Akademia Wychowania Fizycznego im. Eugeniusza Piaseckiego w Poznaniu

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Rozprawa doktorska

Stabilność posturalna oraz jej zmiany pod wpływem treningu proprioceptywnego z wykorzystaniem rzeczywistości wirtualnej u pracowników wysokościowych

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im. Eugeniusza Piaseckiego w Poznaniu

W formie cyklu artykułów opublikowanych w czasopismach naukowych

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Doctoral dissertation

Postural stability and its changes under the influence of proprioceptive training with the use of virtual reality in workers working at the height

In the form of series of articles published in scientific journals

Supervisor:

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Spis treści

Objaśnienia stosowanych w pracy symboli/ Explanation of used symbols

AP - kierunek przednio - tylny (ang. *anterio-posterior*)

BMI - wskaźnik masy ciała (ang. *body mas index*)

BOS - płaszczyzna podparcia (ang. *base of support*)

CG - grupa kontrolna (ang. *control group*)

COM - środek masy (ang. *center of mass*)

COP - środek nacisku stóp (ang. *centre of pressure*)

EC - grupa eksperymentalna (ang. *experimental group*)

EC HT DT - oczy zamknięte, wyższe zagrożenie (1 m od podłoża), podwójne zadanie (ang. *eyes closed, high threat (1m above the ground), dual task*)

EC HT QS - oczy zamknięte, wyższe zagrożenie, stanie swobodne (ang. *eyes closed, high threat, quiet standing*)

EC LT DT - oczy zamknięte, niższe zagrożenie (na poziomie podłoża), podwójne zadanie (ang. *eyes closed, low threat (ground level), dual task*)

EC LT QS - oczy zamknięte, niższe zagrożenie, stanie swobodne (ang. *eyes closed, low threat, quiet standing*)

EO HT DT - oczy otwarte, wyższe zagrożenie, podwójne zadanie (ang. *eyes open, high threat, dual task*)

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EO LT QS - oczy otwarte, niższe zagrożenie, stanie swobodne (ang. *eyes open, low threat, quiet standing*)

HR - częstość skurczów serca (ang. *heart rate*)

HW - pracownicy wysokościowi (ang. *workers working at the height*)

ML - kierunek przyśrodkowo-boczny (ang. *medio-lateral*)

OLST-EO - test stania na jednej nodze z oczami otwartymi (ang. *one-leg standing test with eyes open*)

OLST-EC - test stania na jednej nodze z oczami zamkniętymi (ang. *one-leg standing test with eyes closed*)

OW - pracownicy biurowi (ang. *office workers*)

PA - aktywność fizyczna (ang. *physical activity*)

PS - stabilność posturalna (ang. *postural stability*)

SP - całkowita długość przemieszczeń środka nacisku ciała (ang. *sway path*)

VR - wirtualna rzeczywistość (ang. *virtual reality*)

I. Autoreferat w języku polskim

Rozprawę doktorską oparto o cykl publikacji pod wspólnym tytułem: „Stabilność posturalna oraz jej zmiany pod wpływem treningu proprioceptywnego z wykorzystaniem rzeczywistości wirtualnej u pracowników wysokościowych". W skład dysertacji wchodzą trzy prace opublikowane w czasopismach o zasięgu międzynarodowym.

W publikacji pierwszej i drugiej przeprowadzone zostało badanie przekrojowe, mające na celu porównanie grup pracowników wysokościowych oraz pracowników biurowych w kontekście oceny poziomu stabilności posturalnej, aktywności fizycznej oraz stresu sercowo-naczyniowego. Natomiast w trzeciej publikacji przeprowadzone zostało badanie eksperymentalne, które wiązało się z oceną efektywności treningu proprioceptywnego z wykorzystaniem technologii wirtualnej rzeczywistości.

1. Cyma, M., Marciniak, K., Tomczak, M., Stemplewski, R. (2018). Postural stability and physical activity of workers working at height. *Am J Men's Health*, 12(4), 1068–1073, doi: 10.1177/1557988318774996; IF – 2,141, punktacja MNiSW – 20 pkt.
2. Cyma-Wejchenig, M., Maciaszek, J., Marciniak, K., Stemplewski, R. (2020). The Effects of Cognitive Task and Change of Height on Postural Stability and Cardiovascular Stress in Workers Working at Height. *Int J Environ Res Public Health*, 17(18):E6541, doi:10.3390/ijerph17186541; IF – 2,849, punktacjaMNiSW – 70pkt.
3. Cyma-Wejchenig, M., Tarnas, J., Marciniak, K., Stemplewski, R. (2020).The Influence of Proprioceptive Training with the Use of Virtual Reality on Postural Stability of Workers Working at Height. *Sensors*, 20(13), doi: 10.3390/s20133731; IF – 3.510, punktacja MNiSW – 100 pkt.

Łącznie IF – 8,500, punktacja MNiSW – 190 pkt (w tym 20 pkt wg starej punktacji + 170 pkt wg nowej punktacji MNiSW).

Prace opublikowane poza cyklem:

1. Marciniak, K., Maciaszek, J., Cyma-Wejchenig, M., Szeklicki, R., Maćkowiak, Z., Sadowska, D., Stemplewski, R. (2020). The Effect of Nordic Walking Training with Poles with an Integrated Resistance Shock Absorber on the Functional Fitness of Women over the Age of 60. *Int J Environ Res Public Health*, 25;17(7):2197, doi: 10.3390/ijerph17072197, IF – 2,849, punktacja MNiSW – 70pkt.

Ogólny dorobek:

Łącznie IF – 11,349, punktacja MNiSW – 260 pkt., cytowania – 4, indeks Hirscha – 2

1. Wstęp

Branża budowlana charakteryzuje się wysoką liczbą wypadków ciężkich i śmiertelnych. W szczególności praca na wysokości zaliczana jest do tych najbardziej niebezpiecznych (Jebelli, Ahn i Stentz, 2016). Wypadki spowodowane upadkami z wysokości są główną przyczyną zgonów i obrażeń, stanowiąc ponad 33% wszystkich wypadków budowlanych (NSC 2013, BLS 2013). Według statystyk ich liczba na przestrzeni ostatnich dwóch dekad nie zmniejszyła się, pomimo zaostrzonych wytycznych dotyczących miejsca pracy, jak i doskonalenia praktyki zawodowej (BLS 2013). Do pracy na wysokościach zostają zakwalifikowane tylko osoby doświadczone, które posiadają odpowiednie cechy psychofizyczne. Pracownicy wysokościowi powinni przejść badania lekarskie, w tym okulistyczne, neurologiczne i laryngologiczne (BLS, 2013). Według definicji Administracji ds. Bezpieczeństwa i Zdrowia w Pracy (ang. *Occupational Safety and Health Administration*) (2016) każda praca, podczas której różnica poziomów między stanowiskiem pracy a podłożem grozi upadkiem z wyższego poziomu na niższy, to praca na wysokości, np.: na rusztowaniach, drabinach lub innych podwyższeniach.

Zgodnie z polskim Kodeksem pracy (Dz Ustawa nr 69, poz. 332) osoby pracujące na wysokości powyżej 1 metra, powinny być przebadane pod kątem stabilności posturalnej[1] (PS, ang. *postural stability*). Jednak minimalne wymagania dotyczące potencjalnego pracownika i zakres przeprowadzanych badań nie są jednoznacznie określone (Zamysłowska-Szmytke i Śliwińska-Kowalska, 2012; Dz Ustawa nr 69, poz. 332). W ostatniej dekadzie sektor bezpieczeństwa i higieny pracy rozwinął się w celu zapewnienia bezpiecznych warunków i praktyk pracy wśród pracowników wysokościowych. Niestety zawód ten nadal pozostaje niebezpieczny. Ponadto pracownicy wysokościowi (HW, ang. *workers working at the height*) posiadają niską świadomość zagrożenia związanego ze swoją pracą, co prowadzi do bagatelizowania przez nich ryzyka, a w konsekwencji do wypadków (European Commission, 2009). Aby skutecznie zapobiec wypadkom w tej branży, ważne jest zrozumienie, jakie sytuacje do nich prowadzą.

Jednym z głównych czynników przyczyniających się do wypadków wśród pracowników wysokościowych jest utrata PS (Nadhim i wsp., 2016). Takie wypadki często prowadzą do poważnych skutków, takich jak złamania, krwiaki, rozległe siniaki, a nawet śmierć

[1] W piśmiennictwie stosuje się zróżnicowaną terminologię w odniesieniu do zbliżonych zagadnień dotyczących wyprostowanej postawy ciała opisywanych na bazie analizy wskaźników posturogarficznych (często z zastosowaniem analogicznych metod pomiaru). W celu ujednolicenia wywodu, w dalszej części opracowania, stosowany będzie termin „stabilność posturalna" również w przypadkach cytowania prac, gdzie w stosowane były inne terminy, tj. „równowaga ciała" i/lub „kontrola posturalna".

(Wade, Davisi i Weimar, 2014). PS jest uważana za zdolność, w której ośrodkowy układ nerwowy wykorzystuje bodźce sensoryczne odbierane przez narządy zmysłów do utrzymania pionowej postawy ciała. Degradacja lub defekt w którymkolwiek z tych systemów zwiększa prawdopodobieństwo niestabilności postawy, a tym samym możliwość upadku (Chander, Garner i Wade, 2014).

Przeciwdziałanie zaburzeniom PS jest skuteczne tylko wtedy, gdy układ nerwowy jest w stanie zidentyfikować destabilizujący bodziec w ciągu 70–100 ms. Ponadto musi wykonać zestaw typowych wzorców i synergii mięśniowych, które przywracają PS, w oparciu o szybkie automatyczne reakcje (Tao, Khan i Blohm, 2018). Adkin i wsp. (2000) zauważyli, że im większy jest zestaw wzorców i synergii mięśniowych, tym dłuższy jest proces doboru odpowiedniej reakcji motorycznej. Na podstawie tych badań można przypuszczać, że jeśli potencjalne wzorce i synergie mięśniowe wykorzystywane do wyrównania PS zostaną ograniczone do minimum, to utrzymanie prawidłowej postawy ciała będzie skuteczniejsze. Davis i wsp. (2009) analizując korelacje między strachem przed upadkiem a kontrolą postawy wykazali, że takie strategie kompensacyjne można zauważyć u osób starszych a także u stojących na niestabilnym podłożu czy dużych wysokościach. Możliwe jest, że u pracowników wysokościowych dochodzi do automatyzacji ww. strategii, jak również zmniejszenia liczby możliwych wzorców ruchowych w celu utrzymania prawidłowej PS. Huffman i wsp. (2009) zauważyli, że zwiększone ryzyko związane z utrzymaniem postawy wyprostowanej, wpływa bezpośrednio na kontrolę postawy ciała.

Na podstawie dostępnych wyników badań, dotyczących ryzyka upadków można stwierdzić, że postawa ciała kontrolowana jest przez zwiększenie aktywności nerwowo-mięśniowej mięśni kończyn dolnych (Vuillerme i Nafati, 2007). W zależności od wielkości zaburzenia pionowej pozycji ciała, wykorzystywana jest strategia stawu skokowego, stawu biodrowego lub strategia kroku (Allum, Carpenter i Honegger, 2003). Reakcja stawu skokowego występuje gdy przy nieznacznym zaburzeniu PS osoby stojącej aktywowane są mięsnie brzuchate łydki przy ruchu do tyłu, a następnie mięśnie piszczelowe przednie podczas wychylenia ciała do przodu (Ogaya, Okita i Fuchioka, 2016). Strategia stawu biodrowego jest wykorzystywana przy większych zaburzeniach PS. W tym przypadku mięśniami odpowiadającymi za przywrócenie PS ciała są zginacze i prostowniki stawu biodrowego. W sytuacji, gdy dwie pierwsze strategie nie są wystarczające, wykorzystywana jest strategia kroku, polegająca na poszerzeniu płaszczyzny podparcia, w celu skorygowania zakłóceń. Wykorzystywana jest w przypadku, gdy pionowy rzut środka ciężkości przekroczy fizjologiczne granice stabilności (Cheng i Yeh, 2015). Skuteczne stosowanie wszystkich trzech strategii i wykorzystywanie ich we właściwej kolejności może redukować ryzyko upadku. (Rogers i Mille 2018).

Carpenter i wsp. (2006) w swoich badaniach wykazali, że zwiększony niepokój jest skorelowany z usztywnieniem stawu skokowego u młodszych i starszych dorosłych. Takie zjawisko zauważono już przy wysokości 0,4 m. Na podstawie innych badań, zauważa się również, że niepokój i subiektywny stres wywołany strachem przed upadkiem, wpływa na układ nerwowo-mięśniowy zarówno u osób zdrowych, jak i chorych (Davis i wsp., 2009). Ponadto badani znajdujący się w warunkach stresowych, wywołanych zwiększaniem zagrożenia wynikającego np. ze zmiany wysokości, wykorzystują strategie utrzymania wyprostowanej postawy ciała oparte na automatycznych reakcjach (Carpenter i wsp., 2006; Sturnieks i wsp., 2016; Kogan i wsp., 2008). Podobne reakcje zaobserwowano także w grupie HW (Min, Kim i Parnianpour, 2012; Koepp, Snedden i Levine, 2015). Możliwe jest, że ze względu na specyficzne warunki pracy, a także związane z nią ryzyko, HW skutecznie wykorzystują wszystkie trzy strategie w celu utrzymania PS. Spekuluje się, że u HW może dochodzić do automatyzacji systemu odpowiedzialnego za utrzymanie stabilnej postawy (Redfern, Yardley i Bronstein, 2001).

Utrzymanie PS jest trudne ze względu na ciągłe zmiany rzutu pionowego środka masy (COM, ang. *center of mass*) na płaszczyznę podparcia (BOS, ang. *base of suport*), na które mogą mieć wpływ czynniki środowiskowe i wewnętrzne (Chander i wsp., 2019). System kontroli postawy składa się ze współpracujących ze sobą układów mięśniowo-szkieletowego i ośrodkowego układu nerwowego (Smalley, White i Burkard, 2018). Owa współpraca uzależniona jest również od jakości odbioru i przetwarzania informacji sensorycznej. W kontroli stabilności postawy ważna jest integracja informacji somatosensorycznych (np. informacja o długości i napięciu mięśni oraz ścięgien pochodząca z wrzecionka mięśniowego lub aparatu Golgiego), przedsionkowych (np. informacja o kątowych zmianach pozycji głowy z kanałów półkolistych narządu przedsionkowego) i układu wzrokowego (np. informacja dotycząca pola widzenia z narządu wzroku) (Jeter i wsp., 2015). Układy sensoryczne są ze sobą ściśle powiązane, co pozwala prawidłowo interpretować rzeczywistość i odpowiednio na nią reagować. Taka integracja sensoryczna pozwala odbierać wrażenia płynące z ciała i środowiska w taki sposób, by mogły być użyte do celowego działania (Nishiike i wsp., 2013; Smalley, White i Burkard, 2018). W przypadku, gdy jeden z tych układów jest zagrożony lub informacja sensoryczna jest niedokładna, może dojść do zaburzenia PS (Assländer, Hettich i Mergner, 2015).

Hsiao i Symeonowa (2001) zauważyli, że ruchome sceny wizualne a także percepcja głębi wpływają negatywnie na stabilność posturalną. Stwierdzono również, że na obniżenie poziomu PS wpływa wykonywanie zadań na wysokości. Zaburzenia stabilności podczas wykonywania zadań na wysokości są wzmacniane bodźcami odbieranymi przez układ wzrokowy, które mogą powodować dodatkowy niepokój, ponieważ zadanie wydaje się niebezpieczne (Orrell, Masters i Eves, 2009; Huffman i wsp., 2015).

Innym czynnikiem wpływającym na stabilność posturalną, może być wykonywanie podwójnych zadań lub przełączanie się między nimi. Skuteczność kontroli postawy podczas wykonywania zadnia podwójnego może zmaleć w porównaniu do wykonywania jedynie pojedynczego zadania (Cullen i Agnew, 2016). Ponadto w tym przypadku, aby nie dopuścić do utraty stabilności, a w konsekwencji do upadków ważne jest swobodne dzielenie uwagi pomiędzy wykonywanymi zadaniami (Schnittje, 2017).

Kolejnym czynnikiem wpływającym na poziom PS może być aktywność fizyczna (PA, ang. *physical activity*), a także jej rodzaj (aktywność fizyczna w pracy, sportowa i rekreacyjna) (Gram i wsp., 2016). Punakallio (2003) badała wpływ wieku, zawodu i aktywności fizycznej na funkcjonalną i posturalną stabilność pracowników fizycznych. Pracownicy o wyższym poziomie PA, charakteryzowali się wyższym poziomem PS. Również Prioli i wsp. (2005) wykazali, że PA wydaje się pomagać w utrzymaniu odpowiedniego poziomu kontroli postawy i interakcji sensorycznej.

Bezpieczeństwo pracowników wysokościowych zależy od właściwego użytkowania sprzętu i zachowania ostrożności podczas wykonywanej pracy, ale przede wszystkim od wiedzy praktycznej i posiadanych umiejętności (Antwi-Afari i wsp., 2018). Bardzo istotnym elementem w ochronie pracownika przed upadkiem są treningi i szkolenia w tym zakresie (Shia i wsp., 2019; Wang i wsp., 2018; Wilkins, 2011). Kluczowym czynnikiem determinującym zachowanie pracowników wysokościowych i ich bezpieczeństwo jest zdolność do identyfikacji i oceny ryzyka, która nabywana jest przez szkolenia i doświadczenie.

W programach kształcenia w zakresie inżynierii budowlanej, szybkie uznanie zyskały technologie wirtualnej rzeczywistości [2] (VR, ang. *virtual reality*) (Wang i wsp., 2018). Metody te pozwalają zrozumieć, jak pracownicy reagują na niebezpieczne warunki związane z takimi zdarzeniami jak poślizgnięcia, potknięcia i utrata równowagi (Antwi-Afari i wsp., 2018).

[2] Wirtualna rzeczywistość (VR) polega na multimedialnym kreowaniu komputerowej wizji przedmiotów, przestrzeni i zdarzeń. W wąskim znaczeniu termin stosuje się do zanurzenia (imercji) w przestrzeni cyfrowej z wykorzystaniem specjalnych gogli lub wieloekranowych pomieszczeń. W szerszym znaczeniu VR stosowana jest również do emitowanych obrazów na ekranach zewnętrznych, z którymi użytkownik może wchodzić w interakcję, jak w przypadku gier aktywizujących (ang. exergames) na konsole typu Nintendo Wii lub Play Station. W tym opracowaniu termin VR użyto w szerszym znaczeniu.

Przykładowo Rokooei i Goedert (2015) badali możliwość wykorzystania VR w edukacji budowlanej. Na podstawie badań można stwierdzić, że VR jest skutecznym narzędziem, a także wspiera rozwój edukacji w zakresie zarządzania budową. Ponadto szkolenie oparte na grach z wykorzystaniem symulacji i modelowania może być z powodzeniem zastosowane w programach kształcenia w zakresie bezpieczeństwa pracy (Goedert i wsp., 2016).

Donath, Rossler i Faude (2016) w swoich badaniach wykazali, że nowa technologia, znalazła zastosowanie również podczas treningów. Ten uzupełniający i alternatywny rodzaj treningu może wypełnić lukę między graniem a ćwiczeniami (Boulos i Yang, 2013). Dzięki technologiom VR można skuteczniej trenować i wzmacniać poszczególne partie ciała oraz w prosty sposób dostosowywać trening do indywidualnych możliwości i potrzeb (Chander i wsp., 2019). Z przeglądu piśmiennictwa wynika, że środowisko VR może być z powodzeniem stosowane do poprawy ogólnej sprawności fizycznej i PS, a także w celach terapeutycznych (Lange i wsp., 2012; Guo i wsp., 2012). Schubert i wsp., (2015) w swoich badaniach wykazali, że eksperci w grach wideo, w przeciwieństwie do osób bez doświadczenia, są lepsi w wielu dziedzinach wymagających uwagi wzrokowej. Przykładowo w zakresie progu percepcji i szybkości przetwarzania obrazu. VR została również zintegrowana z innymi ewoluującymi technologiami i badaniami. Wirtualne eksperymenty nad bezpieczeństwem w czasie pracy, takie jak postrzeganie ryzyka lub czynniki kulturowe mogą zwiększyć wydajność edukacji i szkoleń w przemyśle budowlanym, w szczególności wśród HW (Habibnezhad i wsp., 2019; Wang i wsp., 2018).

W XXI wieku popularnym sprzętem treningowym stały się platformy balansowe umożliwiające ćwiczenia proprioceptywne z wykorzystaniem VR. Pozwalają one odtwarzać naturalne poczucie niestabilności, dzięki któremu ciało zmuszone jest do wykonania większej pracy (Rizzo i wsp., 2002). Można w ten sposób ćwiczyć mięśnie, stymulować szybkość reakcji oraz kształtować PS (Kalron i wsp., 2016; Ko i wsp., 2015). Trening tego typu może przynieść dodatkowe efekty w stosunku do tych osiąganych podczas standardowych ćwiczeń równoważnych, co można przewidywać na podstawie badań dotyczących osób chorych i zdrowych, a także młodych i starszych (Schwenk i wsp., 2014; Srivastava i wsp., 2009; Ko i wsp., 2015).

VR może być używana jako kompleksowy system integrujący niezbędne elementy do aktywnego uczenia grupy pracowników wysokościowych (Lia i wsp., 2018). Przykładowo Amritha i wsp. (2016) badali efekt wykorzystania platformy balansowej, która zapewnia statyczne i dynamiczne treningi równowagi poprzez interaktywne gry z VR dla osób z zaburzeniami PS. W swoich badaniach autorzy wykazali, że trening znacznie poprawia poziom PS i wpływa pozytywnie na czynności dnia codziennego. Również Wang i wsp. (2014) analizowali skuteczność wykorzystania poważnych gier w technologii 4D (3D + czas) w szkoleniach z zakresu bezpieczeństwa i higieny pracy w budownictwie. Odnotowano, że VR może zwiększyć zaangażowanie użytkowników i wpłynąć na ich zdolność do wykrywania zagrożeń dla BHP. Podobne wnioski przedstawili Strobach, Frensch i Schubert (2012), którzy wykazali, że praktyka gier wideo poprawia umiejętności kontroli wykonawczej podczas wykonywania zadania podwójnego.

Uzasadnienie podjęcia badań

Jak dotąd nadal niejasny jest mechanizm działania czynników wpływających na poziom stabilności posturalnej wśród pracowników wysokościowych. Spekuluje się, że cechą charakterystyczną pracowników wysokościowych jest zwiększony stopień automatyzacji systemów odpowiedzialnych za kontrolę postawy (Huweler i wsp., 2009). Ponadto, wciąż nie jest znany mechanizm działania czynników wpływających na stabilność postawy w miejscu pracy czy w terenie. Brak jest badań dotyczących analizy stabilności postawy związanej z poziomem aktywności fizycznej pracowników wysokościowych.

Choć udokumentowano wpływ zagrożeń na modyfikację kontroli postawy, wciąż niewiele jest informacji o mechanizmach i strategiach, które te zmiany spowodowały, zwłaszcza wśród pracowników wysokościowych (Umer i wsp., 2018; Willmann i wsp., 2012). Do tej pory badania koncentrowały się na wpływie określonych warunków (pojedyncze-podwójne zadanie kognitywne) lub określonego poziomu wysokości (niskie-wysokie zagrożenie). W piśmiennictwie trudno odnaleźć badania dotyczące pracowników wysokościowych, w których zwrócono by uwagę jednocześnie na wszystkie ww. warunki badania.

Nie stwierdzono prac dotyczących stabilności posturalnej oraz jej zmian pod wpływem treningu proprioceptywnego z wykorzystaniem VR u pracowników wysokościowych. Niejednoznaczny jest też wpływ warunków pracy oraz wieloletniego doświadczenia na poziom ich stabilności posturalnej. W piśmiennictwie odnaleziono jedynie prace ukazujące wykorzystanie treningów z elementami VR wśród osób starszych bądź chorych, co mogłoby sugerować możliwość ich wykorzystania u pracowników wysokościowych (Ciou i wsp., 2015; Kümmel i wsp., 2016; Maciaszek, 2018). Nie oceniano również tego zagadnienia w próbie z wykorzystaniem pojedynczego lub podwójnego zadania z oczami otwartymi lub zamkniętymi u pracowników wysokościowych.

W związku z lukami w istniejącym piśmiennictwie zaplanowano projekt badawczy dotyczący stabilności posturalnej oraz jej zmiany pod wpływem treningu proprioceptywnego z wykorzystaniem rzeczywistości wirtualnej u pracowników wysokościowych. Utrzymanie właściwej sprawności lokomocyjnej i odpowiedniego poziomu stabilności posturalnej w grupie pracowników wysokościowych może zapobiegać wypadkom, zmniejszać ryzyko urazów i upadków, a w konsekwencji zapobiegać niepełnosprawności czy śmierci.

2. Cele i Hipotezy

2.1. Cel badań

Głównym celem pracy była ocena wpływu treningu proprioceptywnego na platformie balansowej z wykorzystaniem VR na stabilność posturalną pracowników wysokościowych.

