the Spearman correlation test were used. In the group of the youngest boys, a statistically significant relationship and correlation between the body COP and the WHR parameter was observed. The examined boys with an increase in this parameter had a greater problem with balance while standing on both feet. However, a similar correlation was not obtained for the correlation and dependence with BMI, BFM, PBF, VFL and obesity degree. In the age group between 11 and 13 years of age, there was no correlation between body composition related to adipose tissue and body balance. In the group of the oldest boys, a statistically significant relationship and correlation between body COP and BFM was demonstrated. However, it was a negative correlation. The same relationship was noted between body COP and PBF, VFL, WHR and obesity degree. Taking into account the entire sample, there was a statistically significant correlation between body COP and BMI. With the increase in BMI, greater disturbances were noted in the examined boys. The same relationships were noted between body COP and PBF and obesity degree.

Table 6. Characteristics of selected body composition parameters (InBody) and the level of statistical significance of differences between the investigated footballers classified in age groups.

	TBW	Proteins	Minerals	BFM	FFM	SMM	BMI	PBF	WHR	VFL	Obesity Degree
Footballers aged 8–10 (*n* = 28)											
Me	18.10	4.85	1.80	7.15	24.75	12.65	17.50	22.15	0.77	3.00	106.5
Q1	16.15	4.20	1.47	5.00	22.00	10.98	15.70	18.20	0.75	2.00	99.75
Q3	21.55	5.70	2.06	10.33	29.50	15.43	19.35	27.30	0.79	3.00	111.0
Footballers aged 11–13 (*n* = 29)											
Me	28.20	7.50	2.74	7.60	38.40	20.80	18.30	16.50	0.77	3.00	98.00
Q1	25.90	6.90	2.52	6.10	35.40	18.80	17.10	13.00	0.76	2.00	94.00
Q3	30.80	8.20	2.92	10.50	42.00	22.70	20.10	21.50	0.79	4.00	105.00
Footballers aged 14–16 (*n* = 33)											
Me	37.50	10.10	3.62	6.80	51.30	28.40	20.20	11.30	0.77	2.00	97.00
Q1	33.10	9.10	3.12	5.80	45.20	25.10	18.70	10.20	0.76	2.00	92.00
Q3	43.40	11.70	4.11	9.00	59.20	33.40	21.70	14.90	0.79	3.00	102.00
p	0.000	0.000	0.000	0.757	0.000	0.000	0.001	0.000	0.799	0.411	

TBW—total body water, BFM—total body fat mass, FFM—lean body mass, SMM—skeletal muscle mass, BMI—body mass index, PBF—percentage of adipose tissue, WHR—waist–hip index, VFL—visceral fat.

