Low back pain in ballet, modern, and hip-hop dancers

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Date…………23 June 2023…………………………

Abstract

Low back pain (LBP) is a global medical issue that continues to rise in the general population. However, the consequences of low back pain in dance populations have been difficult to quantify, in part due to varying injury definitions. Low back pain is a multifaceted problem that is anecdotally common, but more research is needed to understand how low back pain impacts dancers' lives and movements. The key aim of this thesis was to investigate low back pain in ballet, modern, and hip-hop dancers, and provide practical recommendations based on the findings. The aims of this thesis were to: (a) investigate the dancers' perspectives on low back pain and what aspects of their lives and dancing it affects, including a determination of what movements dancers associate with exacerbating their low back pain, and (b) to further examine these movements, through archival and biomechanical research, to provide recommendations to the dance community.

Study 1 assessed the dancers' perspective on the impact and management of low back pain through an online questionnaire disseminated to primarily ballet, modern, and hip-hop dance populations. The results showed that low back pain negatively impacted dancers' dance movements and non-dance activities, with spinal extension movements being most frequently reported as a movement that increased the dancers' low back pain.

Therefore, Study 2 utilized archival dance videos from YouTube.com to identify how often dancers were exposed to the movements that they reported in Study 1 as exacerbating their low back pain. Results showed that the dance movements that exacerbate low back pain were present in all the dance environments studied: ballet class and performance, modern dance class and performance, and hip-hop breaking, cyphers, and battles. Ballet performance environments had the highest number of total spinal extension movements (77±69.8), and hip-hop cypher environments had the highest frequency of spinal extension movements per minute (7±9.6). Recommendations for training focuses, based on the complete movement profile for each dance genre, are also presented.

Study 3 used a case study to examine the biomechanics of three spinal extension movements: the ballet arabesque, the modern dance attitude with body roll, and the hip-hop dolphin dive. The influence of speed on the forces of the spine in dance had not been studied previously. Results suggest that thoracic and lumbar spine joint angles, angular velocity, and angular acceleration increase all three dance genres when performing movements from slow to fast speeds.

Collectively, the results in this thesis verified that low back pain is an impactful condition with significant negative consequences for those dancers who are afflicted. The results also revealed dancers are frequently exposed to movements that they report can increase their low back pain. The results show increased angular displacements, angular velocity, angular acceleration in spinal extension movements performed at progressively increasing speeds. However, further research is needed to confirm if the forces at the low back increase as speed increases, and to clarify the role of asymmetry in movements that increase dancer LBP.

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I would like to dedicate this thesis to my grandfather, who unfortunately passed away before its completion. I always think of you when I see a German translation; you are loved and missed.

1 Introduction

1.1 Definitions of key areas

The prevalence of low back pain (LBP) is an increasing problem worldwide,[1-3] with a prevalence in the general population of 9.4% (2010) and a one-month prevalence of 23.2+/-2.9%.[1] Dancers show an increased prevalence of LBP as compared to non-dancers.[4] Much of existing literature on athletes with low back pain that includes dancers does not subdivide the study population by dance genre, often using the umbrella term 'dancers' or combination labels like 'modern and ballet dancers'. These terms do not give context to the dance genres that have been studied and therefore prevent comparisons. As discussed in Chapter 2, current literature prioritizes female professional ballet dancers as the subjects of study in low back pain research, with fewer studies on modern and hip-hop dancers. Please note that throughout this thesis, the terms 'male' and 'female' are used to refer to biological sex.