Sformułowano następujące cele szczegółowe:

1. Ocena poziomu stabilności posturalnej u pracowników wysokościowych w odniesieniu do pracowników biurowych (*publikacja 1*).
2. Ocena związku między stabilnością postawy a aktywnością fizyczną u pracowników wysokościowych i biurowych *(publikacja 1)*.
3. Ocena różnic w stabilności postawy ciała u pracowników wysokościowych w odniesieniu do pracowników biurowych przy zmianie wysokości platformy pomiarowej *(publikacja 2)*.
4. Ocena różnic w stabilności postawy ciała u pracowników wysokościowych w odniesieni do pracowników biurowych przy dodatkowym zadaniu poznawczym *(publikacja 2)*.
5. Ocena zmiany częstości skurczów serca u pracowników wysokościowych w odniesieniu do pracowników biurowych w niebezpiecznych warunkach spowodowanych zmianą wysokości platformy pomiarowej *(publikacja 2)*.
6. Ocena wpływu treningu proprioceptywnego z wykorzystaniem VR na poziom stabilności posturalnej pracowników pracujących na wysokości. W szczególności oceniano różnice w stabilności postawy ciała po treningu w przypadku standardowego testu stabilności w warunkach:
    1) oczu otwartych,
    2) redukcji bodźców wzrokowych,
    3) zmiany wysokości platformy pomiarowej oraz
    4) wprowadzenia dodatkowych zadań kognitywnych *(publikacja 3)*.

2.2. Hipotezy badawcze

Weryfikacji poddane zostały następujące hipotezy:

1. Wyższym poziomem stabilności posturalnej charakteryzuje się grupa pracowników wysokościowych w odniesieniu do pracowników biurowych *(publikacja 1)*.
2. Poziom i rodzaj aktywności fizycznej pracowników wysokościowych i pracowników biurowych jest dodatnio skorelowany z poziomem stabilności posturalnej *(publikacja 1)*.
3. Zwiększenie wysokości platformy pomiarowej w większym stopniu zaburza stabilność postawy w grupie pracowników biurowych niż pracowników wysokościowych *(publikacja 2)*.
4. Stabilność postawy podczas wykonywania zadania poznawczego jest wyższa w grupie pracowników wysokościowych niż wśród pracowników biurowych *(publikacja 2)*.
5. Podczas zmiany wysokości, u pracowników biurowych występuje wyższy poziom częstości skurczów serca niż u osób pracujących na dużych wysokościach *(publikacja 2)*.
6. Trening proprioceptywny na platformie balansowej z wykorzystaniem VR wpływa pozytywnie na poziom stabilności posturalnej pracowników wysokościowych. Zwiększenie stabilności posturalnej można zauważyć w przypadku standardowego testu stabilności w warunkach:
   1) oczu otwartych,
   2) redukcji bodźców wzrokowych,
   3) zmiany wysokości płaszczyzny testowej oraz
   4) wprowadzenia dodatkowego zadania kognitywnego *(publikacja 3)*.

3. Grupa badana i metody badań

3.1. Grupa badana

Badania zostały zaakceptowane przez Komisję Bioetyczną Uniwersytetu Medycznego w Poznaniu (Decyzja nr 1111/16) i są zgodne z Deklaracją Helsińską. Wszyscy uczestnicy zostali szczegółowo poinformowani o badaniu i wyrazili pisemną zgodę poddania się procedurze badawczej.

Kryteria włączenia do poszczególnych grup podlegających badaniu były następujące: minimalny wiek 20 lat, wysokie umiejętności w zakresie komunikacji werbalnej, możliwość udzielenia przemyślanych i logicznych odpowiedzi, wysoka mobilność oraz w przypadku pracowników wysokościowych co najmniej rok doświadczenia w pracy na wysokości.

Publikacja 1

Badaniami objęto grupę 17 zdrowych mężczyzn pracujących na wysokości. Natomiast grupę kontrolną stanowiło 17 pracowników biurowych (OW, ang. *office workers*).

Publikacja 2

Badaniem objęto grupę 16 mężczyzn pracujących na wysokościach oraz 16 mężczyzn pracujących biurowo.

Publikacja 3

W badaniu wzięło udział 24 zdrowych mężczyzn pracujących na wysokości w wieku od 22 do 47 lat. Uczestników podzielono losowo (program Excel) na dwie grupy:

- Grupa eksperymentalna (EG, ang. *experimental group*) - trening na platformie balansowej z wykorzystaniem VR –początkowe: n = 12, końcowe: n = 10;
- Grupa kontrolna (CG, ang. *control group*) –brak treningu - początkowe: n = 12, końcowe: n = 11;

W rezultacie w badaniu wzięło udział 21 mężczyzn z obu grup. Żaden z badanych nie miał wcześniejszego doświadczenia w treningu na platformie balansowej z wykorzystaniem VR.

3.2. Pomiary wstępne – charakterystyki somatyczne

Przed badaniem wykonano pomiary cech somatycznych, tj. pomiaru wysokości i masy ciała oraz obliczono wskaźnik masy ciała (BMI, ang. *body mas index*) pracowników wysokościowych i biurowych. Ponadto przeprowadzono wywiady z respondentami i oceniono ich ogólny stan zdrowia i samopoczucia.

Nie stwierdzono istotnych statystycznie różnic między grupami pod względem wieku i BMI.

3.3. Pomiary

Poziom aktywności fizycznej

Publikacja 1

Poziom PA (aktywność fizyczna w pracy, sportowa i rekreacyjna) został oceniony na podstawie kwestionariusza Baecke'a (Baecke, Burema i Frijters, 1982). Jest to narzędzie badawcze rzetelne i wiarygodne do pomiaru nawykowej PA (Florindo, i Latorre, 2003). Wynik oparto na wzorze i kodach dołączonych do kwestionariusza, przedstawiających intensywność i czas trwania aktywności.

Publikacja 2 i 3

PA została oceniona za pomocą urządzenia Caltrac (Muscle Dynamics, Inc., Tarrance, CA), które podaje wyniki wydatku energetycznego na podstawie pomiaru przyspieszeń ciała (Bassett i wsp., 2015, Młynarski i wsp., 2014). Badani nosili Caltrac przez 7 dni. Całkowity wynik kcal został dzielony przez liczbę dni i masę ciała, aby otrzymać wartości względne.

Stabilność posturalna

Publikacja 1

Do oceny PS wykorzystano test stania na jednej nodze z oczami otwartymi (OLST-EO, ang. *one-leg standing test with eyes open*) i zamkniętymi (OLST-EC, ang. *one-leg standing test with eyes closed*). Podczas badania, pracownik stał wyprostowany, z opuszczonymi kończynami górnymi wzdłuż tułowia, najpierw na jednej nodze z otwartymi, a następnie z zamkniętymi oczami. Odliczanie było przerywane, gdy podniesiona noga dotknęła podłogi lub gdy badany odsunął ręce od ciała, aby ustabilizować swoją pozycję. Przyjęto, że test jest wykonany prawidłowo jeśli badany utrzymuje pozycje przez 45 sekund w przypadku oczu otwartych i 15 sekund w przypadku oczu zamkniętych. (Zasadzka i Wieczorowska-Tobis, 2012).

Publikacja 2 i 3

Do zebrania danych związanych z przemieszczeniem środka nacisku stóp (COP, ang. *centre of pressure*) zastosowano przenośną płytę siłową AccuGait (Model AMTI PJB-101, AMTI, Watertown, MA). Oprogramowanie Balance Trainer (dostarczone przez producenta) zostało użyte do połączenia platformy z komputerem. Częstotliwość próbkowania wynosiła 100 Hz (Ruhe, Fejer i Walker, 2010; Bizid i wsp., 2009). W badaniu zostały przeanalizowane długość ścieżki przemieszczeń COP (SP) oraz jego składowych w kierunkach przednio-tylnym (AP, ang. *anterio-posterior*) i przyśrodkowo-bocznym (ML, ang. *medio-lateral*).

Podczas badania, pracownik stał nieruchomo na środku platformy z bosymi stopami rozstawionymi na szerokość bioder i ramionami wzdłuż tułowia. Platforma posturograficzna była umieszczona 3 metry przed białą ścianą.

Następujące próby dotyczyły:

Publikacja 2

- Stanie swobodne z otwartymi oczami przeprowadzone na poziomie podłoża i na wysokości 1 metra.

- Stanie z zadaniem kognitywnym przeprowadzone na poziomie podłoża i na wysokości 1 metra, polegającym na odliczaniu w czasie rejestracji danych co trzecią liczbę wstecz od liczby 200 (Sample i wsp., 2016).

Publikacja 3

- EO LT QS - oczy otwarte, niższe zagrożenie (na poziomie podłoża), stanie swobodne (ang. *eyes open, low threat (ground level), quiet standing*).
- EO LT DT - oczy otwarte, niższe zagrożenie, podwójne zadanie (ang. *eyes open, low threat, dual task*).
- EO HT QS - oczy otwarte, wyższe zagrożenie (1 m od podłoża), stanie swobodne (ang. *eyes open, high threat (1m above the ground), quiet standing*).
- EO HT DT - oczy otwarte, wyższe zagrożenie, podwójne zadanie (ang. *eyes open, high threat, dual task*).

Wszystkie zadania przy oczach zamkniętych (EC, ang. *eyes close*) wykonywane były analogicznie jak przy oczach otwartych (odpowiednio, EC LT QS, EC LT DT, EC HT QS, EC HT DT).

Testy wykonywane były w kolejności losowej (aby uniknąć czynnika uczenia się) na poziomie podłogi oraz wysokości 1 metra od podłoża. Każda próba trwała 30 sekund i wykonywana była dwukrotnie (pod uwagę brano średnią z 2 prób). Ze względu na dużą liczbę prób, zastosowane zostały 20-sekundowe przerwy pomiędzy pomiarami. W przypadku wystąpienia zawrotów głowy lub zmęczenia, uczestnicy mogli również odpocząć w pozycji siedzącej. W związku z tym, że żaden z uczestników nie zgłosił podobnych dolegliwości, podczas wszystkich testów na niskim lub wysokim poziomie, pozostawali oni na tym samym poziomie platformy.

Stres sercowo-naczyniowy

Publikacja 2

Jako fizjologiczny i psychologiczny wskaźnik stresu zmierzono częstość skurczów serca w spoczynku i porównano ze wzrostem częstości skurczów serca podczas wykonywania zadania (Min, Kim i Parnianpour, 2012; Sandercock i wsp., 2005). Podczas pomiaru odczytywano ciśnienie krwi i zmiany częstości skurczów serca (McCraty i Shaffer, 2015).

Analiza statystyczna

Wszystkie obliczenia wykonano przy użyciu Statistica v. 13.0 software (Tibco Software Inc., Palo Alto, CA, USA). Poziom istotności statystycznej ustalono na $p \leq 0,05$.

Publikacja 1

Do oceny różnic między grupami w zakresie zmiennych ilościowych (stanie na jednej nodze z otwartymi i zamkniętymi oczami, wskaźniki aktywności fizycznej, BMI, wiek) zastosowano test T-studenta dla danych niezależnych. W celu określenia korelacji między zmiennymi obliczono współczynniki r Pearsona, natomiast w celu porównania grup pod względem testu stania na jednej nodze z zamkniętymi oczami, pod kontrolą aktywności fizycznej, zastosowano analizę kowariancji (ANCOVA).

Publikacja 2

Do oceny różnić pomiędzy podstawowymi zmiennymi tj. wiek, BMI, wskaźniki aktywności fizycznej został wykorzystany test T-studenta. Do analizy stabilności postawy i stresu sercowo-naczyniowego zastosowano dwukierunkową analizę wariancji (ANOVA). Oceniono następujące efekty interakcji: „wysokość × grupa" i „zadanie × grupa" (z dwoma poziomami dla każdego czynnika: niskie-wysokie zagrożenie oraz z zadaniem kognitywnym lub bez zadania kognitywnego w obu grupach HW i OW), oraz efekty główne dla warunków badania ("wysokość", "zadanie") i efekt międzygrupowy ("grupa").

Publikacja 3

Główne obliczenia związane z oceną zróżnicowania zmiennych zależnych oparto na metodzie analizy wariancji ANOVA (test F). Zastosowano analizę z uwzględnieniem czynnika międzygrupowego (z poziomami EG i CG) oraz czynnika powtarzanego pomiaru „time" (z poziomami Pre i Post). Oceniono efekty interakcji i efekty główne. Analogiczne obliczenia zostały zastosowane dla wszystkich analiz związanych z eksperymentem: EO LT QS, EO LT DT, EO HT QS, EO HT DT, EC LT QS, EC LT DT, EC HT QS i EC HT DT.

3.4. Interwencja

Publikacja 3

Grupa eksperymentalna uczestniczyła w treningu proprioceptywnym na platformie balansowej z wykorzystaniem VR przez 6 tygodni, po 30 minut na sesję, dwa razy w tygodniu. Wymagany był 100% udział w szkoleniach (12x). Do treningu wykorzystano platformę balansową - Sigma (element ACX. rehab), będącą nowoczesnym urządzeniem do treningu propriocepcji z wykorzystaniem VR (platforma balansowa Sigma, prod. AC International). Platforma ocenia zmianę kąta wychylenia przy pomocy żyroskopu. Częstotliwość próbkowania wynosi 40 Hz, a opóźnienie 25 ms. Za pomocą czujnika Bluetooth odbywa się transmisja w czasie rzeczywistym do komputera z oprogramowaniem.

Podczas szkolenia wykorzystano audiowizualne sprzężenie zwrotne ułatwiające ćwiczenia w postaci gier wideo, które były proste i obejmowały poruszające się obiekty, takie jak ryba, samolot, samochód i piłki. Przykładowo w grze „rybka," badany miał za zadanie, odpowiednio balansując na platformie, poruszać niebieskim kółkiem, aby chronić źródło iskier przed rybą. Owe źródło było bezpieczne gdy znajdowało się w środku koła. Celem treningu (według producenta urządzenia) było powtarzanie ruchów w przestrzeni 3D, a także trening ruchów planowanych, precyzji ruchów, koordynacji wzrokowo-ruchowej czy wzmocnienie siły mięśniowej.

Każdy trening na platformie zaczynał się od najprostszych zadań i stopniowo przechodził do bardziej złożonych i skomplikowanych ćwiczeń. Podczas interwencji badany stał nieruchomo na środku platformy ze stopami rozstawionymi na szerokość bioder tak, aby znajdowały się one po przeciwnych stronach dysku, ale równolegle do siebie. Platforma była umieszczona 2 metry przed stojakiem z monitorem emitującym gry. Uczestnik został poproszony o wykonanie zadania zgodnie z instrukcjami zawartymi w grach. Podczas interwencji balansował swoim ciałem stojąc na platformie i wykonywał ćwiczenia Każdy badany był proszony o każdorazowe rozegranie pełnego zestawu, gier. Długość pojedynczej gry ustawiono na 2-3 minuty tak, aby sesja, łącznie z przerwami związanymi z przełączaniem pomiędzy grami, wynosiła około 30 minut. Badani mogli także odpoczywać w pozycji siedzącej przez 30–60 sekund po każdej grze.

4. Wyniki oraz ich omówienie

Publikacja 1

Postural stability and physical activity of workers working at height. *Am J Men's Health*, 2018, 12(4), 1068–1073, doi: 10.1177/1557988318774996

Celem pracy była analiza poziomu stabilności postawy i aktywności fizycznej w grupie pracowników wysokościowych. Oceniono również związek między stabilnością postawy a aktywnością fizyczną.

Za pomocą kwestionariusza Baecke'a oceniono PA. Grupa HW charakteryzowała się najwyższą aktywności fizyczną w czasie pracy i najniższą w czasie wolnym. Natomiast w grupie OW odnotowano odwrotne tendencje. Zmniejszona aktywność rekreacyjna grupy HW może być uzasadniona zwiększoną aktywnością w czasie pracy (Chau i wsp., 2012; Clemes, O'Connell i Edwardson, 2014). Jednak w przeciwieństwie do korzyści zdrowotnych związanych z PA w czasie wolnym, wysoki poziom zawodowej PA może wpływać na mechaniczne obciążenie mięśniowo-szkieletowe i zwiększać ryzyko urazów (Krause et al. 2007). Porównywalne wyniki w ogólnym poziomie PA w obu grupach mężczyzn mogą być związane z podobnym wiekiem, preferowanym stylem życia czy modelem rodziny.

Podobne wyniki uzyskała Punakallio (2003), która analizowała stabilność posturalną i funkcjonalną pracowników wykonujących prace fizyczne w zależności od wieku, wykonywanego zawodu i poziomu PA. Pracownicy fizyczni charakteryzowali się wyższym poziomem równowagi funkcjonalnej i PA. W innych badaniach zauważono, że PA wydaje się pomagać w utrzymaniu odpowiedniego poziomu kontroli postawy ciała i interakcji sensorycznej (Prioli i wsp., 2005).

Do oceny stabilności postawy wykorzystano test stania na jednej nodze z oczami otwartymi (OLST-EO) i zamkniętymi (OLST-EC). Grupa HW osiągała wyższe wyniki w obu testach PS w porównaniu do grupy OW, ale istotne statystycznie wyniki odnotowano jedynie w przypadku próby OLST-EC. Stwierdzono również, że poziom PA nie miał wpływu na uzyskane wyniki. Na podstawie badań można przypuszczać, że rodzaj i charakter wykonywanej pracy może wpływać na poziom PS grupy HW (Gatti, Giovanni i Migliaccio, 2014; Yang i wsp., 2017). Min, Kim i Parnianpour (2012) w swoich badaniach wykazali, że niższy poziom doświadczenia pracownika i wyższa wysokość rusztowania wpływa na znaczne obniżenie stabilności postawy przy jednoczesnym zwiększeniu stresu sercowo-naczyniowego. Również na podstawie badań DiDomenico i wsp. (2010), można stwierdzić, że miejsce pracy i doświadczenie HW wpływa na PS niezależnie od branży i wieku pracownika. Ponadto kontrola postawy może być też precyzyjnie dopasowana do poziomu zagrożenia i zwiększać się wraz z poziomem doświadczenia (czyli wcześniejszego wielokrotnego doświadczania sytuacji zagrożenia) badanej osoby (Adkin i wsp., 2000).

Publikacja 2

The Effects of Cognitive Task and Change of Height on Postural Stability and Cardiovascular Stress in Workers Working at Height. Int J Environ Res Public Health, 2020, 17(18), 6541, doi:10.3390/ijerph17186541.

Celem pracy była ocena różnic w poziomie stabilności posturalnej ciała w różnych warunkach: zarówno przy zmianie wysokości platformy pomiarowej, jak i podczas wykonywania dodatkowego zadania kognitywnego. Ocenione zostały również zmiany częstości skurczów serca w niebezpiecznych warunkach spowodowanych zmianą wysokości platformy.

Wpływ wysokości na stabilność posturalną pracowników

Analizując wyniki stwierdzono, że niezależnie od badanej grupy (HW i OW) zmiana wysokości podczas stania swobodnego powoduje pogorszenie PS (Cleworth i Carpenter, 2016; Adkin i wsp., 2000; Sturnieks i wsp., 2016; Zaback, Carpenter i Adkin, 2016). W próbach stania swobodnego wraz ze wzrostem wysokości, na której stał badany, stwierdzono zwiększoną długość ścieżki przemieszczania się COP w obu grupach. W grupie HW zmiany były niższe (co może wskazywać na wyższy poziom PS) we wszystkich analizowanych parametrach. Na podstawie badań innych autorów można przypuszczać, że wyższa PS w grupie HW wynika z codziennego treningu poszczególnych grup mięśniowych wykorzystywanych w codziennych zadaniach zawodowych pracowników wysokościowych. Ponadto ważną rolę może też odgrywać trening równowagi związany z warunkami i charakterem pracy oraz poziomem PA pracowników (Gatti, Giovanni i Migliaccio, 2014; Yan i wsp., 2017; Cyma i wsp., 2018).

Powyższe wyniki znalazły swoje uzasadnienie zarówno w badaniach Adkin i wsp. (2000) jak również Sturnieks i wsp. (2016). Autorzy obserwowali czy kontrola postawy koreluje z poziomem ryzyka postawy takich jak zmiana wysokości podestu. Analizowano także wpływ wieku, lęku i obawy o upadek na zwiększonej wysokości. W obu badaniach zaobserwowano, że w sytuacjach zwiększonego ryzyka postawy, takich jak zmiana wysokości platformy, zwiększa się kontrola postawy wśród badanych. Ponadto kontrola PS była dokładnie dopasowana do poziomu zagrożenia i zwiększała się wraz z poziomem doświadczenia (tj. wcześniejszym doświadczaniem zagrożenia postawy) badanego. Osoby odczuwające lęk przyjęły również strategię zwiększonej kontroli równowagi.

Wpływ wykonywania zadań kognitywnych na stabilność posturalną pracowników

W próbie zadania kognitywnego odnotowano większą długość ścieżki COP w porównaniu do zadania kontrolnego. Chociaż istnieją znaczne różnice w parametrach sygnału COP między próbą kontrolną a zadaniem kognitywnym, zmiana wysokości nie wpłynęła na PS obu grupach. Niższy poziom zmian COP i jej składników w kierunku AP i ML został odnotowany w grupie HW podczas wykonywania zadania kognitywnego i zmianie wysokości. Na podstawie wyników można przypuszczać, że wykonywanie zadania i zmiana wysokości nie wpływają w istotny sposób na poziom PS w grupie doświadczonych HW (DiDomenico i wsp., 2010; Cullen i Agnew, 2016; Schnittjer, 2017). Lęk przed upadkiem i wcześniejsze doświadczenia w pracy na wysokości mogą odgrywać ważną rolę w kształtowaniu zmian w strategiach kontroli postawy w warunkach wysokiego ryzyka spowodowanych zmianami wysokości (Adkin i Carpenter, 2018; Yang i wsp., 2017; Sibley i wsp., 2010; Davis i wsp., 2009). Na podstawie badań można przypuszczać, że osoby z mniejszą odpornością na sytuacje lękowe i stresowe mogą stosować strategie, które nie sprzyjają utrzymaniu kontroli postawy, gdy ryzyko zagrożenia postawy wzrasta w przypadku zwiększenia wysokości platformy, na której stoi, wykonywania zadań lub przetwarzania informacji wizualnej. W takim kontekście powyższa sytuacja może powodować większą niestabilność posturalną tych osób (Hainaut i wsp., 2011; Sibley i wsp., 2010; Redfern, Furman i Jacob, 2007).

Przykładowo Pellecchia (2003) badała czy PS u młodych dorosłych zmienia się pod wpływem trzech zadań kognitywnych w zależności od ich stopnia trudności. Autorka wykazała, że na PS wpłynęło odliczanie, co 3 w tył, czyli wykonywanie najtrudniejszego zadania. Podczas tej próby odnotowano również najdłuższą ścieżkę przemieszczania się COP. Warty podkreślenia jest fakt, iż wraz z trudnością wykonywania zadania wzrastała długość ścieżki. Efekty te mogą mieć uzasadnienie w wynikach badań uzyskanych w tym artykule. Przypuszczać można, że niezależnie od branży i wieku pracowników, typowe czynności wykonywane podczas pracy na dużych wysokościach oraz zwiększona świadomość zagrożeń związanych z postawą u HW, wpływają w nieznacznym stopniu na poziomi ich stabilności posturalnej.

Wpływ wysokości na stres sercowo-naczyniowy

Analiza stresu sercowo-naczyniowego wykazała istotny efekt interakcji. Podobnie jak w przypadku stabilności posturalnej częstość skurczów serca podczas wykonywania zadania wzrosła wraz ze zwiększeniem wysokości platformy pomiarowej w obu grupach (Kaskutas i wsp., 2009; Chang i wsp., 2009; Min, Kim i Parnianpour, 2012). Odnotowano istotny statystycznie efekt główny „wysokość", który wynikał ze zmian w grupie OW. Niższy poziom stresu sercowo-naczyniowego w grupie HW może wynikać z doświadczenia zawodowego, związanego z takimi zadaniami jak budowa, rozbiórka i modyfikowanie rusztowań na wysokich budynkach, co z kolei zmusza pracowników do radzenia sobie z precyzyjną pracą i trudnymi warunkami atmosferycznymi, takimi jak silny wiatr, deszcz i śnieg (Min, Kim i Parnianpour, 2012, Zamysłowska-Szmytke i Śliwińska-Kowalska, 2012; DiDomenico i wsp., 2010). Ponadto można też przypuszczać, że wysokość 1 metra była niewystarczająco groźna aby wywołać istotne statystycznie indywidualne zmiany w grupie HW (Sturnieks i wsp., 2016; Davis i wsp., 2009).

W badaniu Hsu i wsp. (2016) jak również Min, Kim i Parnianpour (2012) uzyskano podobne rezultaty. Najprawdopodobniej, wpływ wysokości powierzchni roboczej znacząco wpływa na poziom stresu sercowo-naczyniowego i PS. Zauważono, że poziom stresu jest dodatnio skorelowany ze zwiększeniem wysokości powierzchni roboczej. Duże znaczenie odgrywa też doświadczenie pracowników. U niedoświadczonych pracowników wraz ze zwiększeniem wysokości platformy, PS znacznie się zmniejsza, podczas gdy, stres sercowo-naczyniowy wzrasta. Zbliżone wyniki zostały uzyskane w niniejszym artykule.

Publikacja 3

The Influence of Proprioceptive Training with the Use of Virtual Reality on Postural Stability of Workers Working at Height. *Sensors*, 2020, 20(13), 3731. doi:10.3390/s20133731.

Celem pracy była ocena wpływu treningu proprioceptywnego z wykorzystaniem VR na poziom stabilności posturalnej pracowników pracujących na wysokości. Oceniono również wpływ treningu na poziom stabilności posturalnej w przypadku zastosowania: (1) standardowego testu stabilności przy oczach otwartych, (2) redukcji bodźców wzrokowych, (3) zmiany wysokości płaszczyzny testowej oraz (4) wprowadzenia dodatkowego zadania kognitywnego.