4. Discussion

Human biological development usually proceeds according to the norms. This enables the comparison of percentiles and the decision of whether the changes comply with the physiological norm or not. When assessing body composition, all parameters in the study group are consistent with the physiological norm. This indicates the correct selection of the examined adolescents and the proper training process, which does not disturb the proper development of the organism in terms of tissue and biochemical composition. The problem of body composition in young footballers was studied by Santos-Silva et al. The 16-week futsal training program contributed to the improvement of body composition and cardiovascular capacity in a group of boys before puberty (7–10 years). There was a significant increase in total body weight (4%), height (3%), lean body mass (8%) and a significant 6% decrease in body fat percentage [21]. The research presented in this study also shows that in older boys (14–16 years old) there was a greater percentage of boys who were below the norm than in the other groups. Similar results were obtained by Ørntoft et al. [22] found that Danish children aged 10–12 engaged in club football (FC) and other ball games (OBGs) had more muscle mass and a lower body fat percentage than children who did not play sports in their free time (NSC). Children participating in club ball games had a higher ($p < 0.05$) lean body weight than NSC and OBG: participation in soccer classes also affects the percentage of body fat. Significant scientific reports indicate the improvement of the body's ability to maintain balance until the age of 10–12. The differences in the limits of the ability maximization are determined by the measurement method, or rather the conditions for showing the body's ability to balance. Different limits are indicated by the authors for measurements under static conditions, others under dynamic conditions. In our own study, it was observed that the body balance was better with the increasing duration of the training rigor. The oldest group of the boys under study showed the lowest balance disturbances during the stabilometric test. The research conducted by Lebiedowska M. and Syczewska M. [23] showed that despite changes in the body dimensions of children between 7 and 18 years of age in balance tests, the invariability of the swing amplitude is noticeable, which confirms the view that the same patterns of muscle activation are used in children and adolescents. Different results, but adequate to the authors of this study, were obtained by Riach C.L. and Starkes J.L. [24] who in studies of children (4–13 years old) and adults showed an age-related change in the velocity of the center of gravity and in the position of the feet. The problem of the influence of regular football training on balance was investigated by Olchowiak G. and Czwalik A. [25]. The authors carried out research on women training in football (n = 25) and a control group (n = 50). In the tests used, statistically significant differences between the groups were obtained. Women training in football showed better postural stability and balance. The study showed that regular training can improve the balance system. The authors' conclusions are consistent with the results obtained by the authors of this study, as they showed statistically significant differences between the groups in terms of body posture stability. Kumala M.S. et al. [26] also dealt with balance in athletes, comparing the balance between normal and flat feet. None of the tests performed showed statistically significant differences between the groups ($p > 0.05$) in the balance of the body. Jaszczur-Nowicki J. et al. [27–29] in their works analyze changes in the balance and distribution of pressure forces on the plantar side of the foot under the influence of various factors. In children, under the influence of an external load (backpack), the results of body balance were statistically significant. They concerned measurements of the area of the center of gravity of the body, the area of the center of gravity of the left foot and the parameter comparing the distance to area ratio. In all these parameters tested, $p < 0.05$ was obtained. The authors obtained statistically significant results in all parameters of the body balance by analyzing the influence of exercise (Harvard Step Test) on the examined parameters in students. The authors of the above studies also analyzed the distribution of pressure forces on the plantar side of the foot; in children, the results indicated that after putting on the backpack for the entire study group, statistically significant differences ($p < 0{,}05$) were found in the distribution of the foot pressure on the ground in the left foot, forefoot, and heel area. However, in the right foot, this difference was noted for the forefoot and the metatarsus. The p-value in these parameters was also below 0.05. On the other hand, among students, when comparing the mean results of measurements at rest and after exercises for the forefoot, the value of the rest vs. the post-training values for the left foot were comparable, as for the right foot. The image of the metatarsal area, being a reference to the correct longitudinal cavity of the foot. It was different for both feet when measured at rest compared to after exercise. For the heel area, the mean differences in the values between the measurements for the right and left foot was also noted. Additionally, in the author's study, differences in the pressure on the ground of individual parts of the foot between the right and left foot were noted. Systematic football training, as well as external load and physical effort, affects changes in body balance and the distribution of pressure forces on the sole of the foot. Further studies confirming the results obtained by the authors of this study are the analyses of Bibro M. et al. [29]. They took up the problem of the analysis of the arching and pressure distribution of the plantar side of the feet of young men under the influence of strength training of the lower limbs. The surveyed men were divided into two groups of 30. Group I, subjected to training, completed training in the gym including lower limb exercises within 60 minutes, and group II spent the same period of time passively, in a sitting position. In the group subjected to strength training, in the measurements before and after exercise, the lateral and medial side of the hindfoot were symmetrically loaded, while the load on the forefoot increased significantly, especially on the medial part. One hour of effort also had a slight effect on the height of the arches of both feet. Bogut I. et al. [30] conducted research on the occurrence of foot deformities in city children, as well as on possible generation and sex differences. The results of the research showed that the highest percentage of children did not have a noticeable foot deformity, so more than three-quarters of children in 2005 and 2011 had healthy feet. The only noticeable percentage of children with foot deformities relates to the first-degree flatfoot category, from 9.39% in 2005 and 14.69% in 2011. There were no significant differences in the occurrence of foot deformities between the 2005 and 2011 generations or by gender and age between and within each subgroup. The results of these studies indicate that the largest number of children aged 7–11 years did not have noticeable foot deformities, so in children studied in 2005 and 2011, so most of the children did not have deformities. The only noticeable percentage of children with foot deformity relates to the first-degree flat foot category; however, their percentage was in the range of 9–15%. The boys studied for the purposes of this study were also city dwellers. The results obtained by the authors were not compatible with the studies cited above. The author's study noted that the total length of the longitudinal arch of both feet of the examined boys showed a tendency to flatten in direct proportion to the age of the examined boys. The arches of the foot differ, however, between the right and left roof. Zdunek M.K. et al. [17] confirmed that people practicing the above disciplines have hollow long arches of the foot. Additionally, the results of the research carried out by the authors showed differences in the distribution of forces on the sole of the foot depending on the sports discipline practiced. In the throwing group, in the right and left feet, the front part of the foot was loaded more frequently, while in the jumping group, the back of the foot was more loaded in the right and left feet. The authors concluded that the observed differences probably resulted from the fact that, due to the specificity of the sports discipline, players have different morphological profiles. The authors of this study also noticed that the studied footballers were mostly characterized by a hollow longitudinal arch. Due to the specifics of their discipline, players are more likely to put stress on the rear of the left foot and the front of the right foot.

5. Conclusions

- The total length of the longitudinal arch of both feet of the examined boys showed a tendency to flatten in direct proportion to the age of the examined boys. The arches of the foot differ, however, between the right and left roof. If this tendency is maintained in the left foot, it does not take such a strong direction in the right foot.
- The youngest group of the boys under study showed the greatest deviations of the balance, while the group subjected to training for the longest time (the group of the oldest boys) had distinct smaller deviations of the pressure center.
- In the youngest group of boys, correlations between body balance deviations and waist–hip index were observed.
- The given mean values of the body composition parameters reflect changes with the ontogenetic development, basic somatic parameters (body height and weight) and training experience, and thus with the intensity and volume of training.

Some aspects require further research. The dominant side of the respondents should be taken into account, which may be the reason for the observed differences. The observed correlations may suggest a relationship between body composition parameters and the ability to maintain balance and stabilization performance.

Practical Implication

The training rigor supports the proper development of children and has a positive effect on balance and body composition. An important aspect of the training process is not to overtrain the players so that the training is beneficial and supports the natural ontogenetic development.

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