1.1.1 Low back pain prevalence

Low back pain is an ailment that does affect dancers, but the published literature on this topic is mixed on how often and how many dancers experience LBP. Lower extremity injuries are the most common injuries dancers experience, followed by neck/trunk/spine injuries;[5-10] this broad category of injury contains the subcategory of LBP. It is difficult to assess mean incidence rates across multiple studies, but LBP in dancers is an ongoing injury that has been documented to have a lasting negative effect on dancers, even after they have stopped dancing professionally.[11] LBP is anecdotally cited as a frequent problem amongst dancers, and literature reviews have cited the prevalence of LBP to be anywhere from 3%-23%[7] to 12%-75%[8] with a calculated prevalence of 14%,[10] with a range of 3% to 75%.[7,8,10,12] Dancers of all ages, sex, proficiency levels, and genres may experience LBP and injury. Most researchers have examined LBP in female professional and pre-professional ballet or modern dancers, finding a lifetime LBP prevalence of 50% and a median point prevalence of 27% across studies.[12] Fewer researchers have examined LBP, or injuries at all, in hip-hop dancers,[13,14] but those that have examined this issue suggest a higher LBP prevalence than other dance forms like ballet, tap, and modern dance, with an injury prevalence similar to gymnastics.[15]

It is possible that differing injury definitions have caused this range of LBP prevalence values. Studies on LBP in the general population do not always agree on a standard definition of what LBP is, and this is also true for LBP research on dancers. A modified Delphi study published in 2008 suggested that questionnaires adhere to the following guidelines when studying LBP: 1) ask for a recall of no more than four weeks, 2) clarify with subjects whether this low back pain limited or changed daily activities for more than one day, and 3) include an anatomical diagram that highlights the low back.[16] LBP studies do not always heed these suggestions, reducing the utility of the data extracted from the research to make clinical or practical decisions. Because LBP tends to recur,[17-20] the definition of what constitutes one episode of LBP is also an important consideration; one which is not always addressed in general injury studies.

1.1.2 Low back pain impact

LBP presents an increasing global problem in the general population, being ranked fourth amongst global health issues in 2017.[21] The monetary cost of LBP is substantial.[22] In a systematic review and meta-synthesis examining LBP in the general population,[23] Froud et al. described that LBP had “pervasive and life-changing effects” that threatened the participants’ “quality of life”.[23] Furthermore, three of the most important themes identified in people with LBP were loss of function, negative impact on employment, and fear of stigma. LBP has been shown to be an affliction that can have a long-term negative impact on general population.[24] Non-dancers with LBP experience difficulties with everyday tasks, such as sitting, standing, and sleeping.[23,25] LBP recovery is considered a complex issue with multiple biopsychosocial factors.[26,27]

Publications on the effects of LBP on the lives and careers of dancers are sparse. Ojofeitimi and Bronner have quantified the monetary costs of injuries in a modern dance company,[28] however, LBP was not one of the specific injuries examined in their study. Researchers examining pre-professional dancers found that regardless of LBP history, most dancers had negative back pain beliefs, and associated extreme spinal extension (backwards port de bras) with being dangerous to their back even if they themselves did not experience LBP.[29] The negative psychological impact of non-specific injuries on dancers has been studied previously, with researchers stating that injuries which prevent a dancer from participating fully in dance experiences can threaten their identity as a dancer, causing negative psychological consequences.[30,31] However, there seems to be no literature on the impact or cost of LBP specifically on dancers.

As discussed further in Chapter 2, those studies that report on LBP in dancers do not typically report pain intensity. LBP intensity studies on the general population have found that 79% of participants had mean pain intensity of less than 49 out of 100 at baseline[32]. In athletes, pain intensity was reported to be 4.2±0.6 – 4.5±0.8 on an 11-point scale at baseline in older, male recreational ice hockey players.[33] While little data exists on LBP intensity in dancers, an undergraduate thesis studying hip flexor extensibility and LBP in advanced jazz and ballet dancers reported average LBP intensities of 2.70±1.89 on an 11-point scale across a dance class, with pain intensity values taken before, during, and after dancing.[34] Other studies on LBP across disciplines either do not measure or do not publish the pain intensity; participants are separated into LBP or no LBP groups for purposes of comparison, without specifying pain intensity values.