Wpływ interwencji na stabilność postawy przy otwartych oczach

Trening proprioceptywny na platformie balansowej z wykorzystaniem VR znacząco poprawia poziom PS zarówno w warunkach na poziomie podłoża, jak i na zwiększonej wysokości platformy pomiarowej (Esculier i wsp., 2012; Ciou i wsp., 2015). W próbach stania swobodnego przy kontroli wzrokowej na obu wysokościach, uzyskano zmniejszenie ogólnej długości ścieżki przemieszczania się COP oraz jej składowych w kierunku przód-tył (SPAP) i prawo-lewo (SPML). We wszystkich analizowanych parametrach grupa EG osiągnęła niższe wyniki po treningu. Ten rodzaj treningu mógł wpływać na zaangażowanie poszczególnych grup mięśni wykorzystywanych w zadaniach wykonywanych na platformie balansowej. Na podstawie wyników można przypuszczać, że trening VR niweluje nie tylko negatywny wpływ wysokości, ale także bodźców wzrokowych na poziom PS. Można również przypuszczać, że trening VR wpływa pozytywnie na system wizualno-przedsionkowo-somatosensoryczny. Carozza i wsp., (2013) badali możliwość wykorzystania gogli VR do szkolenia pracowników budowlanych w zakresie umiejętności rozpoznawania ryzyka. Autorzy zauważyli, że wykonywanie realistycznego treningu niweluje ryzyko, związane z wykonywaniem zadań w warunkach rzeczywistych. Aktualnie nie ma badań dotyczących wpływu treningu VR na platformie balansowej na poziom PS pracowników wysokościowych. Dowodów pośrednich można szukać w badaniach z wykorzystaniem interaktywnych treningów u osób starszych lub chorych. Przykładowo Schwenk i wsp. (2014) zauważyli, że osoby starsze zagrożone upadkiem mogą skorzystać na uczestnictwie w programie interaktywnego treningu równowagi opartego na czujnikach wizualnego sprzężenia zwrotnego ruchu.

W próbach stania kognitywnego przy kontroli wzrokowej na obu wysokościach, grupa EG osiągnęła po treningu niższe wyniki we wszystkich analizowanych parametrach COP (SP, SPAP i SPML). Prawdopodobnie zwiększenie zaangażowania kognitywnego podczas wykonywania realistycznych zadań w treningu VR wpłynęło na wyższy poziom PS w grupie EG. Na podstawie badań można przypuszczać, że poza wartością rozrywkową, gry mogą zapewnić poprawę zdolności uwagi wzrokowej, integracji sensorycznej, możliwości percepcyjnych a także przełączania się między zadaniami (Cain, Landau i Shimamura, 2012; Green i wsp., 2012). Jak dotąd nie przeprowadzono badań u pracowników wysokościowych dotyczących wpływu treningu VR na platformie balansowej na poziom PS w próbie podwójnego zadania z otwartymi oczami. Jednak badania wśród graczy wykazały pozytywny wpływ gier na wykonywanie zadań kognitywnych (Colzato i wsp., 2013; Strobach, Frensch i Schubert 2012).

Wpływ interwencji na stabilność postawy przy zamkniętych oczach

Grupa EG w próbach stania swobodnego bez kontroli wzrokowej osiągnęła niższe wyniki (co może świadczyć o wyższym poziome PS) po treningu we wszystkich analizowanych parametrach PS na obu wysokościach. Na podstawie wyników można przypuszczać, że grupa EG podczas próby w celu utrzymania stabilności posturalnej, w przeciwieństwie do grupy CG polegała bardziej na propriocepcji a mniej na bodźcach wzrokowych. Na podstawie badań można stwierdzić, że poleganie na propriocepcji wiąże się ze zwiększonymi możliwościami utrzymania stabilności posturalnej, ponadto zdolność tę można z powodzeniem rozwijać (Hutt i Redding, 2014). Można przypuszczać, że takie zdolności zostały podniesione w grupie EG podczas treningu proprioceptywnego na platformie balansowej z wykorzystaniem VR. Hutt i Redding (2014) zauważyli, że program treningowy oparty na ograniczeniu bodźców wzrokowych może wpływać na zwiększenie poziomu PS.

W próbach stania kognitywnego na poziomie podłoża bez kontroli wzrokowej grupa EG uzyskała pozytywne efekty treningu, osiągając niższe wyniki we wszystkich analizowanych parametrach COP (SP, SPAP i SPML). Przypuszczalnie wyższa PS w grupie EG wynika z codziennego treningu propriocepcji, a także poszczególnych grup mięśniowych wykorzystywanych w codziennych zadaniach zawodowych oraz warunków i charakteru pracy uczestników badania (Colzato i wsp., 2013; Umer i wsp., 2018).

W próbie EC HT DT nie stwierdzono istotnych statycznie zmian w obu grupach. Pomimo, że trening był wykonywany wyłącznie przy oczach otwartych, wyniki pomiaru z oczami zamkniętymi były zbliżone do istotnych statystycznie. Niewątpliwa trudność wykonywanego zadania, a także niewystarczające poleganie na propriocepcji przy braku kontroli wzrokowej mogła wpływać na wynik interwencji. Prawdopodobnie kontynuacja treningu spowodowałaby uzyskanie istotnych różnic także w tej próbie. Na podstawie badań można stwierdzić, że trening z wykorzystaniem gier może być z powodzeniem wykorzystywany w celu poprawy PS. Po sześciu tygodniach uczestnictwa w treningu z wykorzystaniem gier u zdrowych osób starszych, zauważono zwiększenie PS we wszystkich analizowanych próbach (Van Diest i wsp., 2015). W innych badaniach wykazano, że gry wideo poprawiają wydajność w różnych zadaniach a także mogą zwiększać umiejętności percepcyjne, w tym uwagę, zdolności pamięci, pamięć roboczą i wykonywanie podwójnych zadań. Wyniki tych badań świadczą o potencjalnej przydatności gier i ich praktycznego zastosowania w świecie rzeczywistym, między innymi do rehabilitacji lub szkolenia umiejętności związanych z pracą na wysokości (Green i Baveliera, 2015).

Zastosowanie praktyczne

Na podstawie uzyskanych wyników można zauważyć, że trening proprioceptywny na platformie balansowej z wykorzystaniem VR może mieć szereg pozytywnych efektów, które wydają się być trudne do osiągnięcia podczas standardowych ćwiczeń równoważnych. Niewykluczone, że trening tego typu, można skutecznie włączyć do szkolenia w zakresie bezpieczeństwa pracowników budowlanych, aby zmniejszyć częstotliwość wypadków związanych z zaburzeniami stabilności posturalnej podczas pracy na wysokości.

5. Wnioski

1. Pracownicy wysokościowi charakteryzują się wyższym poziomem stabilności posturalnej w odniesieniu do pracowników biurowych *(publikacja 1)*.
2. Zbliżony ogólny poziom aktywności fizycznej pracowników wysokościowych i biurowych może wskazywać, iż na stabilność postawy wpływa raczej narażenie na stresujące warunki, takie jak praca na wysokości *(publikacja 1)*.
3. Wyższy poziom stabilności posturalnej pracowników wysokościowych, może wskazywać, że zwiększone ryzyko utrzymania stabilności posturalnej prowadzi do bardziej świadomej kontroli postawy w tej grupie *(publikacja 2)*.
4. Wyższa stabilność postawy podczas wykonywania zadania poznawczego w grupie pracowników wysokościowych może wskazywać, że strategia kontroli postawy przyjmowana w warunkach spowodowanych zwiększonym zagrożeniem posturalnym kształtowana jest przez ich doświadczenie zawodowe *(publikacja 2)*.

5. W grupie pracowników wysokościowych narażenie na warunki stresowe wypływa w mniejszym stopniu na stabilność postawy, niż w grupie pracowników biurowych *(publikacja 2)*.
6. Trening proprioceptywny na platformie balansowej z wykorzystaniem VR poprawia poziom stabilności posturalnej we wszystkich analizowanych próbach niskiego–wysokiego zagrożenia, oczu otwartych – oczu zamkniętych oraz pojedynczego–podwójnego zadania *(publikacja 3)*.

- Trening proprioceptywny na platformie balansowej z wykorzystaniem VR może być odpowiednim elementem do bezpośredniego treningu układu wzrokowo-przedsionkowo-somatosensorycznego, w celu wyuczenia pracowników wysokościowych adekwatnej reakcji na zagrożenia bez narażania ich na niebezpieczeństwo.
- Trening proprioceptywny na platformie balansowej z wykorzystaniem VR prawdopodobnie skutkował większym zaangażowaniem poznawczym pracowników wysokościowych, a także mógł zwiększyć skuteczność przełączania się między zadaniami.
- Można przypuszczać, że trening proprioceptywny z wykorzystaniem VR przyczynił się do większego polegania na propriocepcji, a w mniejszym stopniu na kontroli wzrokowej, w zachowania stabilności posturalnej.

II. Dissertation summary

This doctoral dissertation is based on a series of publications under the common title: "Postural stability and its changes under the influence of proprioceptive training with the use of virtual reality in workers working at the height". The dissertation consists of three papers published in international journals.

In the first and second publications, a cross-sectional study was conducted to compare groups of workers at height and office workers in the context of assessing the level of postural stability, physical activity, and cardiovascular stress. In the third publication, an experimental study was carried out, which was related to the assessment of the effectiveness of proprioceptive training with the use of virtual reality technology.

1. Cyma, M., Marciniak, K., Tomczak, M., Stemplewski, R. (2018). Postural stability and physical activity of workers working at height. *Am J Men's Health*, 12(4), 1068–1073, doi: 10.1177/1557988318774996; IF – 2,141, scoring by the Ministry of Science and Higher Education – 20 points.

2. Cyma-Wejchenig, M., Maciaszek, J., Marciniak, K., Stemplewski, R. (2020). The Effects of Cognitive Task and Change of Height on Postural Stability and Cardiovascular Stress in Workers Working at Height. *Int J Environ Res Public Health*, 17(18):E6541, doi:10.3390/ijerph17186541; IF – 2,849, scoring by the Ministry of Science and Higher Education – 70 points.
3. Cyma-Wejchenig, M., Tarnas, J., Marciniak, K., Stemplewski, R. (2020).The Influence of Proprioceptive Training with the Use of Virtual Reality on Postural Stability of Workers Working at Height. *Sensors*, 20(13), doi: 10.3390/s20133731; IF – 3.510, scoring by the Ministry of Science and Higher Education – 100 points.

Total IF – 8,500, scoring by the Ministry of Science and Higher Education – 190 points (including 20 points according to the old score + 170 points according to the new scoring of the Ministry of Science and Higher Education).

Works published outside the cycle:

1. Marciniak, K., Maciaszek, J., Cyma-Wejchenig, M., Szeklicki, R., Maćkowiak, Z., Sadowska, D., Stemplewski, R. (2020). The Effect of Nordic Walking Training with Poles with an Integrated Resistance Shock Absorber on the Functional Fitness of Women over the Age of 60. *Int J Environ Res Public Health*, 25;17(7):2197, doi: 10.3390/ijerph17072197, IF – 2,849, scoring by the Ministry of Science and Higher Education – 70 points.

Overall achievements:

Total IF – 11,349, scoring by the Ministry of Science and Higher Education – 260 points, citations – 4, Hirsch index – 2

1. Introduction

The construction industry is characterized by a high number of severe and fatal accidents. In particular, working at height is one of the most dangerous (Jebelli, Ahn, & Stentz, 2016). Accidents caused by falls from a height are the leading cause of death and injury, accounting for over 33% of all construction accidents (NSC 2013, BLS 2013). According to statistics, their number has not decreased over the last two decades, despite stricter guidelines for the workplace and professional practice development (BLS 2013). Only experienced people with appropriate psychophysical features are qualified to work at heights. Workers at height should undergo medical examinations, including ophthalmological, neurological and laryngological (BLS, 2013). According to the definition of the Occupational Safety and Health Administration (2016), any work in which the difference in levels between the workplace and the ground is likely to fall from a higher level to a lower level is work at height, e.g. on scaffolding, ladders or other platforms.

Pursuant to the Polish Labour Code (Journal of Laws no. 69, item 332), persons working at a height of more than 1 meter should be tested for postural stability[3] (PS). However, the minimum requirements for a potential employee and the scope of the research to be carried out are not clearly defined (Zamysłowska-Szmytke, & Śliwińska-Kowalska, 2012; Journal of Laws no. 69, item 332). In the last decade, the occupational health and safety sector has developed to provide safe working conditions and practices for workers at height. Unfortunately, this profession remains dangerous. In addition, workers working at the height (HW) have a low awareness of the risks associated with their work, which leads them to downplay the risk and, consequently, to accidents (European Commission, 2009). In order to successfully prevent accidents in this industry, it is important to understand what situations lead to them.

One of the major contributors to accidents among workers at height is the loss of PS (Nadhim et al., 2016). Such accidents often lead to serious consequences such as fractures, hematomas, extensive bruising, and even death (Wade, Davis, & Weimar, 2014). PS is considered to be the ability by which the central nervous system uses sensory inputs received by the sense organs to maintain an upright body posture. A degradation or defect in any of these systems increases the probability of postural instability and thus the possibility of a fall (Chander, Garner, & Wade, 2014).

Counteracting PS disturbances is effective only if the nervous system is able to identify the destabilizing stimulus within 70–100 ms. In addition, it must perform a set of common muscle patterns and synergies that restore PS, based on fast automatic responses (Tao, Khan, & Blohm, 2018). Adkin et al. (2000) noted that the larger the set of patterns and muscle synergies, the longer the process of selecting the appropriate motor response. Based on these studies, it can be assumed that if the potential muscle patterns and synergies used to balance PS are kept to a minimum, maintaining a correct body posture will be more effective. Davis et al. (2009), analysing the correlations between the fear of falling and the postural stability, showed that such compensation strategies can be noticed in the elderly as well as in people standing on unstable ground or at high altitudes. It is possible that in the case of at-height workers, to

[3] In the references, various terminology is used to refer to similar issues regarding body posture described on the basis of the analysis of upright posture indicators (often using analogous measurement methods). In order to standardize the argument, the term “postural stability” will be used later in the study also in cases of citing studies where other terms were used, such as “body balance” and/or “postural control”.

automate the above-mentioned strategy as well as reducing the number of possible movement patterns in order to maintain normal PS. Huffman et al. (2009) noted that the increased risk associated with maintaining an upright posture directly influenced postural control.

Based on the available research results regarding the risk of falls, it can be concluded that body posture is controlled by an increase in the neuromuscular activity of the muscles of the lower extremities (Vuillerme, & Nafati, 2007). Depending on the size of the disturbance in the vertical position of the body, the ankle, hip, or step strategy is used (Allum, Carpenter, & Honegger, 2003). The reaction of the ankle joint occurs when, with a slight disturbance of the PS of a standing person, the gastrocnemius muscles are activated when moving backwards, and then the tibial muscles during the forward inclination (Ogaya, Okita, & Fuchioka, 2016). The hip strategy is used for major PS disturbance. In this case, the muscles responsible for restoring the PS of the body are the hip flexors and extensors. In a situation where the first two strategies are not sufficient, a step strategy is used to widen the support plane to correct for disturbances. It is used when the vertical projection of the centre of gravity exceeds the physiological limits of stability (Cheng, & Yeh, 2015). Successfully applying all three strategies and using them in the correct order can reduce the risk of a fall. (Rogers, & Mille 2018).

Carpenter et al. (2006) showed in their studies that increased anxiety is correlated with stiffening of the ankle joint in younger and older adults. Such a phenomenon has already been noticed at a height of 0.4 m. Based on other studies, it is also noticed that anxiety and subjective stress caused by fear of falling affect the neuromuscular system in both healthy and sick people (Davis et al., 2009). In addition, subjects in stressful conditions, caused by increasing the risk of, e.g., height changes, use strategies to maintain an upright body posture based on automatic reactions (Carpenter et al., 2006; Sturnieks et al., 2016; Kogan et al., 2008). Similar reactions were also observed in the HW group (Min, Kim, & Parnianpour 2012; Koepp, Snedden, & Levine, 2015). It is possible that, due to the specific working conditions and the risks involved, HW are effectively using all three strategies to maintain PS. It is speculated that HW may automate the system responsible for maintaining a stable posture (Redfern, Yardley, & Bronstein, 2001).

Maintaining PS is difficult due to the constant changes in the vertical projection of the center of mass (COM) onto the base of support (BOS), which may be influenced by environmental and internal factors (Chander et al., 2019). The posture control system consists of cooperating musculoskeletal and central nervous system (Smalley, White, & Burkard, 2018). This cooperation also depends on the quality of the reception and processing of sensory information. In the control of postural stability, it is important to integrate somatosensory information (e.g. information on the length and tension of muscles and tendons coming from the muscle spindle or Golgi apparatus), vestibular information (e.g. information on angular changes in the position of the head from the semi-circular canals form the vestibular organ) and the visual system (e.g. information on the field of view from the organ of vision) (Jeter et al., 2015). Sensory systems are closely related to each other, which allows correctly to interpret reality and react to it appropriately. Such sensory integration allows the perception of body and environmental sensations in such a way that they can be used for deliberate actions (Nishiike, et al., 2013; Smalley, White, Burkard, 2018). When one of these systems is compromised or the sensory information is inaccurate, PS disturbance may develop (Assländer, Hettich, & Mergner, 2015).

Hsiao and Symeonowa (2001) noticed that moving visual scenes as well as depth perception adversely affect postural stability. It was also found that the performance of tasks at height affects the reduction of PS level. Stability disturbances when performing tasks at altitude are amplified by stimuli perceived by the visual system, which may cause additional anxiety because the task appears to be dangerous (Orrell, Masters, & Eves, 2009; Huffman et al., 2015).

Another factor that affects postural stability is performing or switching between dual tasks. The effectiveness of postural control when performing a double task may decrease compared to performing only a single task (Cullen, and Agnew, 2016). Moreover, in this case, in order to avoid loss of stability and, consequently, falls, it is important to freely divide attention between the tasks performed (Schnittje, 2017).

Another factor influencing the PS level may be physical activity (PA), as well as its type (physical activity at work, sports, and recreation) (Gram et al., 2016). Punakallio (2003) investigated the effects of age, occupation, and physical activity on the functional and postural stability of manual workers. Employees with a higher PA level were characterized by a higher PS level. Also, Prioli et al. (2005) showed that PA appears to help maintain an adequate level of postural control and sensory interaction.

The safety of workers at height depends on the proper use of equipment and caution during the work performed, but most of all on practical knowledge and skills (Antwi-Afari et al., 2018). A very important element in protecting the employee against falling is training and educating in this area (Shia et al., 2019; Wang et al., 2018; Wilkins, 2011). A key factor in determining the behaviour of workers at height and their safety is the ability to identify and assess risks, which is acquired through training and experience.

Virtual reality (VR) technologies[4] (VR) have gained quick recognition in construction engineering education programs (Wanget al., 2018). These methods help understand how workers react to dangerous conditions related to events such as slips, trips, and loss of balance (Antwi-Afari et al., 2018). For example, Rokooei, & Goedert (2015) studied the possibility of using VR in construction education. Based on the research, it can be concluded that VR is an effective tool and supports the development of construction management education. In addition, game-based training using simulation and modelling can be successfully applied to occupational safety education programs (Goedert et al., 2016).

Donath, Rossler and Faude (2016) showed in their research that the new technology was also used during training. This complementary and alternative type of training can bridge the gap between playing and exercising (Boulos, & Yang, 2013). Thanks to VR technologies, it is possible to train and strengthen individual parts of the body more effectively, and to easily adapt training to individual abilities and needs (Chander et al., 2019). The literature review shows that the VR environment can be successfully used to improve overall physical fitness and PS, as well as for therapeutic purposes (Lange et al., 2012; Guo et al., 2012). Schubert et al., (2015) showed in their research that video game experts, as opposed to inexperienced people, are better in many areas requiring visual attention. For example, in terms of the threshold of perception and the speed of image processing. VR has also been integrated with other evolving technologies and research. Virtual safety experiments at work, such as risk perceptions or cultural factors, can increase the efficiency of education and training in the construction industry, in particular among HW (Habibnezhad et al., 2019; Wang et al., 2018).

In the 21st century, balance platforms enabling proprioceptive exercises with the use of VR became a popular training equipment. They can recreate the natural sense of instability that forces the body to do more work (Rizzo et al., 2002). In this way, muscles can be trained, reaction speed can be stimulated and PS shaped (Kalron et al., 2016; Ko et al., 2015). This type of training may bring additional effects compared to those achieved during standard equivalent exercises, which can be predicted from studies on sick and healthy people, as well as young and old people (Schwenk et al., 2014; Srivastava et al., 2009; Ko et al., 2015).

VR can be used as a comprehensive system integrating the necessary elements for active learning of a group of employees at height (Lia et al., 2018). For example, Amritha et al., (2016) studied the effect of using a balance platform that provided static and dynamic balance training

[4] Virtual reality (VR) is based on the multimedia creation of a computer vision of objects, spaces and events. In a narrow sense, the term is used for immersion in digital space with the use of special goggles or multi-screen rooms. In a broader sense, VR is also applied to images broadcast on external screens with which the user can interact, such as in the case of exergames for consoles such as Nintendo Wii or Play Station. The term VR is used in a broader sense in this study.

through interactive VR games for people with PS disorders. In their research, the authors showed that training significantly improves PS levels and has a positive effect on everyday activities. Also Wang et al. (2014) analysed the effectiveness of the use of serious games in 4D technology (3D + time) in training in occupational health and safety in construction. It has been reported that VR can increase user engagement and affect their ability to detect OSH hazards. Similar conclusions were presented by Strobach, Frensch, & Schubert, (2012), who showed that the practice of video games improves the skills of executive control when performing a dual task.

Justification for undertaking research

So far, the mechanism of action of factors influencing the level of postural stability among employees at height is still unclear. It has been speculated that a hallmark of workers at height is the increased degree of automation of posture control systems (Huweler et al., 2009). In addition, the mechanism of action of factors influencing postural stability in the workplace or in the field is still unknown. There are no studies on the analysis of postural stability related to the level of physical activity of employees at height.

Although the impact of threats on modifying posture control has been documented, there is still little information about the mechanisms and strategies that caused these changes, especially among workers at height (Umer et al., 2018; Willmann et al. 2012). Until now, research has focused on the effect of certain conditions (single-double cognitive task) or a certain level of altitude (low-high risk). In the literature, it is difficult to find research on at-height workers in which all the above-mentioned test conditions.

There were no studies on postural stability and its changes under the influence of proprioceptive training with the use of VR in workers at height. The influence of working conditions and many years of experience on the level of their postural stability is also ambiguous.

In the literature, only studies showing the use of training with VR elements among the elderly or sick have been found, which could suggest the possibility of their use in height workers (Ciou et al., 2015; Kümmel et al., 2016; Maciaszek, 2018). It was also not assessed in a single or dual task with eyes open or closed in height workers.

Due to gaps in the existing literature, a research project was planned on postural stability and its changes under the influence of proprioceptive training using virtual reality in at-height workers. Maintaining proper motion efficiency and an appropriate level of postural stability for this group of employees may prevent accidents, reduce the risk of injuries and falls, and, consequently, prevent disability or death.

2. The purpose and hypotheses

2.1. Purpose of the study

The main aim of the study was to assess the impact of proprioceptive training on a balance platform using VR on the postural stability of workers working at height.

The following specific objectives were formulated:

1. Assessment of the level of postural stability in at-height workers in relation to office workers (*publication 1*).
2. Assessment of the relationship between postural stability and physical activity in at-height and office workers *(publication 1)*.
3. Assessment of differences in the postural stability in at-height workers compared to office workers when changing the height of the measuring platform *(publication 2)*.
4. Assessment of differences in the postural stability in at-height workers compared to office workers for an additional cognitive task *(publication 2)*.
5. Assessment of changes in heart rate in workers at height in relation to office workers in dangerous conditions caused by a change in the height of the measuring platform *(publication 2)*.
6. Assessment of the impact of proprioceptive training with the use of VR on the level of postural stability of workers working at height. In particular, differences in post-training postural stability were assessed for the standard stability test under the following conditions:
   1) open eyes,
   2) reduction of visual stimuli,
   3) changes in the height of the measurement platform and
   4) introducing additional cognitive tasks *(publication 3)*.

2.2. Research hypotheses

The following hypotheses were verified:

1. A higher level of postural stability is found in the group of at-height workers in relation to office workers *(publication 1)*.
2. The level and type of physical activity of at-height workers and officer workers is positively correlated with the level of postural stability *(publication 1)*.
3. Increasing the height of the measurement platform more disturbs the stability of the posture in the group of office workers than in the group of at-height workers *(publication 2)*.

4. The postural stability during the performance of a cognitive task is higher in the group of at-height workers than among office workers *(publication 2)*.
5. When changing altitude, office workers have a higher level of heart rate than those working at high altitudes *(publication 2)*.
6. Proprioceptive training on a balance platform with the use of VR has a positive effect on the level of postural stability of workers working at height. The increase in postural stability can be seen with the standard stability test under the conditions of:
   1) open eyes,
   2) reduction of visual stimuli,
   3) changes in the height of the test plane, and
   4) introducing an additional cognitive task *(publication 3)*.

3. Materials and Methods

3.1. Characteristics of the Research Group

The research was approved by the Bioethics Committee of the Medical University of Poznań (Decision no. 1111/16) and is in line with the Helsinki Declaration. All participants were informed in detail about the study and gave their written consent to undergo the study procedure.

The inclusion criteria for each study group were as follows: minimum age of 20 years, high verbal communication skills, the ability to provide thoughtful and logical answers, high mobility and in the case of employees at height, at least one year of experience in working at height.

Publication 1

The study included a group of 17 healthy men working at height. The control group consisted of 17 office workers (OW).

Publication 2

The study included a group of 16 men working at heights and 16 men working in the office.

Publication 3

The study involved 24 healthy men aged 22 to 47 working at height. The participants were randomly divided (Excel) into two groups:

- Experimental group (EG) – training on a balance platform with the use of VR – initial: n = 12, final: n = 10;
- Control group (CG) – no training – initial: n = 12, final: n = 11;

As a result, 21 men from both groups took part in the study. None of the subjects had previous experience in training on a balance platform using VR.