1.2 Dilemma of disclosure

It is likely that the extent of injury and pain reported by dancers in non-anonymous settings is underestimated due to under-reporting from the dancers themselves[35] or limited capture of injury data.[36] In support, prior authors have noted that dancers may believe a stigma exists for those who become injured that endangers their employment.[37] This is similar to the "dilemma of disclosure"[25] reported in general population LBP experiences, where those with LBP are hesitant to disclose their pain to their employer for fear of negative perception and subsequent employment-related consequences. Additionally, the threat that dancers perceive injury presents to their dancer self-identity can encourage this practice of under-reporting injuries.[31]

1.3 Asymmetry and lateral bias in dance

A consideration in the identification of factors that could result in a spinal extension movement increasing LBP may be the way the movement is performed, whether symmetrically or asymmetrically. Some movements in dance are inherently symmetrical or asymmetrical. However, even the same asymmetrical movement can be performed differently on right sides versus left sides. For example, in a movement where the gesture arm of an asymmetrical movement reaches forward, it is possible that the dancer may "reach further" when the right arm is the gesture arm than when the left arm is the gesture arm, or vice versa. The (asymmetrical) movement is performed asymmetrically. Bodily asymmetries, or a difference between left and right limbs, may influence why a dancer may perform a movement asymmetrically.

In sports literature, depending on the sport, an asymmetry percentage of 10% difference or less between limbs within the Leg Symmetry Index has been suggested to be acceptable.[38,39] However, many methods of calculating asymmetries exist in sport and exercise.[40] The selection of the best asymmetry cut-off values and asymmetry formula requires extensive testing on the movement itself.[40,41] However, there exists a paucity of asymmetry research in dance and to our knowledge, concrete asymmetry values or ideal asymmetry formulas have not been established for the three dance movements studied in Study 3 (Chapter 6). Therefore, for the purposes of

Study 3, the asymmetry formula used in calculating asymmetry percentage was a modified Bilateral Asymmetry Index 1 (BAI-1) formula: *(right value – left value)/(total of both) x 100*. The modification was of our own making, as the BAI-1 traditionally uses dominant and non-dominant limb determinations. However, because Study 3 measured the asymmetry of movement in a population that has shown right lateral biases,[42-45] right and left were used instead of dominant and non-dominant. This operational definition allows for positive values to represent greater right-sided values, and negative values to represented greater left-sided values, helping to quantify possible instances of lateral bias. Additionally, percentages can become inflated when the magnitudes are small; asymmetry magnitude *(right – left)* was also reported to provide a multi-faceted view of the asymmetries. While asymmetry magnitude calculations have been expressed in absolute values,[46] I chose to continue the use of a negative sign as an indicator of laterality (negative = left side greater; positive = right side greater).

In dance, researchers have described asymmetry[43] and right sided preference[44] in ballet and modern dancers. In ballet dance classes, movements are learned and practiced on the right side first, leading to an increased number of repetitions on the right side.[45] Adult dancers with axial asymmetries, such as scoliosis, have reported a higher incidence of back pain than those without axial asymmetries.[47] Dancers from multiple dance genres at the university dance major level have be recorded to have a posterior torso tilt, with ballet dancers also showing a torso tilt to the right.[48] In a study examining patellofemoral pain in young female dancers, the investigators concluded that dynamic postural balance asymmetry was a predictor of patellofemoral pain.[46] While it is assumed that significant asymmetries in the body exist in right versus left movements patterns, a lack of injury data describing injuries on the right versus left side in dancers prevents researchers from verifying this assumption.[43] However, asymmetries can lead to movement compensation strategies.[49] For example, contemporary dancers show alternate landing strategies when landing a leap onto their dominant leg as compared to their non-dominant leg.[49] Asymmetries[50] and compensation strategies could alter the way a movement is performed,[51] and possibly increase the risk of pain or injury.[46,47,50] Yet again, a lack of left versus right injury data prevents direct association between asymmetries, compensation strategies, and injury.[43]

Despite the imbalance in repetitions between sides when performing common dance movements, dancers have been shown to perform unilateral movements like landing jumps symmetrically on both sides – even if they perceive having a preferential leg/side.[52] Researchers suggest that dancers do not have more body asymmetries than those found in the general population.[53] However, multiple authors have reported that dancers do have body asymmetries in dance-specific measures, particularly with passive and active ROM of turnout (how far the toes can rotate away from the midline of the body with the heels staying together on the midline)[43,54] and that dancers can have improved performance when using their dominant leg for support in pirouettes.[55] Asymmetries may exist in other dance tasks, as different profiles of injury risks can occur when completing different tasks,[56] but most studies utilize only one side of a movement when capturing data to assess dance movements.[43]