3.2. Initial measurements – somatic characteristics

Before the examination, measurements of somatic features, i.e. height and weight, were performed, and the body mass index (BMI) of at-height and office workers was calculated. In addition, respondents were interviewed and their overall health and well-being was assessed.

There were no statistically significant differences between the groups in terms of age and BMI.

3.3. Measurements

The level of physical activity

Publication 1

The level of PA (physical activity at work, sport and recreation) was assessed on the basis of the Baecke questionnaire (Baecke, Burema, & Frijters, 1982). It is a reliable and credible research took for measuring habitual PA (Florindo, & Latorre, 2003). The result was based on the formula and codes attached to the questionnaire representing the intensity and duration of the activity.

Publication 2 and 3

PA was assessed using the Caltrac device (Muscle Dynamics, Inc., Tarrance, CA), which reports the results of energy expenditure based on the measurement of body acceleration (Bassett et al., 2015, Młynarski et al., 2014). Subjects wore Caltrac for 7 days. The total kcal result was divided by the number of days and body weight to get relative values.

Postural stability

Publication 1

One-leg standing test with open eyes (OLST-EO) and one-leg standing test with eyes closed (OLST-EC) were used to assess PS. During the examination, the worker stood erect, with the upper limbs lowered along the body, first on one leg with open and then with his eyes closed. The countdown was stopped when the raised leg touched the floor or when the subject removed his arms from his body to stabilize his position. It is assumed that the test is performed correctly if the subject holds the position for 45 seconds for eyes open and 15 second for eyes closed. (Zasadzka, & Wieczorowska-Tobis, 2012).

Publication 2 and 3

The AccuGait portable force plate (Model AMTI PJB-101, AMTI, Watertown, MA) was used to collect data related to the displacement of the centre of pressure (COP). The

Balance Trainer software (provided by the manufacturer) was used to connect the strength platform to the computer. The sampling frequency was 100 Hz (Ruhe, Fejer, & Walker, 2010; Bizid et al., 2009). The study analysed the length of COP (SP) displacement path and its components in the anterio-posterior (AP) and medio-lateral (ML) directions.

During the examination, the worker stood still in the centre of the platform with his bare feet hip-width apart and his arms along his body. The posturographic platform was placed 3 metres in front of the white wall.

The following trials concerned:

Publication 2

- Quiet standing with eyes open at ground level and at a height of 1 metre.
- Cognitive standing: standing with a cognitive task carried out at the ground level and at a height of 1 metre, consisting of counting down every third number during data recording from the number 200 (Sample, et al., 2016).

Publication 3

- EO LT QS - eyes open, low threat (ground level), quiet standing.
- EO LT DT - eyes open, low threat, dual task.
- EO HT QS - eyes open, high threat (1m above the ground), quiet standing.
- EO HT DT - eyes open, high threat, dual task.

All tasks with eyes closed were performed in the same way as with eyes opened (EC LT QS, EC LT DT, EC HT QS, EC HT DT, respectively).

The tests were performed in a random order (to avoid the learning factor) at the ground level and 1 metre above the ground. Each trial lasted 30 seconds and was performed twice (the mean of 2 trials was taken into account). Due to the large number of attempts, 20-second breaks between measurements were applied. In case of dizziness or fatigue, participants could also rest in a sitting position. As none of the participants reported similar complaints, they remained at the same platform level during all low or high level tests.

Cardiovascular stress

Publication 2

As a physiological and psychological stress indicator, the heart rate at rest was measured and compared with the increase in heart rate while performing a task (Min, Kim, & Parnianpour, 2012; Sandercock et al., 2005). During the measurement, blood pressure and changes in the heart rate were read (McCraty, Shaffer, 2015).

Statistical analysis

All calculations were performed using Statistica v. 13.0 software (Tibco Software Inc., Palo Alto, CA, USA). The level of statistical significance was set at $p \leq 0.05$.

Publication 1

Student's T- test for independent data was used to assess differences between groups in terms of quantitative variables (standing on one leg with eyes open and closed, physical activity indexes, BMI, age). Pearson's r coefficients were calculated to determine the correlation between the variables, while the analysis of covariance (ANCOVA) was used to compare the groups in terms of the one-leg stand test with eyes closed, under the control of physical activity.

Publication 2

Student's T-test was used to assess the differences between the basic variables, such as age, BMI, and physical activity indicators. Two-way analysis of variance (ANOVA) was used to analyse postural stability and cardiovascular stress. The following interaction effects were assessed: "height × group" and "task × group" (with two levels for each factor: low – high risk, and with or without a cognitive task in both HW and OW groups), and the main effects for the study conditions ("height", "task") and the intergroup effect ("group").

Publication 3

The main calculations related to the assessment of the differentiation of the dependent variables were based on the ANOVA variance analysis method (test F). The analysis was performed taking into account the intergroup factor (with EG and CG levels) and the repeated measure factor "time" (with Pre and Post levels). Interaction effects and main effects were assessed. Similar calculations were used for all analyses related to the experiment: EO LT QS, EO LT DT, EO HT QS, EO HT DT, EC LT QS, EC LT DT, EC HT QS and EC HT DT.

3.4. Intervention

Publication 3

The experimental group participated in proprioceptive training on a balance platform using VR for 6 weeks, 30 minutes per session, twice a week. 100% participation in training (12x) was required. A balance platform - Sigma (element ACX. rehab) was used for training, which is a modern device for proprioception training with the use of VR (Sigma balance platform, prod. AC International). The platform assesses the change in the angle of deflection using a gyroscope. The sampling rate is 40 Hz, and the delay is 25 ms. Real-time transmission to the computer with the software takes place via the Bluetooth sensor.

During the training, audio-visual feedback was used to facilitate the exercise in the form of video games that were simple and involved moving objects such as a fish, plane, car and balls. For example, in the game "fish", the subject was supposed to move the blue circle while properly balancing on the platform to protect the source of the sparks from the fish. This source was safe when it was in the centre of the circle. The aim of the training (according to the manufacturers of the device) was to repeat movements in 3D space, as well as to train planned movements, precision movements, eye-hand coordination or strengthening muscle strength.

Each training session on the platform started with the simplest tasks and gradually progressed to more complex and complicated exercises. During the intervention, the subject stood still in the centre of the platform with his feet hip-width apart so that they were on opposite sides of the disc, but parallel to each other. The platform was placed 2 metres in front of the display stand that emitted the games. The participant was asked to complete the task in accordance with the instructions contained in the games. During the intervention, he balanced his body standing on the platform and performed exercises. Each participant was asked to play a full set of games each time. The length of a single game was set to be 2-3 minutes so that the session, including interruptions for switching between games, was approximately 30 minutes. The subjects could also rest in a sitting position for 30–60 seconds after each game.

4. The results and discussion

Publication 1

Postural stability and physical activity of workers working at height. *Am J Men's Health*, 2018, 12(4), 1068–1073, doi: 10.1177/1557988318774996

The aim of the study was to analyse the level of postural stability and physical activity in the group of at-height workers. The relationship between postural stability and physical activity was also assessed.

The PA was assessed using the Baecke questionnaire. The HW group was characterized by the highest physical activity during work and the lowest during free time. On the other hand, in the OW group, reverse trends were noted. The reduced recreational activity of the HW group may be explained by the increased activity at work (Chau et al., 2012; Clemes, O'Connell, & Edwardson, 2014). However, in contrast to the health benefits of PA in leisure time, high levels of occupational PA may affect the mechanical stress on the musculoskeletal system and increase the risk of injury (Krause et al. 2007). Comparable results in the overall PA level in both groups of men may be related to similar age, preferred lifestyle, or family model.

Similar results were obtained by Punakallio (2003), who analysed the postural and functional stability of workers performing manual work depending on the age, occupation and PA level. Manual workers were characterized by a higher level of functional balance and PA. Other studies have noted that PA appears to help maintain an adequate level of postural control and sensory interaction (Prioli et al., 2005).

One-leg standing test with eyes open (OLST-EO) and eyes closed (OLST-EC) was used to assess the stability of the posture. The HW group achieved higher results in both PS tests compared to the OW group, but statistically significant results were recorded only in the OLST-EC test. It was also found that the level of PA had no influence on the obtained results. Based on the research, it can be assumed that the type and nature of the work performed may affect the PS level of the HW group (Gatti, Giovanni, & Migliaccio, 2014; Yang et al., 2017). Min, Kim, & Parnianpour (2012) showed in their research that a lower level of employee experience and a higher scaffold height significantly reduce postural stability while increasing cardiovascular stress. Also, based on the studies by DiDomenico et al. (2010), it can be concluded that HW workplace and experience influence PS regardless of the industry and employee age. In addition, postural control can also be precisely matched to the level of threat and increase with the level of experience (i.e. prior repeated experience of a threatening situation) of the examined person (Adkin et al., 2000).

Publication 2

The Effects of Cognitive Task and Change of Height on Postural Stability and Cardiovascular Stress in Workers Working at Height. *Int J Environ Res Public Health*, 2020, 17(18), 6541, doi:10.3390/ijerph17186541.

The aim of the study was to assess the differences in the level of postural stability of the body under various conditions: both when changing the height of the measuring platform and when performing an additional cognitive task. Changes in heart rate under hazardous conditions caused by a change in platform height were also assessed.

Influence of height on the postural stability of employees

Analysing the results, it was found that, regardless of the studied group (HW and OW), the change in height during quiet standing causes deterioration of PS (Cleworth, & Carpenter, 2016; Adkin et al., 2000; Sturnieks et al., 2016; Zaback, Carpenter, & Adkin, 2016). In the quiet standing tests, along with the increase of the height at which the examined person was standing, it was found that the path length of the COP increased in both groups. In the HW group, changes were lower (which may indicate a higher PS level) in all analysed parameters. Based on the research of other authors, it can be assumed that the higher PS in the HW group results from the daily training of individual muscle groups used in the daily professional tasks of at-height workers. In addition, balance training related to the conditions and nature of work and the level of PA of employees can also play an important role (Gatti, Giovanni, & Migliaccio, 2014; Yan, et al., 2017; Cyma, et al., 2018).

The above results were substantiated both by the studies by Adkin et al. (2000), as well as Sturnieks et al. (2016). The authors observed whether postural control correlated with the level of posture risk, such as a change in platform height. The effects of age, anxiety and fear of falling at an increased height were also analysed. In both studies, it was observed that in situations of increased risk of posture, such as changing the height of the platform, postural control increased among the respondents. Moreover, PS control was precisely matched to the level of threat and increased with the level of experience (i.e. prior experience of the threat of attitude) of the subject. People with anxiety also adopted a strategy of increased balance control.

The impact of performing a cognitive task on employees' postural stability

In the cognitive task test, the COP path length was longer compared to the control task. Although there are significant differences in the COP signal parameters between the control and the cognitive task, the change in height did not affect the PS control of both groups. A lower level of changes in path length of COP and its components its AP and ML directions were noted in the HW group during cognitive task performance and height change. Based on the results, it can be assumed that task performance and height change do not significantly affect the PS level in the group of experienced HW (DiDomenico et al., 2010; Cullen, & Agnew, 2016; Schnittjer, 2017). Fear of falling and previous experience of working at height may play an important role in shaping changes in posture control strategies under high-risk conditions caused by changes in height (Adkin, & Carpenter, 2018; Yang et al., 2017; Sibley et al., 2010; Davis et al., 2009). Based on the research, it can be assumed that people with lower resistance to anxiety and stressful situations may use strategies that are not conducive to maintaining postural control, when the risk of posture threat increases in the case of increasing the height of the platform on which they stand, performing tasks or processing visual information. In such a context, the above situation may cause greater postural instability of these people (Hainaut et al., 2011; Sibley et al., 2010; Redfern, Furman, & Jacob, 2007).

For example, Pellecchia (2003) investigated whether PS in young adults was affected by three cognitive tasks depending on their degree of difficulty. The author showed that the PS was influenced by the countdown every 3 backwards, i.e. performing the most difficult task.

The longest path of the COP was also noted during this test. It is worth emphasizing that the length of the path increased along with the difficulty of completing the task. These effects may be justified by the research results obtained in this article. It can be assumed that, regardless of the industry and age of employees, the typical activities performed while working at high altitudes and the increased awareness of the dangers related to the posture of HW result in slight changes in the level of their postural stability.

The influence of altitude on cardiovascular stress

Analysis of cardiovascular stress reported a significant interaction effect. As in the case of postural stability, the rate of heart contractions during the task increased with increasing the height of the measurement platform in both groups (Kaskutas et al., 2009; Chang et al., 2009; Min, Kim, & Parnianpour, 2012). A statistically significant main effect, "height," was noted which resulted from changes in the OW group. The lower level of cardiovascular stress in the HW group may be due to work experience with tasks such as building, demolishing and modifying scaffolding on tall buildings, which in turn forces workers to cope with precise work and difficult weather conditions such as strong wind, rain and snow (Min, Kim, & Parnianpour, 2012, Zamysłowska-Szmytke, & Śliwińska-Kowalska, 2012; DiDomenico et al., 2010). In addition, it can also be assumed that the height of 1 meter was not dangerous enough to cause statistically significant individual changes in the HW group (Sturnieks et al., 2016; Davis et al., 2009).

In a study by Hsu et al. (2016), as well as Min Kim and Parnianpour (2012) similar results were obtained. Most likely, the influence of the height of the work surface significantly affects the level of cardiovascular stress and PS. It was found that the level of stress is positively correlated with an increase in the height of the working surface. The experience of employees is also very important. In inexperienced workers, as the platform height increases, Ps is significantly reduced, while cardiovascular stress increases. Similar results were obtained in this article.

Publication 3

The Influence of Proprioceptive Training with the Use of Virtual Reality on Postural Stability of Workers Working at Height. *Sensors*, 2020, 20(13), 3731. doi:10.3390/s20133731.

The aim of the study was to assess the impact of proprioceptive training with the use of VR on the level of postural stability of workers working at height. The impact of training on the level of postural stability was also assessed in the case of the application of: (1) the standard stability test with the eyes open, (2) reduction of visual stimuli, (3) changes in the height of the test plane, and (4) introduction of an additional cognitive task.

Effect of the intervention on postural stability with eyes open

Proprioceptive training on a balance platform using VR significantly improves PS level both under ground level conditions and at increased height of the measurement platform (Esculier et al., 2012; Ciou et al., 2015). In quiet standing tests with easy open at both heights, the overall path length of the COP and its components in the anterior-posterior (SPAP) and right-left (SPML) directions were reduced. In all analysed parameters, the EG group achieved lower results after training. This type of training could affect the involvement of individual muscle groups used in tasks performed on the balance platform. Based on the results, it can be assumed that VR training eliminates not only the negative impact of height, but also visual stimuli on the PS level. It can also be assumed that VR training has a positive effect on the visual-vestibular-somatosensory system. Carozza et al., (2013) studied the possibility of using VR goggles to train construction workers in risk recognition skills. The authors noticed that performing realistic training reduces the risk associated with performing tasks in real conditions. Currently, there are no studies on the impact of VR training on a balance platform on the PS level of employees at height. Indirect evidence can be found in studies using interactive training in the elderly or sick. For example, Schwenk et al. (2014) found that elderly people at risk of falling may benefit from participating in an interactive balance training program based on visual feedback sensors.

In the cognitive standing tests with visual control at both heights, the EG group achieved lower results in all analysed COP parameters (SP, SPAP and SPML). Probably the increase in cognitive involvement while performing realistic tasks in VR training resulted in a higher level of PS in the EG group. Based on the research, it can be assumed that, in addition to the entertainment value, games can improve the ability of visual attention, sensory integration, perceptive abilities and switching between tasks (Cain, Landau, & Shimamura, 2012; Green et al., 2012). So far, no studies have been conducted in high-altitude workers on the effect of VR training on a balance platform on PS level in a double task with eyes open test. However, research among gamers has shown a positive effect of games on the performance of cognitive tasks (Colzato et al., 2013; Strobach, Frensch, & Schubert 2012).

The influence of interventions on postural stability with eyes closed

The EG group in the quiet standing tests without visual control achieved lower results (which may indicate a higher level of PS) after training in all analysed PS parameters at both heights. Based on the results, it can be assumed that the EG group, in contrast to the CG group, relied more on proprioception and less on visual stimuli during the trial in order to maintain postural stability. Based on the research, it can be concluded that reliance on proprioception is associated with an increased ability to maintain postural stability, moreover, this ability can be successfully developed (Hutt, & Redding, 2014). It can be assumed that such abilities were increased in the EG group during proprioceptive training on a balance platform with the use of VR. In addition, Hutt and Redding (2014) noted that a training program based on the reduction of visual stimuli may increase PS levels.

In attempts to cognitive standing at the ground level without visual control, the EG group obtained positive training effects, achieving lower results in all analysed COP parameters (SP, SPAP and SPML). Presumably higher PS in the EG group results from the daily training of proprioception, as well as the individual muscle group used in everyday professional tasks, and the conditions and nature of work of the study participants (Colzato et al., 2013; Umer et al., 2018).

In the EC HT DT test, no statistically significant changes were found in both groups. Although the training was performed only with eyes open, the results of the measurement with eyes closed were similar to statistically significant. The undoubted difficulty of the task performed, as well as insufficient reliance on proprioception in the absence of visual control, could affect the outcome of the intervention. Probably the continuation of the training would result in significant differences also in this test. Based on the research, it can be concluded that game training can be successfully used to improve PS. After six weeks of participation in game training in healthy elderly people, an increase in PS was noticed in all analysed trials (Van Diest et al., 2015). Other studies have shown that video games improve performance in a variety of tasks and may also increase perceptual skills, including attention, memory abilities, working memory, and dual task performance. The results of these studies show the potential usefulness of games and their practical application in the real world, including for rehabilitation or training of skills related to working at height (Green, & Baveliera, 2015).

Practical application

On the basis of the obtained results, it can be noticed that proprioceptive training on a balance platform with the use of VR may have a number of positive effects that seem to be difficult to achieve during standard balance eservices. It is possible that this type of training can be effectively incorporated into the safety training of construction workers in order to reduce the frequency of accidents related to postural stability disturbance when working at height.

5. Conclusions

1. At-height workers have a higher level of postural stability in relation to office workers *(publication 1)*.
2. The similar overall level of physical activity of at-height and office workers may indicate that postural stability is more influenced by exposure to stressful conditions, such as working at height *(publication 1)*.
3. A higher level of postural stability in at-height workers may indicate that the increased risk of maintaining postural stability leads to more conscious postural control in this group *(publication 2)*.
4. Higher postural stability while performing a cognitive task in a group of employees at height may indicate that the postural control strategy adopted in conditions caused by increased postural risk is shaped by their professional experience *(publication 2)*.
5. In the group of at-height workers, exposure to stress has a lesser impact on postural stability than in the group of office workers *(publication 2)*.
6. Proprioceptive training on a balance platform with the use of VR improves the level of postural stability in all analysed samples of low-high risk, open eyes – eyes closed and single-double task *(publication 3):*

- Proprioceptive training on a balance platform with the use of VR can be an appropriate element for direct training of the visual-vestibular-somatosensory system in order to teach at-height workers and adequate response to threats without endangering them.
- Proprioceptive training on a balance platform using VR probably resulted in greater cognitive involvement of at-height workers, and could also increase the effectiveness of switching between tasks.
- It can be assumed that proprioceptive training with the use of VR contributed to a greater reliance on proprioception, and to a lesser extent on visual control, in maintaining postural stability.

III. Piśmiennictwo / References

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IV. Streszczenie / Abstract

Streszczenie

Wstęp. Zaburzenia stabilności posturalnej są jedną z głównych przyczyn wypadków wśród pracowników wysokościowych. Treningi i szkolenia w tej grupie stanowią bardzo istotny element w ochronie pracownika przed upadkiem.

Cel badań. Celem badań była ocena wpływu treningu proprioceptywnego z wykorzystaniem rzeczywistości wirtualnej (VR) na poziom stabilności posturalnej pracowników wysokościowych. Analizie poddano również związek między stabilnością posturalną a aktywnością fizyczną, a także wpływ zadania poznawczego i zmiany wysokości na stabilność posturalną i stres sercowo-naczyniowy osób pracujących na wysokości.

Metody badań. W badaniu wzięli udział zdrowi mężczyźni w przedziale wiekowym 22–47 lat. Zostali podzieleni na grupy w oparciu o rodzaj wykonywanej pracy: pracownicy wysokościowi (HW) i pracownicy biurowi (OW) (głównie praca przy biurku z komputerem). Aktywność fizyczna, została oceniona za pomocą kwestionariusza Baecke'a oraz akcelerometra Caltrac (Muscle Dynamics, Inc., Tarrance, CA). Do oceny stabilności posturalnej zastosowano testy funkcjonalne (stanie na jednej nodze z oczami otwartymi i zamkniętymi) a także platformę posturograficzną typu AccuGaitTM- analizowano ogólną ścieżkę przemieszczeń środka nacisku ciała (COP). Testy przeprowadzono na dwóch różnych wysokościach platformy (poziom gruntu i 1 metr nad ziemią), z otwartymi lub zamkniętymi oczami i z zadaniem kognitywnym lub bez (liczenie wstecz). Dodatkowo oceniono częstość skurczów serca w trakcie wykonywania wszystkich prób. Jednym z elementów badania było wprowadzenie interwencji o charakterze treningu na platformie balansowej z wykorzystaniem VR (6 tygodni, 2 sesje x 30 min w tygodniu).

Wyniki. W grupie HW wskaźnik przeciętnej aktywności fizycznej w pracy był wyższy niż w grupie OW ($p<0{,}001$), natomiast grupa OW charakteryzowała się większą aktywnością fizyczną w czasie wolnym ($p<0{,}001$). Ponadto grupa HW uzyskała statystycznie istotnie wyższe wartości w staniu na jednej nodze z zamkniętymi oczami ($p<0{,}05$).

Na podstawie analizy stwierdzono również, że zadanie poznawcze i zwiększenie wysokości stanowiska pomiarowego znacząco wpływają na pomiary stabilności posturalnej i stresu sercowo-naczyniowego ($p<0{,}05$).

W przypadku zastosowania treningu proprioceptywnego z wykorzystaniem VR stwierdzono statystycznie istotne efekty interakcji w przypadku niskiego-wysokiego zagrożenia, oczu otwartych-zamkniętych, jak również pojedynczego-podwójnego zadania

(w większości przypadków p<0,01). Wartości po treningowe średniej długości przemieszczeń COP były istotnie niższe w eksperymentalnej grupie HW niż przed treningiem dla wszystkich analizowanych parametrów (p<0,05).

Wnioski. Grupy różniły się stabilnością postawy na korzyść HW. Jednocześnie, pomimo różnic w poszczególnych aspektach, ogólny poziom PA był zbliżony. Może to wskazywać, że na stabilność postawy wpływa raczej narażenie na stres.

Ponadto zaobserwowano, że u niedoświadczonych pracowników OW większa wysokość platformy i wykonywanie zadania kognitywnego powodowały, że stabilność postawy znacząco spadała, natomiast zwiększał się stres sercowo-naczyniowy i trudności w utrzymaniu równowagi. Można przypuszczać, że w grupie HW stany stresowe wpływają w mniejszym stopniu na stabilność posturalną niż w grupie OW.

Trening proprioceptywny na platformie balansowej z wykorzystaniem VR poprawił poziom PS we wszystkich analizowanych parametrach niskiego-wysokiego zagrożenia, oczu otwartych-zamkniętych, oraz pojedynczego-podwójnego zadania. Ponadto zauważono istotne zalety zastosowania środowiska VR dla szkolenia z zakresu poprawy stabilności posturalnej wśród pracowników wysokościowych. Na podstawie tych wyników można stwierdzić, że stosowanie treningu VR w celu poprawy poziomu stabilności posturalnej jest skuteczne i w przyszłości może wspomagać lub nawet zastąpić tradycyjne metody treningu równowagi.

Abstract

Introduction. Postural stability disturbance are one of the main causes of accidents among workers at height. Trainings and education in this group are a very important element in protecting the employee against falling.

Aim. The aim of the study was to assess the impact of proprioceptive training with the use of virtual reality (VR) on the level of postural stability of at-height workers. The relationship between postural stability and physical activity was also analysed, as well as the effect of cognitive task and height changes on posture stability and cardiovascular stress in people working at height.

Methods. Healthy men aged 22-47 took part in the study. They were divided into groups based on the type of work they performed: at-height workers (HW) and office workers (OW) (mainly working at a desk with a computer). Physical activity was assessed using the Baecke questionnaire and the Caltrac accelerometer (Muscle Dynamics, Inc., Tarrance, CA). Functional tests (standing on one leg with eyes open and closed) and the AccuGaitTM posturographic platform were used to assess the stability of the posture – the general path of

body pressure centre (COP) displacement was analysed. The tests were carried out at two different platform heights (ground level and 1 meter above the ground), with eyes open or closed, and with or without cognitive task (counting backwards). In addition, the heart rate was assessed during all tests. One of the elements of the study was the introduction of training interventions on a balance platform using VR (6 weeks, 2 sessions x 30 min per week).

Results. In the HW group, the index of average physical activity at work was higher than in the OW group ($p<0.001$), while the OW group was characterized by greater physical activity in free time ($p<0.001$). Moreover, the HW group obtained statistically significantly higher values in the standing on one leg with eyes closed ($p<0.05$).

Based on the analysis, it was also found that the cognitive task and the increase in the height of the measuring station significantly affect the measurements of postural stability and cardiovascular stress ($p<0.05$).

In the case of proprioceptive training with the use of VR, statistically significant interaction effects were found in the case of low-high risk, eyes open-closed, as well as single-double task (in most cases $p<0.01$). Post-training values of the mean length of COP displacements were significantly lower in the experimental HW group than before training for all analysed parameters ($p<0.05$).