Asymmetry studies are less common in hip-hop dance populations. However, two studies were identified that did examine body asymmetries in breakers and hip-hop dancers by Prus and Zaletel[57] and ballet and hip-hop dancers by Pavlović et al.[50] In both studies, the researchers concluded that body asymmetries did exist in these subgenres and posited that body asymmetries are common in dancers. Still, we did not find any published literature describing compensation strategies for any hip-hop dance genre. One method of examining possible movement compensation strategies or asymmetries is with biomechanical research techniques.

1.4 Dance biomechanics research

Dance researchers have used 2D motion capture, 3D motion capture, and other biomechanical research methods previously; a thorough, peer-reviewed article on the history of dance biomechanics literature, published by Krasnow et al., provides a review of studies on this topic published from 1970 to 2009.[58] Research in ballet and modern dance is especially prevalent, as is research specifically on the arabesque movement. The arabesque (a common spinal extension movement in dance) was cited by both ballet and modern dancers with LBP in Study 1 (Chapter 4) as increasing the dancers' LBP. It was also a common movement seen in Study 2 as part of the spinal extension movements category (i.e., it occurred frequently in class and performance environments of both ballet and modern dance).

The arabesque movement, which originates from a ballet dance tradition, has been studied by previous researchers.[59-64] Researchers have also studied other similar movements, such as the rond de jambe en l'air[65] (moving a straight gesture leg through anterior, lateral, and posterior positions), the grand battement derrière[66] (a "dynamic arabesque"; a straight leg kick posteriorly), and the developpé derrière[67,68] (bending the knee to enter and exit a stationary arabesque posteriorly), all of which contain the arabesque shape within the movement. Due to cross-transfer between movements used in different dance styles, some research on "ballet" movements have been performed on modern dance populations, such as the grand battement derrière.[66] Still, to date, only one study has examined the arabesque movement using a multi-segment model of the spine.[62] Previous researchers have separated dancers into participant groups with pain and non-pain or beginners and experts, had them perform arabesques in a laboratory setting, and tried to identify differences in the movement execution patterns. Pain studies found "only subtle differences" in between pain and non-pain groups.[51] Expertise studies identified significant differences in measures like base of support[60], hip and lumbar spine hyperextension,[61] forward torso flexion,[61] and muscle activation[61].

However, to date, no study has identified any significant differences between the way LBP and non-LBP groups perform the arabesque movement.[62] Some ecological validity has also been lacking in the publication of arabesque research; multiple studies on the arabesque movement allowed dancers to perform at a self-selected pace[60,62], which is rare in a class or performance setting, or did not report speed parameters at all.[59,61]

Modern dance has a notable body of published research as well, details of which can be found in the Krasnow et al. review on biomechanical research in dance.[58] Literature on the biomechanics of ballet movements being performed by modern or contemporary dancers is plentiful.[49,69-78] However, biomechanical study on movements specific to modern dance is sparse: a study by Gorwa et al. on the stag jump in 2014,[79] a dissertation by Murgia on the stag leap in 1995[80], and a thesis by Jones on the calypso leap in 2015[81] were the only modern dance-specific biomechanical movement studies that were able to be located.

Hip-hop dance has been included more frequently in biomechanics research over the last ten years. Several studies by Sato and researchers used motion capture to examine various hip-hop movements within the lens of competitive judging parameters; a two-segment model of the spine was used.[82-86] Kinematic data on movements like the windmill,[87] toprock moves,[88] downrock moves,[88] house moves,[88] side-steps,[85] and finger waves,[86,89] have all been reported. However, to our knowledge, no researchers have published data on the dolphin dive movement, a hip-hop dance spinal extension movement.

Additionally, no studies to date exist examining the biomechanics of the arabesque, the attitude, or the dolphin dive dance movements at different speeds, even though variation of speed throughout a performance is typical, as shown in Study 2 (Chapter 5). While often rigorous, prior published studies on LBP and motion capture are lacking in an important facet of ecological validity. These studies have all been performed in laboratory settings that did not attempt to mirror a critical element of performance conditions, such as performing to music or at a speed that is seen in performance environments.