Conclusions. The groups differed in the stability of their attitude in favour of HW. At the same time, despite differences in individual aspects, the overall level of PA was similar. This may indicate that postural stability is more influenced by exposure to stress.

In addition, it was observed that in inexperienced OW workers, the greater height of the platform and the performance of a cognitive task caused that postural stability significantly decreased, while cardiovascular stress and difficulties in maintaining balance increased. It can be assumed that in the HW group, stress states had a lesser effect on postural stability than in the OW group.

Proprioceptive training on a balance platform with the use of VR improved the PS level in all analysed parameters of low-high risk, open-closed eyes, and single-double task. In addition, significant advantages of using the VR environment for training in improving postural stability among at-height workers were noted. Based on these results, it can be concluded that the use of VR training to improve the level of postural stability is effective and in the future may support or even replace traditional methods of balance training.

V. Załączniki

1. Oświadczenia współautorów

2. Publikacje

- Publikacja nr 1: Postural stability and physical activity of workers working at height.
- Publikacja nr 2: The Effects of Cognitive Task and Change of Height on Postural Stability and Cardiovascular Stress in Workers Working at Height.
- Publikacja nr 3: The Influence of Proprioceptive Training with the Use of Virtual Reality on Postural Stability of Workers Working at Height.

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Wydział Nauk o Kulturze Fizycznej

Zakład Nauk o Aktywności Fizycznej i Promocji Zdrowia

OŚWIADCZENIE

Mój udział w powstawaniu niżej wymienionych publikacji polegał na: konceptualizacji, przygotowaniu oryginalnego projektu, przygotowaniu wniosku do komisji bioetycznej, pozyskaniu środków z funduszu na RMPN, administracji projektu, zbieraniu danych w części empirycznej, analizie i interpretacji danych, napisaniu, redagowaniu, recenzji oraz zatwierdzeniu manuskryptu. Swój udział w każdym projekcie oceniam na 55%.

1. Cyma, M., Marciniak, K., Tomczak, M., Stemplewski, R. (2018). Postural stability and physical activity of workers working at height. *American Journal of Men's Health,* 12(4), 1068–1073, doi: 10.1177/1557988318774996.
2. Cyma-Wejchenig, M., Maciaszek, J., Marciniak, K., Stemplewski, R. (2020). The Effects of Cognitive Task and Change of Height on Postural Stability and Cardiovascular Stress in Workers Working at Height. *Int J Environ Res Public Health*, 7(18):E6541, doi:10.3390/ijerph17186541.
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Mój udział w powstawaniu niżej wymienionych publikacji polegał na: przygotowaniu oryginalnego projektu, zbieraniu danych w części empirycznej, analizie i interpretacji danych, opracowaniu analizy statystycznej, pisaniu, redagowaniu, recenzji oraz zatwierdzeniu manuskryptu. Swój udział w każdym projekcie oceniam na 25%.

1. Cyma, M., Marciniak, K., Tomczak, M., Stemplewski, R. (2018). Postural stability and physical activity of workers working at height. American Journal of Men'sHealth, 12(4), 1068–1073, doi: 10.1177/1557988318774996.
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Mój udział w powstawaniu niżej wymienionych publikacji polegał na: zbieraniu danych w części empirycznej, redagowaniu oraz zatwierdzeniu manuskryptu. Swój udział w każdym projekcie oceniam na 10 %.

1. Cyma, M., Marciniak, K., Tomczak, M., Stemplewski, R. (2018). Postural stability and physical activity of workers working at height. *American Journal of Men's Health*, 12(4), 1068–1073, doi: 10.1177/1557988318774996.
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Mój udział w powstawaniu niżej wymienionej publikacji polegał na: opracowaniu analizy statystycznej, tworzeniu tekstu manuskryptu oraz jego zatwierdzeniu. Swój udział w projekcie oceniam na 10 %.

Cyma, M., Marciniak, K., Tomczak, M., Stemplewski, R. (2018). Postural stability and physical activity of workers working at height. American Journal of Men'sHealth, 12(4), 1068–1073, doi: 10.1177/1557988318774996.

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Cyma-Wejchenig, M., Maciaszek, J., Marciniak, K., Stemplewski, R. (2020). The Effects of Cognitive Task and Change of Height on Postural Stability and Cardiovascular Stress in Workers Working at Height. *Int J Environ Res Public Health*, 7(18):E6541, doi:10.3390/ijerph17186541.

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Postural Stability and Physical Activity of Workers Working at Height

Magdalena Cyma[1], Katarzyna Marciniak[1], Maciej Tomczak[2], and Rafał Stemplewski[1]

Abstract

The purpose of the study was to analyze the level of postural stability and physical activity of at-height workers.

The study included 34 healthy men aged 25–43. Two groups were identified based on the type of work they performed: at-height workers (HW) (n = 17), and office workers (OW) (n = 17). Physical activity, including physical activity at work, sports activity, and leisure, was assessed with a Baecke questionnaire. For evaluation of postural stability, the one-leg standing test with eyes open and closed was used.

The HW group had a higher rate of average physical activity at work than the OW group (p = .000), whereas the OW group showed greater physical activity during leisure time (p = .000). No differences were found between the groups in terms of sports activity. Postural stability analysis shows that the HW group ($p < .05$) scored statistically significantly higher values in one-leg standing with eyes closed.

The groups differed in terms of postural stability in favor of HW. At the same time, despite differences in particular aspects, the overall level of PA was similar. This may indicate that postural stability is rather affected by exposure to distress conditions.

Keywords

postural stability, body balance, physical activity, at-height workers

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Work at heights is considered to be particularly dangerous. Tasks such as building, dismantling, and modifying scaffoldings (Zamysłowska-Szmytke & Śliwińska-Kowalska, 2012) carried out on tall buildings—that is, 23 meters (Mousavi, 2015)—force employees to struggle with both the work which they must carry out precisely and difficult weather conditions such as strong winds, rain, and snow. All such work is assigned to men who are not only experienced and highly qualified, but who also possess suitable mental and physical features (Salassa & Zapala, 2009; Zamysłowska-Szmytke & Śliwińska-Kowalska, 2012). In the European Union countries, men working at heights should undergo valid medical examinations, including the ophthalmic, neurological, and laryngological ones. Appropriate experience is required for the works at the heights of above 1 meter.

Assessment of the level of postural stability of at-height workers is a very important element of prevention and case law in occupational medicine. The "Labor Code" (*Journal of Laws*, No. 69, item 332) recommends examinations of the balance system of people working at heights of above 3 meters, as well as below 3 meters and above 1 meter from the surrounding floor level or an outdoor area, as well as on mobile hanging platforms. The scope of the tests to be performed and the exact minimum requirements with regard to the person to be examined are not specified (Zamysłowska-Szmytke & Śliwińska-Kowalska, 2012). Postural stability disorders are among the most common causes of accidents related to working at height (Central Statistical Office, 2012; European Commission, 2009). The consequence of postural instability is imbalance, which, in turn, often leads to tragic

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results such as fractures, hematomas, extensive bruises, or even death (Horak, 2006; Salassa & Zapala, 2009).

Research indicates that counteracting imbalance is only effective when the nervous system is able to identify a destabilizing stimulus within 70–100 ms and to perform a set of typical patterns and muscle-based muscle synergies that restore balance, based on rapid automatic balance-recovery reactions (Boucher, Stuphorn, Logan, Schall, & Palmeri, 2007; Tao, Khan, & Blohm, 2018). The greater the set of these patterns, the longer the process of selecting the appropriate motor reaction (Adkin, Frank, Carpenter, & Peysar, 2000; Töllner, Rangelov, & Müller, 2012). When it is necessary to make a choice, the speed of balance recovery is greatly reduced. This may mean that balance can be more effectively maintained if the potential reflexes used to compensate for the balance are kept to a minimum. According to research, such compensatory measures can be observed in people standing on unstable ground, at great heights, and in the elderly people (Davis, Campbell, Adkin, & Carpenter, 2009; Zamysłowska-Szmytke & Śliwińska-Kowalska, 2012).

Conditions of increased risk when maintaining an erect posture directly affect control of body position (Brown, Sleik, Polych, & Gage, 2002; Huffman, Horslen, Carpenter, & Adkin, 2009). Based on the available results connected to fall risk, it can be concluded that people control their posture through the increase in neuromuscular activity of the lower limb muscles as well as through the stiffening of the ankle joint (Adkin et al., 2000; Vuillerme & Nafati, 2007). Carpenter, Adkin, Brawley, and Frank (2006) noted that both older and young adults use the same ankle-stiffening strategy to cope with increased anxiety and reduced level of confidence related to standing at a height of above 0.4 meters. Evidence indicates that physiological state, anxiety status, and balance efficiency are related to specific changes in attitude and increased balance (Carpenter et al., 2006).

Min, Kim, and Parnianpour (2012) investigated the effect of scaffolding height on safety results, taking into account subjective and objective assessments of the postural stability and cardiovascular stress of unexperienced and advanced construction workers. It has been reported that the postural stability of workers with less experience was reduced during work on higher scaffolds with no handrails, while cardiovascular stress and subjective difficulty in maintaining balance increased. DiDomenico, McGorry, Huang, and Blair (2010) undertook an analysis of the perception of postural stability among construction workers making the transition to a standing position. The research included a group of 183 men and six women (from 18 to 63 years). Older participants had better scores in tasks including typical postures for construction work. However, there were no statistical differences between older and younger workers with regard to individual tasks. The authors suggested that the place of work and change of position while performing a given task affects stability of posture while standing, regardless of the construction industry or the age of the employee.

Table 1. Average Values, Standard Deviations, and Differences Between Groups for BMI and Age.

Variable	*M* (*SD*) HW	*M* (*SD*) OW	*t* *df* = 32	*p*
BMI [kg/m^2]	25.72 (1.24)	26.46 (2.77)	−1.01	.322
Age [years]	33.76 (3.09)	32.24 (5.52)	1.00	.326

Note. HW = height workers; OW = office workers; BMI = body mass index; *SD* = standard deviation, *M* = mean.

The mechanism of action of the system responsible for proper control of body posture is ambiguous. Presumably, at-height workers (HW) are characterized by the increased automation of the postural stability system (Huweler, Kandil, Alpers, & Gerlach, 2009; Redfern, Yardley, & Bronstein, 2001). It is currently still undiscovered how the mechanism of action of factors affecting postural stability in the field operates. Nowadays, there has been no research on the analysis of postural stability in relation to the level of physical activity of HW. The impact of the working conditions and long-term experience of HW on the level of their postural stability is also ambiguous. Therefore, it would be valuable to examine the level of postural stability and physical activity of workers working at heights above 1 meter.

The purpose of the study was to analyze the level of postural stability and physical activity of HW. The relation between postural stability and physical activity was also evaluated.

Resources and Methods

Characteristics of the Research Group

The study included a group of 17 healthy men working at height (HW: at-height worker). As a control group, 17 office workers (OW: office worker) were examined. The criteria for participation were as follows: a minimum age of 25 years and verbal contact skills enabling conscious, logical answers, and full mobility. Table 1 presents the basic characteristics of the studied groups of males. The groups did not differ statistically in age or BMI (body mass index).

All participants were informed in details of the study and gave their written consent to the experimental procedure. The study was approved by the Bioethical Committee at Poznan University of Medical Science (Decision No. 1111/16).

Research Methods

A Baecke questionnaire was used to measure physical activity at work (WI), sports activity (e.g., jogging, swimming; SI), and leisure (LI) as well as total index of physical activity (TI; Baecke, Burema, & Frijters, 1982). The questionnaire is valid and reliable to measure habitual physical activity (Florindo & Latorre, 2003). The result was based on the pattern and codes attached to the questionnaire representing the intensity and duration of the activity (three levels of intensity of work activity, three levels of sports intensity, and five levels of frequency of performed activities were established).

For evaluation of postural stability, the one-leg standing test with eyes open (OLST-EO) and closed (OLST-EC) was used. The test assesses balance in a static position and it is conducted to evaluate balance with and without vision control. The subject stands straight, arms lowered alongside the hips, first on one leg with eyes open, and then performs the same test with eyes closed. The countdown should be stopped when the lifted leg touches the floor or when the subject moves his arms away from his body to stabilize his position.

Interpretation: It is assumed that the subject passes the test with eyes open after 45 s and later, with eyes closed, after 15 s (Zasadzka & Wieczorowska-Tobis, 2012).

Statistical Methods

Student's *t*-test for independent data was used to evaluate differences between groups with regard to quantitative variables (standing on one leg with open and closed eyes tests, physical activity indexes, BMI, age). To determine the correlation between the variables, Pearson's *r* coefficients were calculated, whereas in order to compare the groups with regard to the test concerning standing on one leg with closed eyes, under control of physical activity, Analysis of Covariance (ANCOVA) was used. Calculations were made using Statistica 10.0 (StatSoft Inc., Tulsa, OK).

Results

The HW group scored statistically significantly higher on the OLST with eyes closed (Table 2). Correlations between work index and total index of physical activity and the OLST with eyes closed were reported to be statistically significant (Table 3).

Between groups differences and total physical activity level (covariate) explain around 39% of variance of OLST-EC (adjusted $R^2 = 0.386$). The effect of total physical activity index (covariate) was statistically significant ($F(1.31) = 10.01$, $p < .01$, $\eta^2 = 0.24$) as well as the group effect ($F(1.31) = 11.24$, $p < .01$, $\eta^2 = 0.27$). The HW group scored significantly higher on the OLST-EC than the OW group under control of physical activity (corrected means: HW group: $M = 10.37$, OW group: $M = 6.07$; Figure 1).

Table 2. Average Values, Standard Deviations, and Differences Between Groups for Physical Activity Indexes and Postural Stability Tests.

Variable	*M* (*SD*) HW	*M* (*SD*) OW	*t* *df* = 32	*p*
SI [pts]	4.55 (1.41)	4.59 (1.10)	−0.09	.930
WI [pts]	3.71 (0.51)	2.74 (0.53)	5.43	.000
LI [pts]	2.53 (0.43)	3.26 (0.51)	−4.53	.000
TI [pts]	10.79 (1.62)	10.60 (1.47)	0.37	.712
OLST-EO [s]	45.06 (10.14)	41.88 (14.84)	0.73	.471
OLST-EC [s]	10.50 (5.24)	5.94 (2.84)	3.15	.004

Note. HW = height workers; OW = office workers; *SD* = standard deviation, *M* = mean; SI = sports activity; WI = physical activity at work; LI = physical activity at leisure; TI = total index of physical activity; OLST-EO = one-leg standing test with eyes open; OLST-EC = one-leg standing test with eyes closed.

Table 3. Correlations Between Physical Activity Indices, Age, BMI, and Results of Postural Stability Tests.

Variables	OLST-EO [s]	OLST-EC [s]
WI [pts]	−0.11	0.65***
SI [pts]	0.16	0.25
LI [pts]	−0.09	−0.10
TI [pts]	0.04	0.46**
Age [years]	−0.12	−0.01
BMI [kg/m^2]	0.20	−0.04

Note. ***p* < .01, ****p* < .001; WI = physical activity at work; SI = sports activity; LI = physical activity at leisure; TI = total index of physical activity; BMI = body mass index; OLST-EO = one-leg standing test with eyes open; OLST-EC = one-leg standing test with eyes closed.

Discussion

The level of physical activity was assessed on the basis of the Baecke questionnaire. A significant difference was noted between the average values of physical activity at work and during leisure time. The group of HW reported the greatest physical activity during work. The analysis of the average value of physical activity during leisure time showed lower results for HW. The reduced involvement of HW in physical activity during leisure time is most likely caused by their increased level of physical activity during work (Chau, van der Ploeg, Merom, Chey, & Bauman, 2012; Clemes, O'Connell, & Edwardson, 2014). The reverse situation can be observed in the OW group, in which reduced activity during work is compensated by increased free-time activity. Similar ages, lifestyles, and family models may influence the comparable results in the level of physical activity in both groups of men.

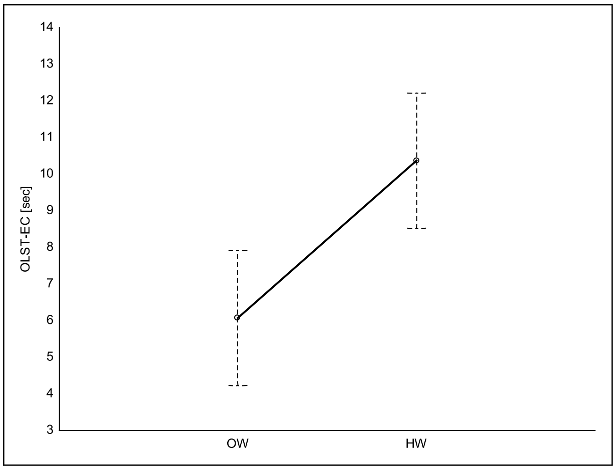

Figure 1. Differences between corrected means for one-leg standing test with eyes closed for office (OW) and high workers (HW) group.

In the case of postural stability, a significant difference was noted in the OLST-EC. The HW group achieved better results even under control of total physical activity level. Presumably, the superior postural stability of HW results from the daily training of particular muscle groups used in the occupational tasks of the at-height worker, balance training related to the conditions and nature of this work, as well as the level of physical activity (Gatti, Giovanni, & Migliaccio, 2014; Lee & Nussbaum, 2012; Yan, Li, Li, & Zhang, 2017).

Punakallio (2003) studied the influence of age, occupation, and physical activity on the functional and postural stability of physical workers. The analysis included firefighters (men, $n = 69$), construction workers (men, $n = 52$), nursing staff (women, $n = 51$), and home care workers (women, $n = 66$). The age of the respondents ranged from 23 to 61 years. Balance was tested with the use of a force platform. In addition, functional balance was also assessed by means of walking on a wooden board. Construction workers obtained better results than firefighters, and both groups had better functional balance and were characterized by higher levels of physical activity than home and nursing staff.

Similar results emerge from the studies of Prioli, Freitas Júnior, and Barela (2005), who analyzed the effects of physical activity on control in the posture of the elderly and the relationship between visual information and body balance. The study included 16 physically inactive elderly people, 16 active elderly people, and 16 young adults (ages: 63.3, 64.3, and 21.7 years, respectively). Inactive elderly people had more difficulty to discriminate and integrate sensory information than active elderly and young adults. It has been concluded that physical activity seems to help in maintaining the appropriate level of posture control and sensory interaction. Age and lack of physical activity can be responsible for insufficient posture control and vice versa; physical activity can modulate the posture control of people of all ages.

Min et al. (2012) studied objective measures of the postural stability, cardiovascular stress, and subjective difficulty in maintaining postural balance among four novice and four expert construction workers with experience with regard to scaffold frames. The experts were 9.3 years older than the novices and had 15 more years of experience in the job. At a lower level of worker experience, a higher scaffold height, and in the absence of a handrail, postural stability was significantly reduced, while cardiovascular stress increased.

Similar results emerge from the studies by DiDomenico et al. (2010), who analyzed the effects of postural stability of construction workers upon standing, after working in different postures. Based on both studies, it can be stated that the workplace and the experience of HW affect their postural stability, regardless of the industry and the age of the worker.

Adkin et al. (2000) analyzed whether posture control correlates with the level of risk of the posture. In conditions of increased posture risk such as alterations in surface height, greater posture control was observed in young, healthy adults (20.3 ± 1.3 years). In addition, postural control precisely matched the level of danger and increased with the level of experience (i.e., prior experience of postural threat) of the tested person. The control of posture was also influenced by the order in which the threat to posture was experienced. These results may be validated by the results of the research obtained in this article.

Finally, some limitations of this study must be mentioned. First of all, the experimental group is relatively small. The study conducted on a larger sample could have generated a stronger overall evidence base. Another limitation is that there was no analysis of physical activity level in leisure time in the context of socioeconomic status. Finally, precise assessment of the level of physical activity in daily life of HW using accelerometers, for example, Actigraph (especially in the context of timeline of performed activity during day), could help enhance the analysis of obtained results.

Conclusion

The study has shown that the increased risk of a posture leads to more conscious posture control on the part of HW. As for postural stability, the groups differed in favor of the HW. At the same time, despite differences in particular aspects, the overall level of physical activity was similar. This may indicate that postural stability is rather affected by exposure to distress conditions, such as work at heights.

Declaration of Conflicting Interests

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Article

The Effects of Cognitive Task and Change of Height on Postural Stability and Cardiovascular Stress in Workers Working at Height

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Abstract: The purpose of the study was to analyze the effects of cognitive task and change of height on the postural stability and cardiovascular stress of at-height workers. The study included 32 healthy men aged 25–47. Due to the type of work performed, two groups were identified: at-height workers, HW (n = 16), and office workers (mainly work at desk with a computer) OW (n = 16). The objective measures of postural stability (posturography) and cardiovascular stress (heart rate monitor) were evaluated for both groups at two different platform heights (ground level and 1 m above the ground) with or without cognitive task (backward counting). The increased height and the cognitive task were found to significantly affect measures of postural stability and cardiovascular stress. It was observed that in inexperienced OW employees, higher platform height and performing a cognitive task meant that posture stability significantly decreased, while cardiovascular stress and difficulties in maintaining balance increased. In HW group postural stability is less affected by distress conditions than in OW group.

Keywords: postural stability; cognitive task; at-height workers; cardiovascular stress

1. Introduction

The construction industry and in particular work at height are often considered to be one of the most dangerous occupations [1]. According to the Occupational Safety and Health Administration [2], any work during which the distance between the working platform and the ground involves a fall from one level to a lower level is work at height, e.g. on scaffoldings or building structures. The "Labor Code" [3] recommends examinations of the balance system of people working at above one meter from ground/floor level. This type of work may result in an accident or illness [2,4,5]. Every year in the UK, 10 million people perform different forms of work at height and falls from a height cause nearly three out of ten fatal injuries (29%) [6,7]. In 2013/2014 alone, they caused losses estimated at 567,000 working days: that is why understanding all the possible challenges related to working at height becomes necessary [4,6]. In the European Union countries, one of the most common causes of accidents during work at height is low risk awareness. This unawareness leads to downplaying the hazardous behaviors, which is associated with employees' lack of knowledge of possible dangers and of suitable procedures in the event of an accident [1]. Only highly qualified and experienced workers with the appropriate mental and physical qualifications are competent to work at height. People working at height should undergo medical examinations, including ophthalmological, neurological and electrophysiological tests [8]. Li and Poon [9] reported that the causes of accidents at height can be classified as technical, organizational, and human.

Among the most common causes of accidents related to work at height are postural stability deficiencies [10]. When working at height, unsafe environmental conditions, inappropriate safety equipment or lack thereof, insufficient collective protection measures, uneven work surfaces, slippery surfaces and the presence of obstacles can lead to loss of postural control [11]. Falls occur when employees suddenly lose their balance as a consequence of slipping, tripping or spraining an ankle [5]. The reason for this situation may be a disorder of one of the functions associated with maintaining proper control of body posture [12–15]. A number of studies have been conducted that compared and assessed the risk of falls in view of physiological and psychological factors [16–20].

It has been identified that increasing the elevation of the surface on which the worker stands alters postural control [21–23]. While maintaining an upright stance, workers were observed to use a strategy of stiffening the body, characterized by reduced amplitude and increased frequency of posture adjustment as well as leaning backwards away from the direction of danger [14,24]. Modifications of postural control are accompanied by psychological [25], and physiological changes because participants are less confident, more afraid of falling, are more anxious and feel less stable when standing on an elevated platform [19,26,27]. It has been confirmed that workers are able to consciously intervene in postural control by increasing ankle stiffness in an upright stance [28,29]. It is important to identify whether postural threat results in a more conscious postural control and whether such a change in cognitive strategy can be linked to changes in postural control [21,30,31].

Min et al. [31] investigated whether safety handrails and scaffolding height affect the subjective and objective assessment of postural stability, and whether they affect cardiovascular stress, in novice and experienced construction workers. They reported that by increasing the altitude of the surface on which the studied person stands, the risk of fall perception rises. This applies especially to people who do not work at heights on a daily basis. The same authors also identified that the perception of loss of balance is reflected in the control of body balance as it alters the strategy adopted by the central nervous system [31]. Chander et al. [32] analyzed the impact of Virtual Reality (VR) generated construction environments at different heights on postural stability and fall risk. Studies have shown that the VR environment, regardless of virtual growth of the elevation platform, also induced increased postural instability. It has been suggested that this can be attributed to visual sensory conflicts in the postural control system created by the VR exposure.

Other studies have confirmed that the effect of elevated height and lack of safety handrails increases anxiety and subjective stress triggered by fear of falling, which has been demonstrated to affect the neuromuscular system in both healthy and unhealthy people [19,20,28]. Similar reactions were also noticed in a group of at-height workers [13,17,23,31]. Respondents often use more conservative strategies to maintain postural control in settings of increased hazard arising from, e.g., elevation change [21,33].

Zaback et al. [25] analyzed the adjustment of the parameters of emotional state and balance in their subjects after repeated exposure to postural threat caused by an increase in height. The emotional response of individuals was weakened after repeated exposure to danger. However, the change in standing balance did not change significantly despite exposure to danger. The results may suggest that some threat-induced balance changes are more closely allied with an emotional response than others. Johnson et al. [34], who researched emotional, cognitive and postural adaptations in young and older adults under the influence of repeated exposure to danger, noticed that some modifications in threat-related postural control may be closely correlated with emotional response to the threat, while others may be dependent on the context. The emotional context was also emphasized in other research concerning human postural control [30,35,36].

Another factor in different perceptions of the threat to postural stability may be the performance of a dual task, or task switching, which is used in research on the engagement of attention in postural control [37]. In these studies, maintaining body posture is considered a basic task and concurrently performing a dual task is the secondary task [38]. Cullen and Agnew [39] have reported that performing a dual task can decrease the effectiveness of postural control compared to performing a single task.

In addition, appropriate reweighting of attention is very important to prevent loss of balance when performing a double task [37]. It has been reported especially that recovering balance is very demanding in terms of information processing [40]. When insufficient attention resources allocated to postural tasks are processed, the risk of losing balance and consequently falling rises [41]. In our previous study [42], we analyzed the postural stability and physical activity of workers working at height. To assess postural stability, the one-leg standing test with eyes open and closed was used. The HW group obtained higher results in the postural stability functional test. Based on the results, it could be assumed that postural stability is influenced by exposure to stressful conditions such as working at height.

Despite the fact that the impact of threat to posture on modification of balance control has been previously documented, there is still little information about the mechanisms and strategies responsible for these changes, especially in the group of at-height workers [43–45]. One of the possible strategies may be to link the threat to more conscious control of body balance [21]. It is suggested that at-height workers are characterized by the increased automation of the postural stability system [46,47]. Previous studies have focused mainly on the effect of specified conditions (cognitive single-double task) or a specified level of height (low-high threat). To our best knowledge, there have been no studies that have examined all these elements together in the group of at-height workers.

The aim of this study was to assess differences in postural stability under various conditions: both when changing the height of the measuring platform and with an additional cognitive task. Changes in heart rate were evaluated in dangerous conditions caused by the change of the height platform. Hypotheses were as follows: (1) increasing the altitude of the measuring platform disturbs postural stability to a greater extent in the group of office workers than in high-altitude workers; (2) postural stability while performing a cognitive task is higher in the group of high-altitude workers than among office workers; (3) when changing altitude, greater cardiovascular stress occurs in office workers than in high-altitude workers.

2. Materials and Methods

2.1. Characteristics of the Study Group

The study involved 16 healthy men working at height (HW: high-altitude workers). 16 office workers were examined as the control group (OW: office workers, mainly working at desk with a computer). Eligibility criteria were as follows: minimum age of 25, verbal communication skills enabling informed, logical answers, full mobility, and a minimum of one year's experience of working at height for the HW group.

All men interested in participating in the experiment agreed in writing to the experimental procedure and were informed in detail about the study procedures (participation was voluntary). The study was approved by the Bioethics Committee of the Poznan University of Medical Sciences (Decision No. 1111/16) and was in line with the Helsinki Declaration [48]. The basic characteristics of both groups were examined before the experiment. No statistically significant differences were identified between the groups in terms of age, BMI, and physical activity (PA) (Table 1).

Table 1. Average values, standard deviations and differences between groups for the general characteristics of the participants and physical activity before the start of the experiment.

Variable	M (sd) HW	M (sd) OW	t df = 30	p
Age [years]	34.5(7.49)	36.00(6.31)	−0.61	0.54
Body height (m)	1.82(0.05)	1.79(0.08)	1.25	0.22
Body weight (kg)	90.5(9.94)	83.5(13.34)	1.69	0.23
BMI [kg/m2]	27.31(2.59)	26.01(3.41)	1.21	0.23
PA [cals used/wk]	21918.94 (2962.42)	19694.56 (4178.72)	1.74	0.09

Note. HW–height workers; OW–office workers; BMI–body mass index; PA–physical activity.

2.2. Procedures

The research procedure included performing posturography tests (in random order to avoid the learning factor) which assess human body balance on a stabilometric platform at ground level and at a height of one meter from the ground (Figure 1).

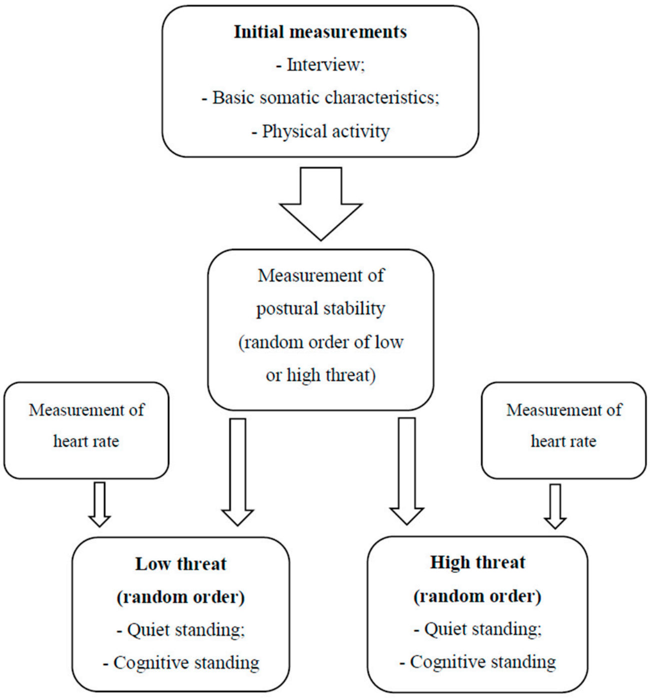


Figure 1. General overview of the experiment.

Each trial test was made twice and lasted 30 s. In previous studies, it was identified that averaging two results is sufficient to obtain an ICC reliability coefficient above 0.9 for the average velocity of center or pressure (COP) [49]. It has been previously reported that recording COP movements for 30 s during a static posture is appropriate to record a reliable measurement [50]. 20-s intervals between the measurements were used (due to the large number of trials). Participants were able to rest in a sitting position in case of dizziness or tiredness. None of the participants took advantage of this opportunity, therefore during all the tests at the low or high level they stayed on the same level of the platform.

A stable, one-meter-high pedestal was used to place the stabilometry platform at a height. To ensure safety, gymnastic mattresses were placed around the platform (Figure 2). Tests were performed on the ground and at height with two different tasks:

- Quiet standing with one's eyes open: the subject stood still in the center of the platform with bare feet hip-width apart and arms down at sides. The posturography platform was placed three meters in front of a white wall, which subjects were asked to look directly at.
- Cognitive standing: the subject stood freely in the above-mentioned position and additionally performed a mathematical task, which consisted of counting backwards every third number down from the number 200 during the time of recording the data [37].

Participants' heart rate was measured during tests in all the experimental conditions.

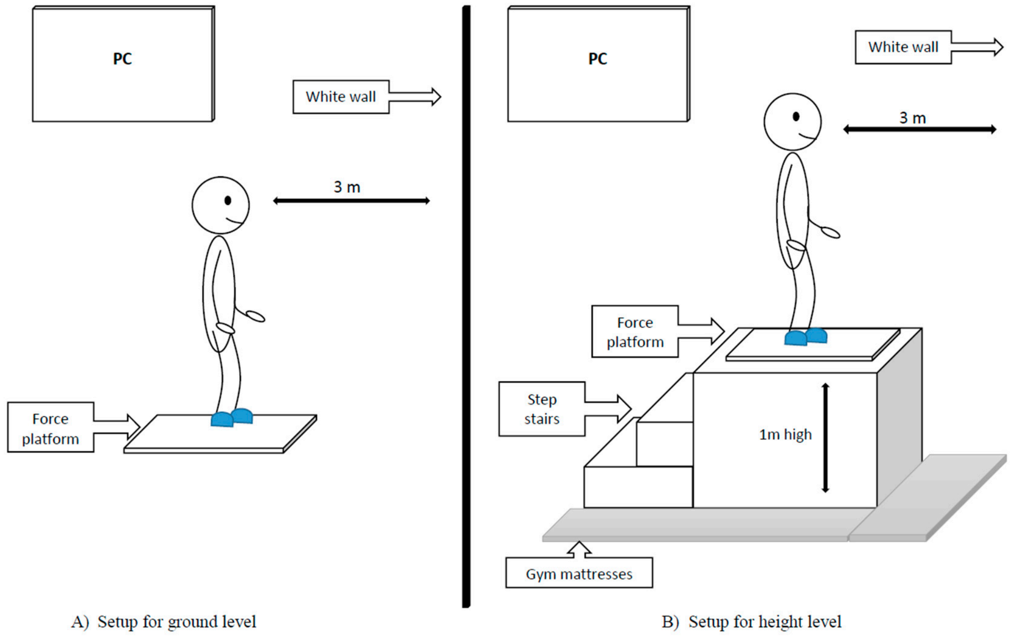


Figure 2. Experimental setup of two measuring stations at ground level (**A**) and at a height of 1 m from the ground (**B**).

2.3. Measurement

2.3.1. Level of Physical Activity (PA)

Some studies reported that PA can modulate the posture control of people of all ages [51,52]. The level of PA was assessed to exclude its impact on the posture control level of both groups.

The level of PA was assessed using the Caltrac activity monitor (Muscle Dynamics, Inc., Tarrance, CA, USA). The accelerometer produces an outcome based on the weekly measurement of energy expenditure due to PA [53,54]. Subjects wore the Caltrac for seven days. The total results in kilocalories were divided by the number of days.

2.3.2. Postural Stability (PS)

COP data was collected using an AccuGait portable force plate (AMTI PJB-101 model, AMTI, Watertown, MA, USA). The plate was connected to the computer using the Balance Trainer software provided by the manufacturer. The sampling frequency was 100 Hz. The fourth-order lowpass Chebyshev II filter [55] with 10-Hz cutoff frequency [56] was used to filter raw data of COP signals. The length of the sway path (SP) of the COP signal and its components in the anteroposterior (AP) and mediolateral (ML) directions were analyzed. This is commonly used as a PS indicator [49,57].

2.3.3. Cardiovascular Stress

The increase in heart rate on exercise compared to resting heart rate was measured as a physiological and psychological indicator of stress. Heart rate was measured for the first minute while the participants were executing the task at low and high threat [31,58,59]. The heart rate was measured with an automatic blood pressure monitor (Oro-Med, ORO-SM2 COMFORT, Warsaw, Poland) placed at the wrist. The pressure gauge has a special sensor for reading blood pressure and change in heart rate. The pressure signal from the blood vessel is read by a pressure sensor. The signal is later amplified and filtered to separate the heartbeat signals [58,60].

2.3.4. Statistical analysis

Statistical analyzes were calculated using STATISTICA Software 13 (TIBCO Software Inc., Palo Alto, CA, USA). Statistical significance level was defined at $p \leq 0.05$. The differences between the groups with respect to basic characteristics (age, BMI, physical activity indicators) were calculated using the t-test. The level of postural stability and cardiovascular stress was analyzed using two-way analysis of variance (ANOVA). The following interaction effects were evaluated: "height × group" and "task × group" (with two levels for each factor: low-high threat and with or without cognitive task among the two groups: HW and OW, respectively), the main effects for the study conditions ("height", "task") and the inter-group effect ("group").

3. Results

3.1. Influence of Height on the Postural Stability of Employees

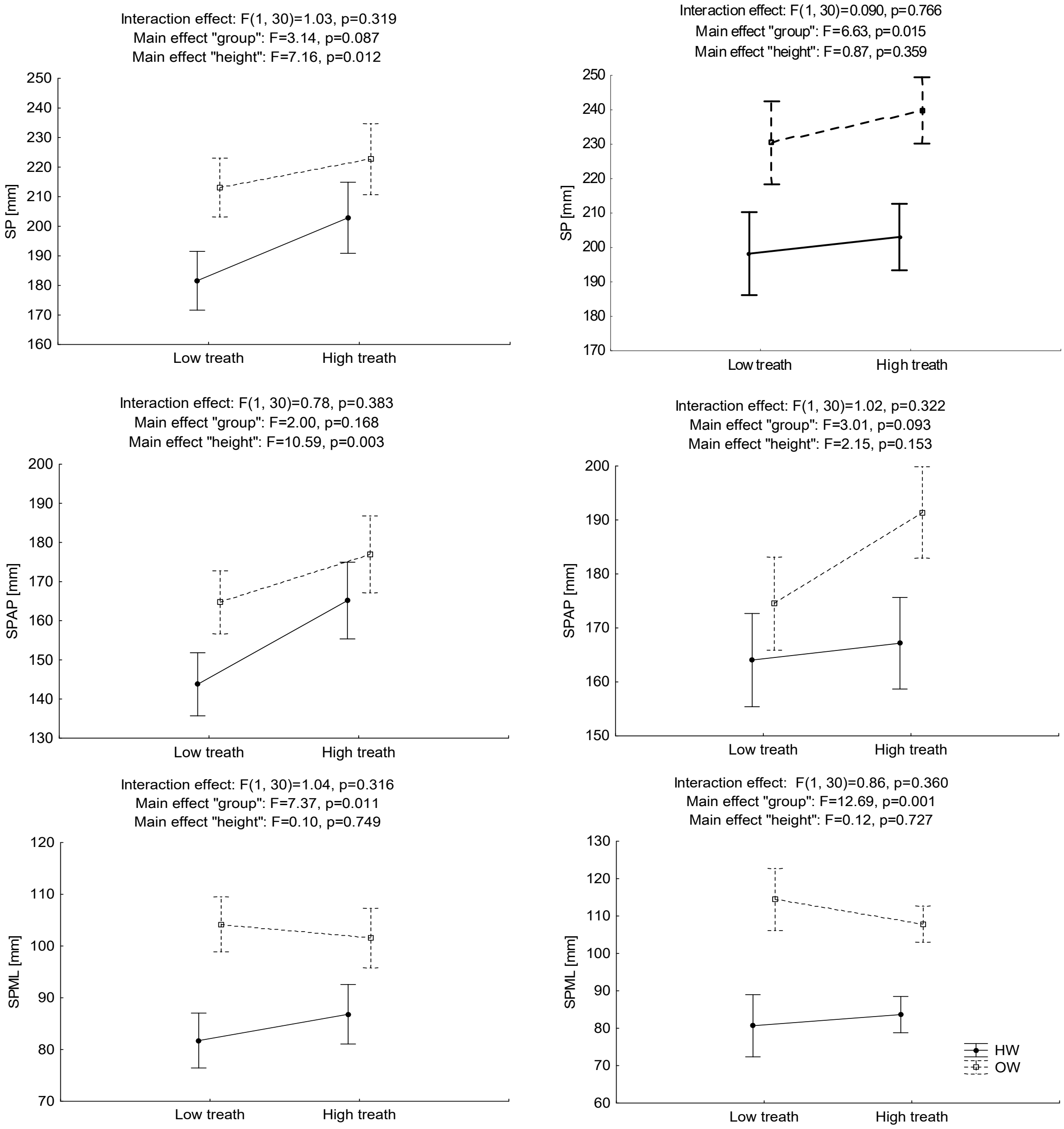
There was no interaction effect ("height × group") for the sway path (SP), the anterior-posterior sway path (SPAP) or the mediolateral sway path (SPML) in conditions of quiet standing (F = 1.03, $p > 0.05$, $\eta^2 = 0.03$; F = 0.78, $p > 0.05$, $\eta^2 = 0.02$ and F = 1.04, $p > 0.05$, $\eta^2 = 0.03$, respectively). Regardless of the conditions under which the measurement was carried out in the OW group, statistically significant higher path length measurements for SPML were identified – the intergroup effect (F = 7.37, $p < 0.01$, $\eta^2 = 0.20$)—which may indicate a lower level of postural stability. A significant main effect "height" was observed for SP and SPAP (F = 7.16, $p < 0.05$; $\eta^2 = 0.19$ and F = 10.59, $p < 0.01$, $\eta^2 = 0.26$, respectively). This indicates that the change in altitude results in a lower level of the outcomes in both groups.

No significant effect of "height × group" interaction was identified in the cognitive standing for any of the tested parameters SP, SPAP and SPML (F = 0.09, $p > 0.05$, $\eta^2 = 0.00$ F = 1.02, $p > 0.05$, $\eta^2 = 0.03$ and F = 0.86, $p > 0.05$, $\eta^2 = 0.02$, respectively). Regardless of the change in the conditions, higher results were identified for SP and SPML (F = 6.63, $p < 0.01$, $\eta^2 = 0.18$ and F = 12.67, $p < 0.001$, $\eta^2 = 0.30$, respectively) in the OW group (Figure 3).

3.2. The Impact of Performing a Cognitive Task on Employees' Postural Stability

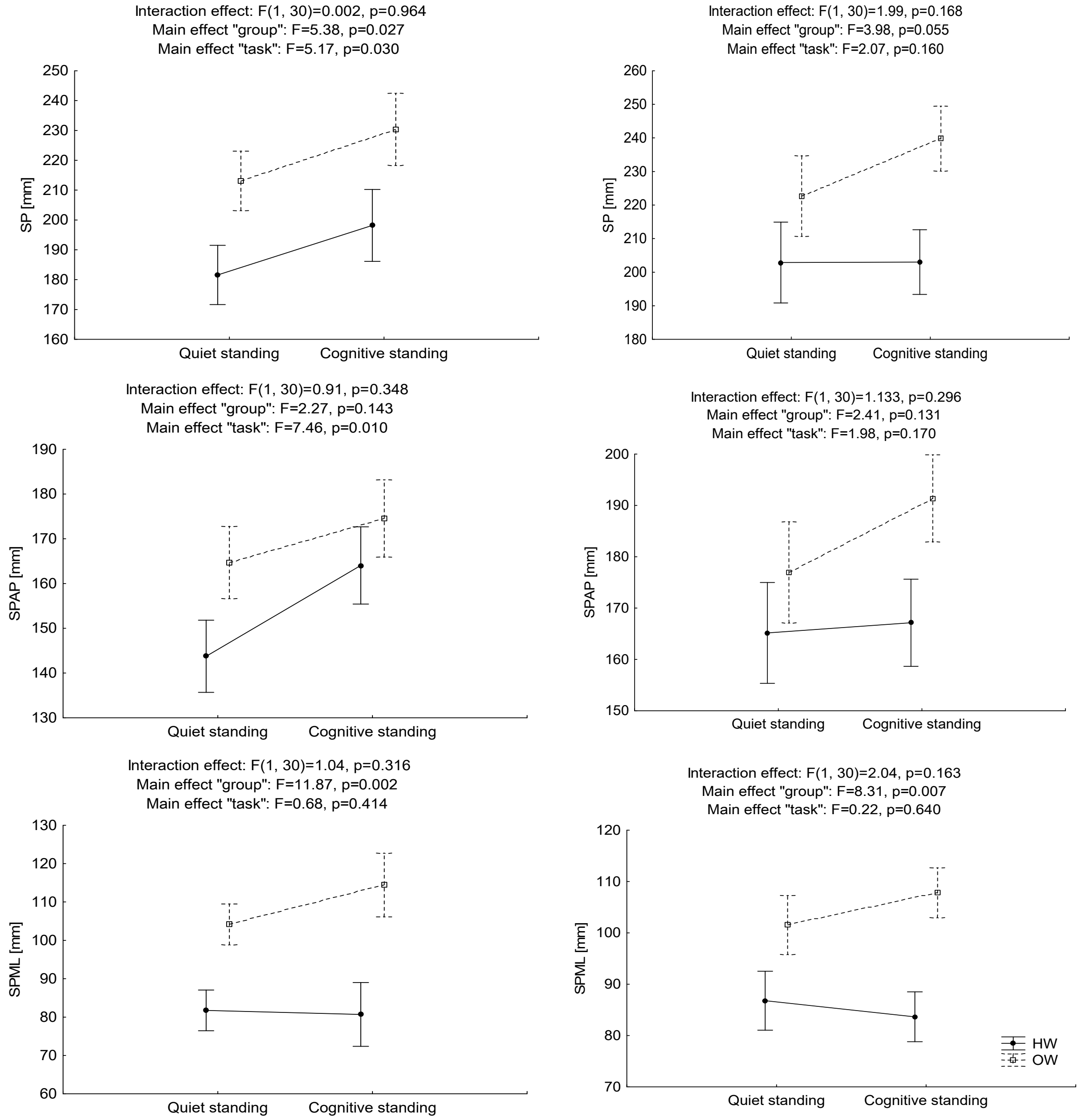
No "task × group" interaction effect for SP, SPAP or SPML is: (F = 0.002, $p > 0.05$, $\eta^2 = 0.00$; F = 0.91, $p > 0.05$, $\eta^2 = 0.03$ and F =1.04, $p > 0.05$, $\eta^2 = 0.03$, respectively) when switching tasks during measurement at ground level. Regardless of the conditions in which the measurement was carried out, the HW group obtained statistically significant lower values for SP and SPML—the intergroup effect (F = 5.38, $p < 0.05$, $\eta^2 = 0.15$ and F = 11.87, $p < 0.01$, $\eta^2 = 0.28$, respectively)—which may indicate a higher level of postural stability. A significant main effect ("task") was identified for SP and SPAP (F = 5.17, $p < 0.05$, $\eta^2 = 0.15$ and F = 7.46, $p < 0.01$, $\eta^2 = 0.20$, respectively). This suggests that performing the cognitive task causes deterioration of results in both groups.

No significant effect of the "task × group" interaction was noted at the increased height of the measuring platform during the performance of the task for any of the tested parameters SP, SPAP and SPML (F = 1.99, $p > 0.05$, $\eta^2 = 0.06$; F = 1.13, $p > 0.05$, $\eta^2 = 0.04$ and F = 2.04, $p > 0.05$, $\eta^2 = 0.06$, respectively). Regardless of the change in the conditions, the OW group obtained higher path length values for SPML (F = 8.31, $p < 0.01$, $\eta^2 = 0.22$). No statistically significant main effect of "task" was identified for any of the tested parameters (F = 2.07, $p > 0.05$, $\eta^2 = 0.06$; F = 1.98, $p > 0.05$, $\eta^2 = 0.06$ and F = 0.22, $p > 0.05$, $\eta^2 = 0.01$, respectively). Regardless of the group and height of the measuring position, higher results were recorded during cognitive standing (Figure 4).



(**A**) Quiet standing (**B**) Cognitive standing

Figure 3. Mean values and standard error of measurements for sway path of center of pressure (COP) displacements (SP) and its components in anteroposterior (AP) and mediolateral (ML) directions for "height" factor (low-high threat) and "group" factor (at-height workers—HW and office workers—OW) for quiet standing (**A**) and cognitive standing (**B**).



(**A**) Low threat (**B**) High threat

Figure 4. Mean values and standard error of measurements for sway path of COP displacement (SP) and its components in AP and ML directions for "task" factor (quiet standing and cognitive standing) and "group" factor (at-height workers—HW and office workers—OW) for low threat (**A**) and high threat (**B**).

3.3. The Influence of Altitude on Cardiovascular Stress

Analysis of cardiovascular stress reported a significant interaction effect (F = 11.25, $p < 0.01$, $\eta^2 = 0.27$). No statistically significant intergroup effect was reported (F = 0.21, $p > 0.05$, $\eta^2 = 0.01$). However, at the height of 1 m, the OW group was characterized by higher values of heart rate. A statistically significant main effect, "height," was noted (F = 84.35, $p < 0.001$, $\eta^2 = 0.74$). Regardless of the group, higher results were recorded at the increased height of the measuring platform (Figure 5).

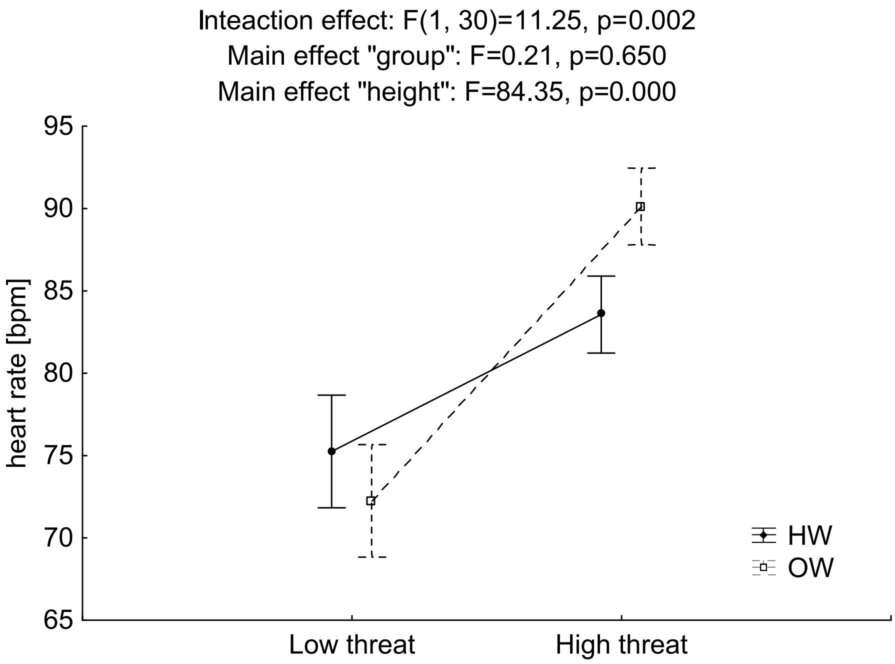


Figure 5. Mean values and standard error of measurements for cardiovascular stress at low and high postural threat in groups of at-height workers (HW) and office workers (OW).

4. Discussion

To our best knowledge there are no previous studies comparing HW group with OW group. However, the overall view of the results, related to changes in stability with height of the platform and cognitive tasks, is consistent with other studies where at height workers were examined in other contexts.

The obtained results confirm that the change in height causes a deterioration in a quiet standing stance regardless of the studied group (HW and OW) [26,28,45,61]. In quiet standing tests, both increase in the length of the COP path and range of sway were observed along with the increase in height at which the subject was standing. For all the analyzed parameters lower results (which may indicate a higher level of postural stability) were achieved by the HW group. Presumably, higher posture stability in HW group can be explained by the daily training of individual muscle groups used in the professional tasks of high-altitude workers, from balance training related to the conditions and nature of their work, as well as from their overall level of physical activity performed at work [30,43,62].

Adkin et al. [28] analyzed changes in posture control at different heights of the measurement platform above ground level. The change in platform height has also been used to modify threat levels. It has been reported that the control of postural stability is closely affected by threat to standing position, but also by the order in which the postural threat occurred. In addition, the control of postural stability increases with level of experience (i.e. previous experience of postural threat). Similar results were reported by Sturnieks et al. [26] who tested the effect of age, anxiety and fear of falling on postural sways in young and older adults standing on a 65-cm-high platform. In response to postural threat, people experiencing anxiety adopted strategies for improved balance control by increasing the frequency of COP sways and minimizing sway ranges. It has been also identified that the 65 cm height used in the study is not adequate enough to induce changes in balance control in a group of young adults.

The findings for the cognitive standing sample revealed a higher length of the COP path as compared to quiet standing. Height did not change the subjects' balance control despite significant differences in COP signal parameters between quiet standing and cognitive standing. A much lower level of changes in COP and its components towards AP and ML planes was noted in the HW group during cognitive standing and after the change in height. These results may suggest that carrying out the task and changing the height do not significantly influence the level of postural stability in the group of experienced HW [39,40,63]. Fear of falling and previous experience of work at height can play an important role in altering posture control strategy in conditions of high risk due to altitude change [35,64,65]. It has been confirmed that the mode of the sensory systems involved in postural control is shaped by different levels of anxiety depending on the individual's intensity of fear [44,66]. In addition, when performing tasks or processing visual information, people who are less resistant to fear and to stressful situations may use strategies which are less conducive to maintaining postural control in conditions of increased postural threat, instigated, for example, by increasing the height of the platform [65–68]. As a consequence, this may lead to greater postural instability in these people [65,66,69].

Pellecchia [70] investigated whether postural balance changes under the influence of three cognitive tasks depending on their difficulty. Young adults participated in the study. The results indicated that performing the most difficult task, i.e. the counting backwards using every third number. impacted postural sway. The longest COP path was recorded for the sample which involved counting every third number backwards. The path length increased with the difficulty of the task. It may confirm the results of this study.

Hainaut et al. [66] analyzed the effect of moderate anxiety on static balance with open and closed eyes in two groups of healthy people with contrasting features of anxiety. It has been reported that anxiety induces a larger and faster body sway in both groups in the open eye test. This suggests that anxiety may modify the processing of various sensory data involved in balance control irrespective of the level of anxiety of the subjects. Results regarding inter-individual differences point to a mutual relationship between static balance control and anxiety.

Based on this research, it can be concluded that typical tasks performed during work at height, as well as increasing awareness of the postural threat in HW, contribute to a slight level of change in postural stability, regardless of the industry and age of the employee [63,64,71]. It is also possible that the high-risk state in the OW group begins at a lower elevation than one meter, which causes high individual variability in level of postural stability [19,26].

Cardiovascular stress is a psychological and physiological indicator that increases with growing height and danger [16,31,60]. In the OW group, a higher surge in cardiovascular stress was observed with a rise in perceived difficulty in maintaining balance due to height and task performance [18,31,72]. The HW Group experienced a lower level of mental stress due to the increase in platform height [31,73]. Lower levels of cardiovascular stress may be associated with professional experience related to tasks such as building, dismantling and modification of scaffolding carried out on tall buildings that force employees to handle both precise work and difficult weather conditions, such as strong wind, rain and snow [27,63]. It is possible that the change in platform height from low to high (one meter) may not be dangerous enough to cause sufficient individual variability in the HW group [19,26].

Similar conclusions were revealed by the research of Hsu et al. [73] who examined the effect of altitude changes on mental stress in workers building high voltage transmission towers. Twelve experienced male employees aged 29 to 58 participated in the experiment. The study analyzed the impact of working surface elevation on heart rate variability of employees during the construction of a high voltage transmission tower on a distant and exposed mountain slope at three different heights. The results of the study demonstrate that the height of the working surface significantly affects heart rate variability (HRV). Construction employees working on high voltage transmission towers exhibit an increased level of mental stress as the elevation of the working platform increases, which may be attributable to insecurity, lack of safety guards, work environment and visual perception. Min et al. [31] also reported a significant impact of work experience, scaffolding height and the presence of safety guards (handrails) on the level of postural stability and cardiovascular stress. With lower employee experience, a higher scaffolding height and absence of security guards, postural stability was significantly reduced, while cardiovascular stress grew. These results were supported by the findings of this study.

Finally, it should be mentioned that this work is limited. The tests were performed only at ground level and at a height of one meter. This height may not have been adequate to produce sufficient individual variation in both groups. Increasing the platform height can significantly increase the difference between groups. An accurate assessment of the emotional state of the subjects could help improve the analysis of the obtained outcomes.

5. Conclusions

It was reported that COP path lengths, cardiovascular stress, and difficulties in maintaining balance during task performance are statistically significantly lower in experienced HW employees. This study provides evidence that professional experience and individual traits, including specific personal qualities and differences, can shape a strategy of postural control adopted in conditions caused by an increased postural threat. Although this research does not have a direct impact on improving the assessment and treatment of balance problems, it is suggested that it may be important in understanding how particular individual characteristics and professional experience affect the level of postural stability in difficult or dangerous conditions. Further studies of level of postural stability, taking into account psychological factors, fear of falling, and the impact of balance training on the above-mentioned aspects are warranted to reduce the risk of accidents among high-altitude workers.

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The Influence of Proprioceptive Training with the Use of Virtual Reality on Postural Stability of Workers Working at Height

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Abstract: The aim of the study was to assess the impact of proprioceptive training with the use of virtual reality (VR) on the level of postural stability of high–altitude workers. Twenty-one men working at height were randomly assigned to the experimental group (EG) with training (n = 10) and control group (CG) without training (n = 11). Path length of the displacement of the center of pressure (COP) signal and its components in the anteroposterior and medial–lateral directions were measured with use of an AccuGaitTM force plate before and after intervention (6 weeks, 2 sessions × 30 min a week). Tests were performed at two different platform heights, with or without eyes open and with or without a dual task. Two–way ANOVA revealed statistically significant interaction effects for low–high threat, eyes open-eyes closed, and single task-dual task. Post-training values of average COP length were significantly lower in the EG than before training for all analyzed parameters. Based on these results, it can be concluded that the use of proprioceptive training with use of VR can support, or even replace, traditional methods of balance training.

Keywords: postural stability; virtual reality; proprioceptive training; at-height workers

1. Introduction

Construction industries have the highest statistics of injuries and fatalities and working at height involves a particularly high risk [1]. The risk is associated with being at high altitudes, often combined with difficult weather conditions, e.g., strong winds, rain and snow [2]. Over 10% of all fatal accidents in the construction industry are a consequence of falling from elevated surfaces [3]. According to the Occupational Safety & Health Administration [4] any work where the level difference between the workplace and the floor creates the threat of falling from one level to a lower level is working at height, for example: on scaffolding, ladders or other elevations. For people working from one meter upwards, examinations of the balance system are recommended [5]. Loss of balance, slips and trips are the most common causes of accidents [6,7].

In order to prevent accidents among high-altitude workers, researchers are focusing on indicating factors that affect instability and loss of balance. Maintaining stability and balance of posture is difficult due to continual changes in the vertical projection of the center of mass (COM) on the base of support, which may be affected by environmental and internal factors [8]. The stability of human posture is associated with three main sensory senses: the visual, vestibular and somatosensory systems [9]. These senses are closely related to correctly interpreting reality and responding to it appropriately. Such sensory integration is associated with the function of the central nervous system, as well as a neurological process that organizes sensations flowing from the body and the environment in such a way that they can be used for purposeful action [10,11].

In cases where one of the sensory systems is at risk, or the sensory information is inaccurate, postural stability (PS) and balance may be disturbed, especially when the changes affect the visual system [12]. Hsiao and Simeonov [13] noticed in their studies that moving visual scenes and depth perception are among the key elements provoking instability and negatively affecting balance.

It was also found that lowering PS level is affected by performing tasks at height. Stability disorders during performance of tasks at height are enhanced by visual stimuli, which cause additional anxiety because task performance seems to be dangerous [14–17]. Another factor affecting PS may be performing a dual task or switching between tasks. The effectiveness of posture control while performing a dual task may decrease compared to performing a single task [18]. In addition, it has been shown that it is very important to freely divide attention to prevent loss of balance, and falls as a consequence, when performing a double task [19].

The ability of high-altitude employees to identify and assess risk is acquired through training and experience. It is one of the key factors determining their behavior, and thus their safety. Training and drills in this area are a very important element in protecting employees from falling [20–22]. In education and training programs in construction engineering, virtual reality (VR) technologies have quickly gained recognition [21]. For example, Goedert et al. [23] developed a virtual interactive educational platform to provide safety training. The training was based on games through the use of simulation and modeling. Overall, the project proved to be both effective and engaging for employees.

Donath, Rossler and Faude [24] demonstrated in their studies thatnew technologies such as VR may also be used during training. Thanks to VR technologies, it is possible to train and strengthen individual body parts more effectively and easily adapt the exercises to individual abilities and needs [8]. According to research, training using VR positively affects the improvement of PS [25]. VR has also been integrated with applied science, e.g., these technologies have been applied in architecture and design visualization, medicine and construction health and safety, enabling further improvements in the efficiency of education and training in the construction industry, in particular among high-altitude workers [21].

Recently, training platforms facilitating proprioceptive exercises with the use of VR, which recreate a natural sense of instability because the body is forced to do more work, have become popular training devices [26]. Through these, the muscles can be trained, reaction ability stimulated, and body balance shaped [27,28].

This type of training may bring about additional effects compared to those achieved during standard equivalent exercises, which can be predicted on the basis of studies on the sick and the elderly, as well as the healthy and young [28–30]. Furthermore, VR simulation can be used as a comprehensive system that integrates elements necessary for active learning for a group of high-altitude workers [31]. For example, Wang et al. [32] analyzed the effectiveness of using serious games in 4D technology (3D + time) in training in the field of occupational health and safety in construction. It has been noted that VR can increase users' involvement and affect their ability to detect Occupational Safety and Health risks. Similar conclusions were presented by Strobach, Frensch and Schubert [33] who stated that the practice of video games improves executive control skills while performing a double task.

On the other hand, there are numerous studies showing that the benefits of virtual reality are often surpassed by limitations due to cybersickness. Cybersickness is similar in symptoms to motion sickness and can result in nausea, headaches and dizziness [34]. For example, Nalivaikoa et al. [35] analyzed the influence of how cybersickness, provoked by a head-mounted display, affects cutaneous vascular tone, heart rate and reaction time. It has been noted that Cybersickness evokes nausea, increases body temperature and extends reaction time, raising obvious concerns regarding the safety of this technology [35]. Therefore first, it should be checked if people participating in VR training do not report similar ailments.

To our best knowledge, no research has been conducted regarding the effects of proprioceptive training on a balance platform using VR for individual PS parameters in high-altitude workers. However, based on the research of the elderly, the sick and those with neurological disorders, as well as healthy people [36–38], it can be assumed that this type of training can also produce positive effects in high-altitude workers. For example, Amritha et al. [39] studied the effect of using a balance platform that provides static and dynamic balance training through interactive VR games for those with balance disorders. Studies have shown that balance training using a balance platform significantly improves PS levels and has a positive effect on daily activities.

The aim of the work was to assess the impact of proprioceptive training using VR on the PS level of employees working at height. We assumed the general hypothesis that proprioceptive training with VR using a balance platform has a positive effect on the level of PS. Moreover, we assumed that proprioceptive training with VR would contribute to increased stability in the case of (1) a standard stability test with eyes open, (2) reduction of visual stimuli, (3) changing the height of the test plane and (4) introducing an additional cognitive task.

2. Materials and Methods

2.1. Characteristics of the Research Group

The study involved 24 healthy men working at height between the ages of 22–47. High-altitude workers (HW) were randomly assigned (Excel software) to the study and divided into two groups:

- Experimental group (EG)—HW training on a balance platform using VR: initial $n = 12$;
- Control group (CG)—HW not training on a balance platform using VR: initial $n = 12$.

During the study, 2 men in the EG withdrew from the study due to injury (injury was not related to the experiment) and 1 man in the CG withdrew from the study without giving a reason. As a result, 21 men in both groups participated in the study (Figure 1). The eligibility criteria were as follows: at least one year of experience in working at height, minimum age of 20, full mobility, verbal contact skills enabling informed and logical answers.

All men participating in the experiment were informed in detail about the study procedures and gave their written consent for the experimental procedure. Participation in the experiment was voluntary. None of the subjects had experience in training on a balance platform using VR. The basic characteristics of both groups are presented in Table 1. The study was approved by the Bioethics Committee of the Poznan University of Medical Sciences (decision no. 1111/16) and was in line with the Helsinki Declaration [40].

Table 1. Average values, standard deviations and differences between groups for the general characteristics of the participants and physical activity before the start of the experiment.

Variable	M (sd) EG	M (sd) CG	t df = 19	*p*
Age [years]	34.00(8.04)	37.27(7.87)	−0.94	0.36
Body height (m)	1.81(0.04)	1.81(0.06)	−0.37	0.72
Body weight (kg)	88.52(9.64)	88.85(13.14)	−0.06	0.95
BMI [kg/m^2]	27.13(2.32)	26.97(3.40)	0.12	0.90
PA-E [cals/day/kg]	9.31(9.25)	11.63(9.14)	−0.57	0.57

Note. EG—experimental group; CG—control group; BMI—body mass index; PA-EE—physical activity-energy expenditure.

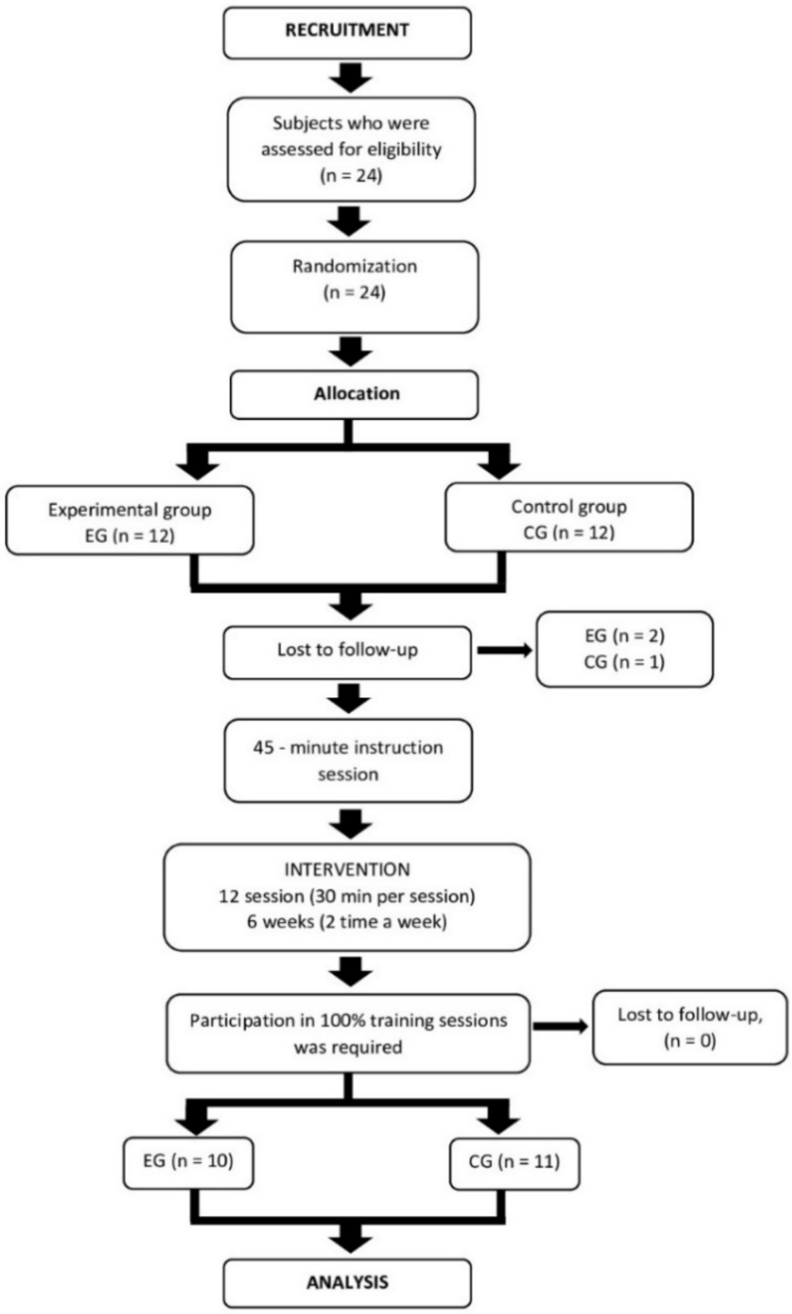

Figure 1. Flowchart of the study participants.

2.2. *Experimental Procedures*

2.2.1. General Course of the Experiment

A general review of the experiment is shown in Figure 2. Intervention with the use of VR on the balancing platform was introduced in the subjects. The level of postural stability was examined before and after the intervention. The research was carried out at the Poznan University of Physical Education in Poland, at the Department of Physical Activity and Health Promotion Science.

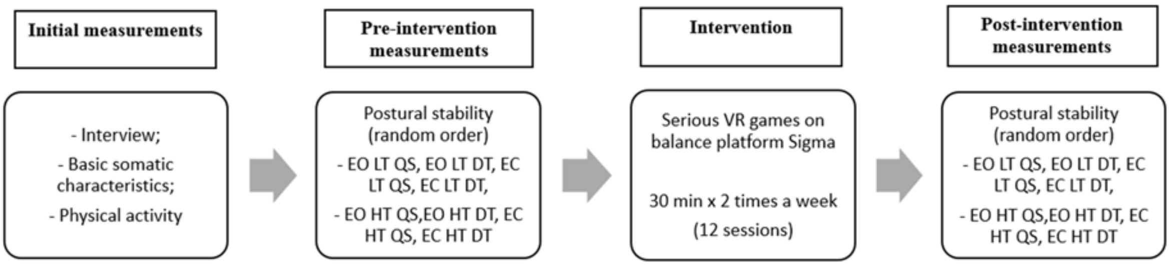

Figure 2. General overview of the experiment. EO—Eyes Open, EC—Eyes Open, LT—Low Threat, HT—High Threat, QS—Quiet Standing, DT—Dual Task.

2.2.2. Initial Measurements

Before the experiment, measurements of somatic characteristics were carried out, i.e., height and weight measurement and BMI (Body Mass Index). In addition, patients were interviewed and their overall health and well-being assessed. The level of physical activity was assessed using Caltrac (Muscle Dynamics, Inc., Tarrance, CA) accelerometer reports, and the results were based on weekly measurement of the energy expenditure associated with physical activity [41,42]. Subjects wore the Caltrac for 7 days. The total result in kilocalories was divided by the number of days and body weight (PA–EE) to obtain normalized values.

2.2.3. Intervention

The experimental group participated in proprioceptive training on a balance platform for 6 weeks for 30 min per session. The trainings took place twice a week. The total number of training sessions was 12, and 100% participation in the training sessions was required. A balance platform was used for the training, Sigma (ACX.rehab element), which is a modern device for training proprioception using VR (Sigma balance platform, Prod. AC International). It was equipped with an independent system for assessing the swing angle of the platform using a gyroscope. The sampling frequency was 40 Hz and the delay of 25 ms. The sensor registered every change in the position of the platform, converting these changes into an appropriate output signal and transmitting data in real time to a computer with the software. This transmission was done wirelessly using a Bluetooth sensor.

During training, audio-visual feedback for participants was used, i.e., biofeedback in the form of video games facilitating exercises through play. The games were simple and involved moving objects like a fish, plane, car and balls. For instance, in the fish game, the subject mainly practiced movement precision. The subject had the task of moving a blue circle to protect the fish from a source of sparks, which was safe when it was in the center of the circle (Figure 3). The game made it possible to measure and practice individual skills in implementing specific movement patterns while maintaining a set speed and range. The goal of the exercise was to repeat movements in 3D space, planned movement training, precision of movements and improving muscle strength. Alternatively, in the sample plane game, the subject practiced functional movements. The subject's task was to fly a plane through circles. The closer to the circle they flew, the more points they scored (Figure 3). The subject was thus able to practice focus, perceptiveness, precision of movements, predicting the trajectory of moving objects in 3D space, as well as balance during the game.

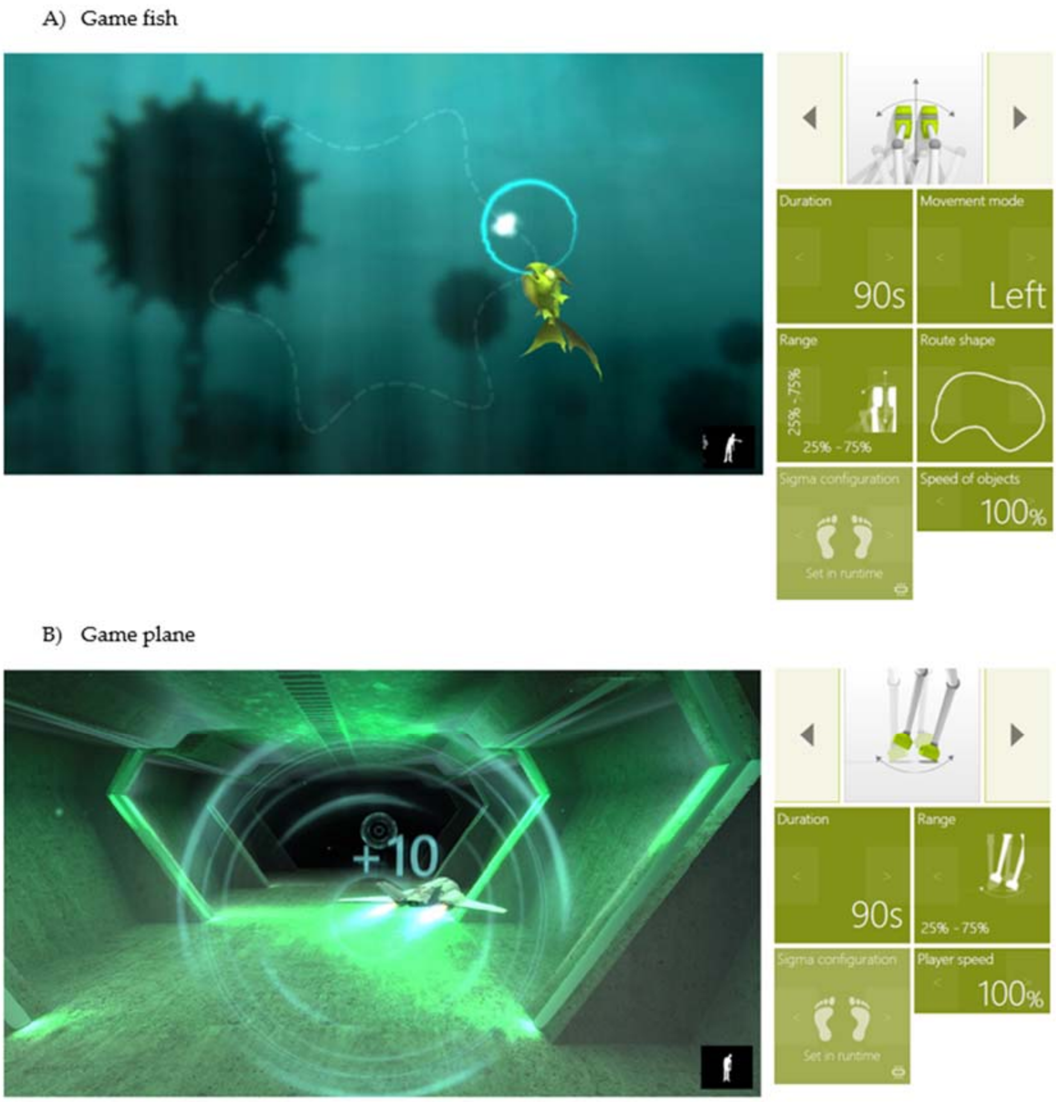

Figure 3. Sample settings for games (**A**) fish and (**B**) plane.

After each training, the subject could see the result obtained in a given game. After each game, the program analyzed the accuracy, number of points and precision of moves and also showed the progress that was achieved between individual trainings (Figure 4).

Exercises on the platform began with the simplest ones, and then the subjects proceeded to more complex and complicated exercises. The guidelines for the experimental group were as follows: the subject stood motionless in the center of the platform with feet spaced at hip width so that the feet were on opposite sides of the disk, parallel to each other. The platform was placed 2 m in front of the monitor stand where the games were broadcast. The subject was asked to perform a task according to instructions in the games. During the intervention, the subject balanced their body standing on the platform and carried out the exercises using their body and limbs (Figure 5). Exercises on the balance platform took place in an area where there was free space so that in the event of falling off the disk there was no risk of injury. During the tests, the person being examined was supported by the researcher who, in addition to physical assurance, also verbally controlled the well-being of the examinee. As part of their participation, each subject was asked to play all 9 games every time. The game time could be set through the program and the length of a single game was set between 2–3 min so that the whole single session lasted 30 min. Respondents were also able to rest in the sitting position for 30–60 s after each exercise.

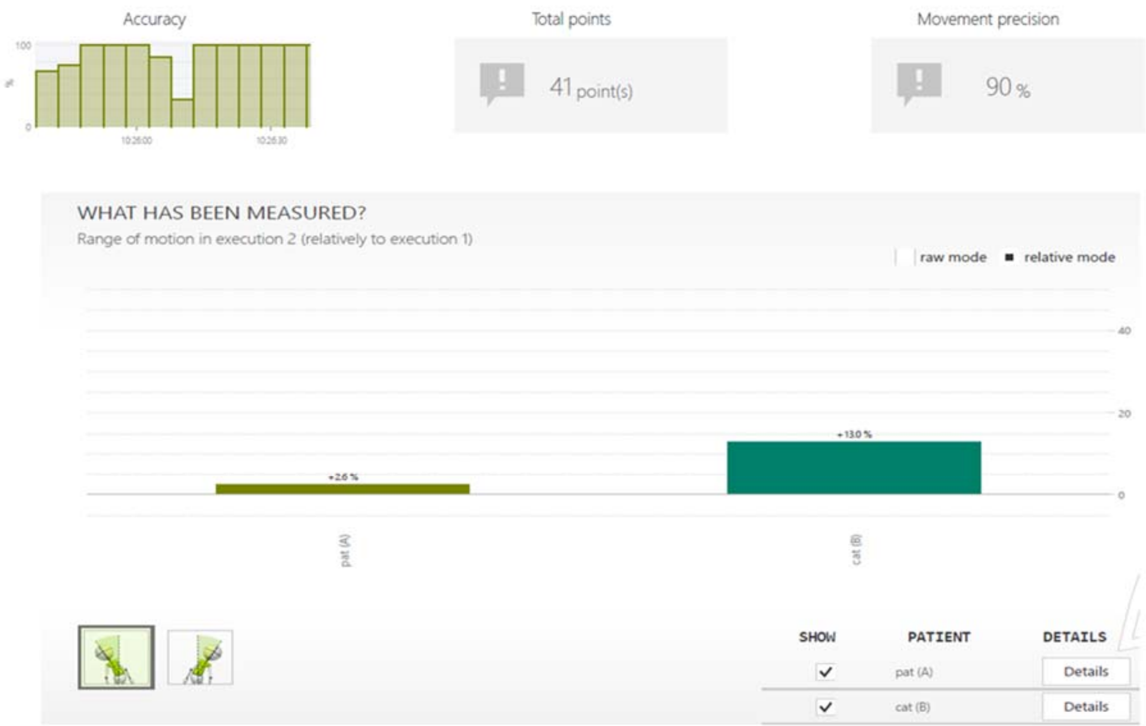

Figure 4. Sample analysis of results for the game fish.

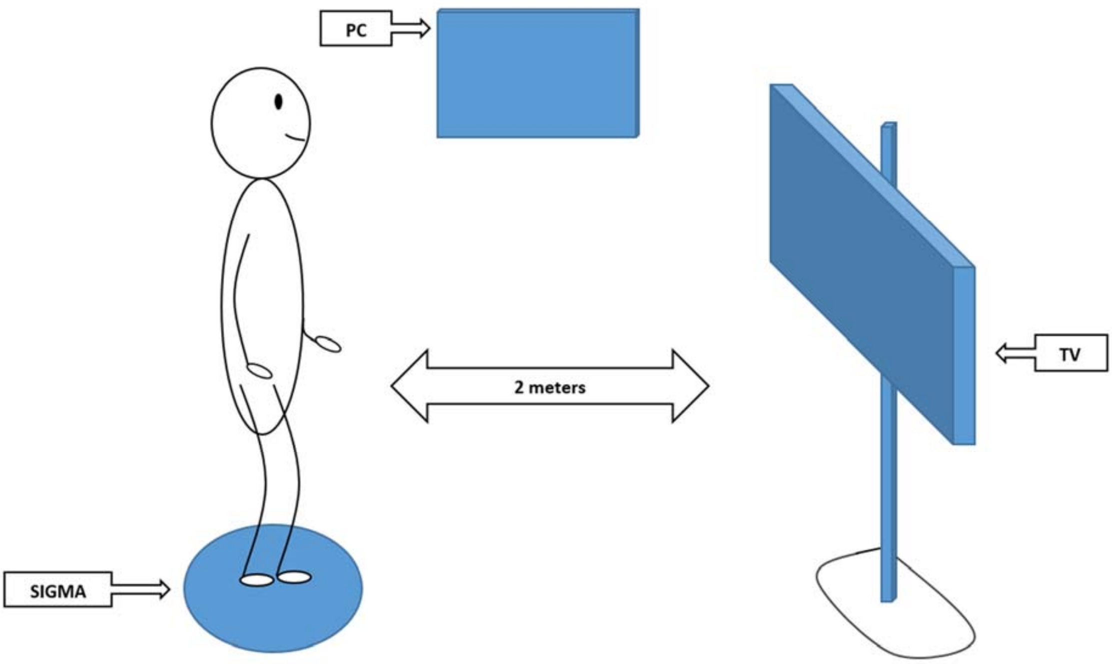

Figure 5. Correct position during a training session on SIGMA balance platform.

2.3. Measurement

2.3.1. Postural Stability (PS)

The level of postural stability was measured before and after the intervention using an AccuGaitTM power plate system (Model AMTI PJB-101, AMTI, Watertown, MA, USA) with Balance Trainer software. The sampling frequency was 100 Hz.

The research procedure included posturographic tests assessing the balance of the human body on a stabilometric platform at ground level and at a height of 1 m from the ground. A single trial lasted 30 s and was carried out twice (the average of 2 trials was taken into account). A 20 s break was used between measurements due to the large number of trials. In the event of fatigue or dizziness, participants could rest in the sitting position. None of the participants took advantage of this opportunity, which is why during all tests at low or high level they stayed on the platform at the same level. A stable, one-meter-high pedestal was used to place the stabilometry platform at a height. Participants climbed the pedestal via three-step stairs. Gym mattresses were positioned around the platform to ensure safety. The subject, both on the ground and at height, performed tests with open and closed eyes and with or without a cognitive task. During the examination, the subject stood still in the center of the platform with their bare feet spaced at hip width and arms along the torso. The posturographic platform was placed 3 m in front of a white wall, and subjects were asked to look directly at the wall. The following tests were carried out in random order to avoid the learning factor:

- EO LT QS—Eyes Open—Low Threat (ground level)—Quiet Standing.
- EO LT DT—Eyes Open—Low Threat—Dual Task (the subject additionally performed a mathematical task, which consisted of counting every 3 numbers down from 200, for the period of the test registration [43])
- EO HT QS—Eyes Open—High Threat (1m above the ground)—Quiet Standing.
- EO HT DT—Eyes Open—High Threat—Dual Task.

All tasks with the eyes closed (EC) were performed in the same way as with the eyes open (EC LT QS, EC LT DT, EC HT QS, EC HT DT, respectively).

The study took into account the length of the displacement path of the center of pressure (COP) signal and its elements in the anteroposterior (AP) and medial-lateral (ML) directions. It is widely used as a PC indicator [44]. Each test was performed twice and the results were averaged. Earlier studies confirmed that averaging 2 results was sufficient to obtain the Intraclass Correlation Coefficient (ICC) reliability coefficient above 0.9 for the average COP displacement speed (constant parameter equals path length) [45].

2.3.2. Statistical Analysis

The main calculations related to the assessment of the variability of dependent variables were calculated based on the ANOVA variance analysis method (test F). The analysis was applied taking into account the intergroup factor (with EG and CG levels) and the repeated factor of the time measurement (with the pre and post levels). The aim of the study was not focused on differences between conditions effects so that's why there were counted interaction effects (group x time) for each condition separately. Similar calculations were used for all analyzed conditions related to the experiment: EO LT QS, EO LT DT, EO HT QS, EO HT DT, EC LT QS, EC LT DT, EC HT QS and EC HT DT.

The difference assessments between groups in terms of basic characteristics (age, BMI, physical activity indicators) were made using the Student's t-test. The minimum level of statistical significance was $p \leq 0.05$. The study was conducted using the Statistica v. 13.0 software program (TIBCO Software Inc., Palo Alto, CA, USA).

3. Results

3.1. Effect of the Intervention on Postural Stability with Eyes Open in Conditions of the Low-High Threat during Quiet Standing or Performing a Dual Task (EO LT QS, EO HT QS, EO LT DT, EO HT DT)

In the case of quiet standing with the eyes open under low threat conditions, a significant interaction effect was found only for the sway path medial-lateral (SPML) ($F = 5.47$, $p < 0.05$, $\eta^2 = 0.22$). In an analogical analysis for high threat conditions, a significant interaction effect was observed for the sway path (SP), the sway path anteroposterior (SPAP) and SPML ($F = 14.28$, $p < 0.001$, $\eta^2 = 0.43$;

$F = 8.1$, $p < 0.01$, $\eta^2 = 0.29$ and $F = 24.78$, $p < 0.000$, $\eta^2 = 0.57$, respectively). For all studied variables, a significant main time effect was also found (η^2 between 0.25 and 0.52). In the EG, the post-training values were significantly lower than the baseline values (Table 2).

In the dual-task study conditions, a significant effect of "time x group" interaction was found for SP, SPAP and SPML when measured at ground level ($F = 12.50$, $p < 0.01$, $\eta^2 = 0.40$; $F = 12.38$, $p < 0.01$, $\eta^2 = 0.39$; $F = 7.29$, $p < 0.01$, $\eta^2 = 0.28$, respectively) and at the increased height of the measuring station ($F = 35.65$, $p < 0.0000$, $\eta^2 = 0.65$; $F = 31.72$, $p < 0.0000$, $\eta^2 = 0.62$; $F = 21.17$, $p < 0.0001$, $\eta^2 = 0.52$, respectively). A significant main effect (time) was recorded for SP, SPML and SPAP during measurement at ground level ($F = 19.0$, $p < 0.000$, $\eta^2 = 0.50$; $F = 15.29$, $p < 0.001$, $\eta^2 = 0.44$ and $F = 20.05$, $p < 0.000$, $\eta^2 = 0.51$, respectively) and for SP when measured at the elevated altitude ($F = 5.03$, $p < 0.05$, $\eta^2 = 0.21$). After VR training, lower values of tested variables in the EG were observed during the trial with dual–task (Table 3).

3.2. Effect of the Intervention on Postural Stability with Eyes Closed in Conditions of Low-High Threat during Quiet Standing or Performing a Dual Task (EC LT QS, EC HT QS, EC LT DT, EC HT DT)

A significant interaction effect was observed during quiet standing with the eyes closed for all studied parameters SP, SPAP and SPML at both low threat ($F = 14.17$, $p < 0.001$, $\eta^2 = 0.43$; $F = 12.42$, $p < 0.01$, $\eta^2 = 0.39$ and $F = 8.95$, $p < 0.01$, $\eta^2 = 0.32$, respectively) and high threat ($F = 17.24$, $p < 0.000$, $\eta^2 = 0.47$; $F = 15.72$ $p < 0.001$, $\eta^2 = 0.45$ and $F = 7.33$, $p < 0.01$, $\eta^2 = 0.27$, respectively) altitudes. Post-training values of average COP length were significantly lower in the EG than before training. A significant main effect (time) was found for all studied parameters except for SPML-high threat (>0.05) (Table 4).

In the case of dual-task with the eyes closed, a significant interaction effect was found for all parameters studied during measurement at ground level ($F = 7.36$, $p < 0.01$, $\eta^2 = 0.27$; $F = 6.15$, $p < 0.05$, $\eta^2 = 0.24$ and $F = 20.49$, $p < 0.001$, $\eta^2 = 0.52$, respectively). At the increased height of the measuring station (high threat) during a dual task, a significant effect of the "task x group" interaction was found for SPAP ($F = 6.56$, $p < 0.05$, $\eta^2 = 0.25$). Detailed results of the analysis of variance are presented in Table 5.

Table 2. Mean and standard deviation values of postural stability for quiet standing measures with eyes open on low and high threat in the experimental and the control groups before and after intervention and results of two-way ANOVA.

	Pre		Post							
Variable	**M (sd) EG**	**M (sd) CG**	**M (sd) EG**	**M (sd) CG**	**Interaction *F*(*p*)**	η^2	**Group *F*(*p*)**	η^2	**Time *F*(*p*)**	η^2
Low threat										
SP-[mm]	193.1(44.32)	189.4(21.87)	166.2(36.27)	179.7(25.98)	4.02(>0.05)	0.17	0.11(>0.05)	0.01	20.47(<0.001)	0.52
SPAP-[mm]	153.7(36.55)	148.1(21.70)	131.1(28.65)	138.4(23.29)	2.66(>0.05)	0.12	0.005(>0.05)	0.00	16.82(<0.001)	0.47
SPML-[mm]	87.1(21.58)	87.9(17.38)	76.2(17.16)	85.7(18.19)	5.47(<0.05)	0.22	0.38(>0.05)	0.02	12.35(<0.01)	0.39
High threat										
SP-[mm]	210.0(48.01)	218.1(40.82)	172.7(49.91)	220.5(38.51)	14.28(<0.001)	0.43	2.25(>0.05)	0.11	11.09(<0.01)	0.37
SPAP-[mm]	169.7(40.0)	176.3(32.35)	137.1(39.53)	175.6(27.59)	8.01(<0.01)	0.29	2.51(>0.05)	0.12	8.75(<0.01)	0.31
SPML-[mm]	90.5(24.34)	93.8(27.09)	76.1(21.73)	98.(30.63)	24.78(<0.000)	0.57	11.28(>0.05)	0.06	6.52(<0.01)	0.25

Note. HW—height workers; OW—office workers; SP—Sway Path; ML—medio-lateral; AP—antero-posterior; Low threat—measurement at ground level; High threat—measurement at increased height of the measuring platform.

Table 3. Mean and standard deviation values of postural stability for dual-task with eyes open on low and high threat in the experimental and the control groups before and after intervention and results of two-way ANOVA.

	Pre		Post							
Variable	**M (sd) EG**	**M (sd) CG**	**M (sd) EG**	**M (sd) CG**	**Interaction *F*(*p*)**	η^2	**Group *F*(*p*)**	η^2	**Time *F*(*p*)**	η^2
Low threat										
SP-[mm]	201.4(35.83)	211.9(47.06)	156.5(36.72)	207.3(51.90)	12.50(<.001)	0.40	2.83(>0.05)	0.13	19.0(<0.000)	0.50
SPAP-[mm]	163.0(31.89)	172.8(42.08)	122.5(29.22)	170.6(48.76)	12.38(<0.01)	0.39	3.18(>0.05)	0.14	15.29(<0.001)	0.44
SPML-[mm]	87.2(15.02)	89.5(24.73)	71.9(18.69)	85.7(21.43)	7.29(<0.01)	0.28	0.87(>0.05)	0.04	20.05(<0.000)	0.51
High threat										
SP-[mm]	210.6(33.61)	217.5(35.95)	177.5(38.32)	232.5(42.85)	35.65(<0.0000)	0.65	3.7(>0.05)	0.16	5.03(<0.05)	0.21
SPAP-[mm]	172.9(28.58)	177.8(29.21)	142.7(28.16)	191.8(33.85)	31.72(<0.0000)	0.62	4.63(<0.05)	0.19	4.29(>0.05)	0.18
SPML-[mm]	87.8(15.47)	91.5(20.39)	77.7(17.90)	95.6(23.42)	21.17(<0.0001)	0.52	1.63(>0.05)	0.07	3.76(>0.05)	0.16

Note. HW—height workers; OW—office workers; SP—Sway Path; ML—medio-lateral; AP—antero-posterior; Low threat—measurement at ground level; High threat—measurement at increased height of the measuring platform.

Table 4. Mean and standard deviation values of postural stability for quiet standing with eyes closed on low and high threat in the experimental and the control groups before and after intervention and results of two-way ANOVA.

	Pre		**Post**							
Variable	**M (sd) EG**	**M (sd) CG**	**M (sd) EG**	**M (sd) CG**	**Interaction *F*(*p*)**	η^2	**Group *F*(*p*)**	η^2	**Time *F*(*p*)**	η^2
Low threat										
SP-[mm]	293.2(81.55)	272.2(51.41)	224.4(55.28)	270.5(48.19)	14.17(<0.001)	0.43	0.26(>0.05)	0.01	15.71(<0.001)	0.45
SPAP-[mm]	254.8(72.31)	234.0 (54.31)	195.2(48.29)	235.0(63.04)	12.42(<0.01)	0.39	0.14(>0.05)	0.01	11.62(<0.01)	0.38
SPML-[mm]	101.8(30.98)	105.2(31.39)	84.2(22.98)	107.6(34.11)	8.95(<0.01)	0.32	1.1(>0.05)	0.55	5.16(<0.05)	0.21
High threat										
SP-[mm]	279.4(70.73)	283.3(56.27)	212.1(68.06)	296.4(65.15)	17.24(<0.000)	0.47	2.72(>0.05)	0.12	7.86(<0.01)	0.29
SPAP-[mm]	238.2(64.39)	241.2(51.98)	172.4(61.38)	252.5(61.96)	15.72(<0.001)	0.45	2.92(>0.05)	0.13	7.9(<0.01)	0.29
SPML-[mm]	103.4(28.79)	104.6(23.30)	90.3(27.59)	109.6(25.18)	7.33(<0.01)	0.27	0.88(>0.05)	0.04	1.44(>0.05)	0.07

Note. HW—height workers; OW—office workers; SP—Sway Path; ML—medio-lateral; AP—antero-posterior; Low threat—measurement at ground level; High threat—measurement at increased height of the measuring platform.

Table 5. Mean and standard deviation values of postural stability for dual-task with eyes closed on low and high threat in the experimental and the control groups before and after intervention and results of two-way ANOVA.

	Pre		**Post**							
Variable	**M (sd) EG**	**M (sd) CG**	**M (sd) EG**	**M (sd) CG**	**Interaction *F*(*p*)**	η^2	**Group *F*(*p*)**	η^2	**Time *F*(*p*)**	η^2
Low threat										
SP-[mm]	263.8(49.43)	259.9(53.15)	217.2(42.11)	257.3(73.45)	7.36(<0.01)	0.27	0.6(>0.05)	0.03	9.23(<0.01)	0.33
SPAP-[mm]	225.1(49.19)	224.2(50.23)	186.2(39.92)	224.7(68.33)	6.15(<0.05)	0.24	0.74(>0.05)	0.04	5.82(<0.05)	0.23
SPML-[mm]	96.7(13.49)	97.73(30.62)	79.7(17.11)	100.6(40.43)	20.49(<0.001)	0.52	0.83(>0.05)	0.04	10.26(<0.01)	0.35
High threat										
SP-[mm]	256.8(61.18)	263.1(65.90)	224.5(69.95)	270.4(78.96)	4.15(>0.05)	0.17	0.82(>0.05)	0.04	1.65(>0.05)	0.08
SPAP-[mm]	219.3(57.86)	222.7(60.54)	179.6(63.29)	230.4(73.45)	6.6(<0.05)	0.25	1.04(>0.05)	0.05	3.0(>0.05)	0.14
SPML-[mm]	95.3(19.49)	99.4(25.17)	85.8(20.20)	100.6(26.46)	3.3(>0.05)	0.14	0.94(>0.05)	0.05	1.99(>0.05)	0.09

Note. HW—height workers; OW—office workers; SP—Sway Path; ML—medio-lateral; AP—antero-posterior; Low threat—measurement at ground level; High threat—measurement at increased height of the measuring platform.

4. Discussion

4.1. Effect of Intervention on Postural Stability with Eyes Open

Balance training is necessary to maintain and improve the level of PS, especially in high-altitude workers [8,32]. In this study, we used proprioceptive training on a balance platform using VR technology to improve the PS level of high–altitude workers.

The obtained results confirmed that training significantly improved PS level both under conditions on the ground and with increased height of the measuring platform [33,46]. In quiet standing tests with visual inspection, both a decrease of the overall length of the COP movement path and its components in the forward-backward and right-left directions at both heights were obtained. The EG group achieved lower results (which may indicate a higher level of postural stability) in all analyzed parameters after training. Higher levels of PS in the EG group probably resulted from increased involvement of the visual, vestibular and somatosensory systems, as well as individual muscle groups used in tasks performed on the balance platform during VR training. Based on the results, it can be assumed that even in the case of visual-vestibular-sensory conflict, the EG group would probably maintain the correct PS level, which may reduce the percentage of accidents while working at height. The results obtained at height also suggested that training using VR eliminated the negative impact of height as well as visual stimuli on the level of postural stability.

Carozza et al. [47] used virtual reality goggles to train construction workers in risk recognition skills. The authors of the study stated that performing realistic training reduced the risk associated with performing tasks in real conditions. Positive results were reported especially in the context of work at height. There is no other research on the impact of proprioceptive training on a balance platform using VR on the PS level of high-altitude employees. However, indirect evidence can be sought in studies using interactive training in the elderly or the sick.

Schwenk et al. [29] conducted pilot studies of interactive balance training in the elderly based on visual motion feedback sensors. The authors noted that older people at risk of falling may benefit from participating in a balance training program. In addition, this training may in the future support traditional balance training or completely replace it. In turn, Srivastava at al. [30] noted that even in the chronic phase after stroke, significant improvement in balance and functional outcome can be achieved after training on a balance platform with Visual Feedback (FPVF).

In cognitive standing tests at visual control, the EG group achieved both a reduction in the overall length of the COP path and its components in the forward-backward and right-left directions at both heights. We can assume that the higher level of PS in the EG group probably resulted from an increase in cognitive involvement when performing realistic tasks in VR training [33,48]. Experience in action games results in the improvement of a wide range of perceptual skills. Players also show an improvement in other cognitive skills, in particular the ability to effectively switch between tasks [49,50]. So far, no studies on the impact of proprioceptive training on a balance platform using VR on the PS level in a dual task with the eyes open have been conducted in high-altitude workers. However, research among players has shown the positive impact of games on cognitive performance.

Colzato et al. [51] studied whether, and to what extent, experience in video games affected the performance of a cognitive task. Experienced players were faster and more accurate in monitoring and updating working memory, and also reacted faster to the signals sent compared to inexperienced players. The authors suggest that the use of games was associated with increased flexibility in updating information while performing a cognitive task. In turn, Strobach, Frensch and Schubert [33] noticed that when performing a task that requires split attention, action-game players had an excellent ability to perform two tasks at the same time and to switch efficiently between tasks.

4.2. Effect of the Intervention on Postural Stability with Eyes Open

When visual control is restricted, mainly proprioceptive information is used. In this study, during the trial, we turned off the visual effect to check whether proprioceptive training on a balance platform using VR would have a positive effect on the level of PS of high-altitude workers.

The EG group in quiet standing tests without visual control obtained both a reduction in the length of the COP path as well as both its components towards AP and ML. Significant differences were also found in all parameters of the COP path length in the test at the elevated height of the measuring station. This indicated that training had a positive effect on the level of PS in the EG regardless of the altitude.

Based on the result, we can assume that the EG group relied more on proprioception, and less on visual input to maintain balance, than the CG, which was associated with increased ability to maintain balance. Research has shown that this type of ability can be successfully developed [52]. It is likely that the EG group acquired such skills during proprioceptive training on a balance platform using VR. Hutt and Redding [52] studied the impact of specific training on balance control among ballet dancers. They stated that a program based on reducing visual stimuli increased the level of balance. Other studies have found that training with the Nintendo Wii Fit console improved balance and gait in those with Parkinson's disease [53].

Positive training effects were also obtained in tests at ground level with the eyes closed during a dual task. The EG group achieved lower results in all analyzed parameters. Presumably, the better PS in the EG group resulted from the combination of proprioceptive training with the daily training of individual muscle groups used in the professional tasks of high-altitude workers, as well as the conditions and nature of the work [2,11,51].

In both groups, no significant changes were observed in the PS level with an increase in perceived difficulty in maintaining balance due to height and task performance. Despite the fact that the training was performed only with the eyes open, the measurement results with the eyes closed were close to statistically significant. The result may have been affected by the difficulty of the task being performed, as well as insufficient ability to rely on proprioception in the absence of visual control. Perhaps continuing training would also result in significant differences in the test with the eyes closed at height.

Van Diest et al. [54] studied the impact of 6 weeks of training using games on the level of balance, where participants trained at home. The training led to a reduction in postural swaying after 6 weeks of participation in healthy older people in all analyzed tests.

Research on the impact of video games on cognitive performance suggests that some types of video games may increase attention, memory capacity, working memory, and performance of dual tasks. This demonstrates the potential of usefulness of these commercial games for practical applications in the real world, such as rehabilitation or training of skills related to work at height [55]. The above results have been confirmed by the results of the research obtained in this article.

Finally, it should be mentioned that this work was limited. It only included VR technologies related to games on a balance platform using proprioceptive training. In the future, VR glasses could be implemented to deepen the immersion and learning processes through experiences in VR. For example, Angelov [56] found out that the usage of the balance training program while using VR glasses (with increased difficulty level conditions) led to balance stability improvement. Similar conclusions were presented by Duque et al. [57] who studied the effect of balance training using a new VR system (the Balance Rehabilitation Unit) in older fallers. It has been showed that training is an effective and well-accepted intervention to improve balance, increase confidence and prevent falls in the elderly.

Secondly, the CG did not take any training exercise, so it's difficult to separate between two factors acting here, namely, proprioceptive training and VR. In future studies, the control group should participate in training on the platform without VR feedback to separate the influence of these two factors.

The results of the study are expected to be a useful source of information for future research or practice in implementing VR in the field of education and training among high-altitude workers to prevent accidents at height and related injuries, and even death.

5. Conclusions

We provided evidence that proprioceptive training on a balance platform using VR improved the PS level in all analyzed parameters of low-high threat, eyes open-eyes closed and single task–dual task. Firstly, the proprioceptive training on a balance platform using VR turned out to be an appropriate element for direct training of the visual-vestibular-sensory system in order for high-altitude employees to learn an adequate response to threats without exposing them to danger. Secondly, proprioceptive training on a balance platform using VR likely resulted in greater cognitive involvement and could also increase the effectiveness of switching between tasks. Thirdly, we can assume that the EG group, after proprioceptive training with the use of VR, relied more on proprioception, and less on visual control, to maintain balance. These facts can be used to teach high-altitude workers how to automatically respond to a threat and control safety in their work environment.

Overall, training on the platform can have a number of positive effects that seem to be difficult to achieve during standard balance exercises. It is possible that the improvement of the PS level of high-altitude workers under the influence of proprioceptive training with the use of VR will positively affect quality and safety at work and prevent falls and injuries in the future.

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