1.5 Study validity

The research presented here exists on a continuum of internal and external validity. Throughout this thesis project, there was a focus on increasing ecological validity to ensure results were practically applicable. However, this can decrease internal validity. For example, in Study 2 (Chapter 5), the use of YouTube videos increased ecological validity, because the videos are directly from dancers and dance teachers, presenting their movement vocabulary through recorded video. Yet the internal validity may be reduced, as it is difficult to control for subjective variables like dancer skill level. Some dancers may also have altered their movement to fit a video presentation format or because of the space limitations caused by the COVID-19 pandemic, and these are limitations to this study. A short comment on ecological and internal validity is mentioned at the end of each study's Methods section.

1.6 Injury risk framework

In 2008, van Tiggelen and researchers[90] published a modification of Finch's[91] TRIPP injury risk framework. The van Tiggelen framework posits a seven-step process to prevent overuse injuries. Importantly, the sixth step in this framework includes an assessment of compliance and risk-taking behaviour. This step in the process is particularly essential in dancers, where a culture of dancing through pain is common.[31] Dancers can perceive that pains and injuries threaten their self-identity, increasing fear, and reducing compliance with any modifications or cessation of dancing, especially in chronic or recurring conditions.[31] When applying the van Tiggelen model to LBP in dancers, the first step requires an establishment of the injury's extent. However, as discussed in detail in section 2.1, it has not been possible to confidently estimate the number of dancers affected by LBP to this point in time. Therefore, although interventions have been attempted previously, true prevention methods for this condition have not reached consensus to date.

Additionally, LBP is considered both a symptom of other illnesses, such as spondylolysis and stress fractures in the lumbar area, and also a standalone, 'non-specific' condition; the aetiology of LBP in aggregate is complex. Traditionally, a biopsychosocial model of assessment and treatment has been used clinically. Yet a recent publication[92] suggests a biopsychosocial model with extensions. The extensions include stigma, culture, and interpersonal aspects as factors for treating LBP. The extended biopsychosocial model may better serve clinicians who treat LBP in dancers, as 'dance culture' and injury stigma may have outsized influence in this population.[31]

1.7 Delimitations

The research contained within this thesis focused on ballet, modern, and hip-hop male and female dancers who were at least 18 years old. As discussed in the previous section, LBP is multifactorial, and while it can be a symptom of other diseases, this research was primarily concerned with non-specific LBP. It should also be noted that while dance exists globally, the research presented here focuses primarily on dancers in the United States and cannot necessarily be overgeneralized to other countries. Research was conducted between 2017 and 2023, and both quantitative and qualitative data were utilized:

- The literature review spanned November 2017 - March 2018
- Research for Study 1 completed a pilot survey in April 2019, and the revised survey was sent out in two rounds: May 2019 - June 2019 and August 2019 - September 2019
- Study 2 archival videos were screened between December 2020 and February 2021, which the users had uploaded to YouTube.com between 11 January 2009 and 2 October 2020
- Study 3 motion capture case study data were recorded in January and February 2023

1.8 Summary

In summation, LBP is likely prevalent in dancers, but to what extent is unclear. LBP is not limited to a certain age, proficiency, or type of dancer. The pain intensity of the LBP in dancers seems to be low to moderate. The specific impact of LBP on dancers’ lives has not been quantified; however, in non-dance populations, the negative impacts of LBP on daily life are significant. Asymmetry may be common in dancers, but more research is needed, particularly on modern and hip-hop dancers. Biomechanical research on ballet, modern dance, and hip-hop movements does exist, but none in the context of speed and LBP. Because the prevalence of LBP was inconclusive, a literature review was undertaken with the goal of summarizing prevalence of LBP and low back injuries in ballet, modern, and hip-hop dancers.

2 Review of literature

Parts of this chapter have been previously published as two full study references (Henn et al., 2020 & Henn et al., 2022)[93,94] and one conference proceeding (IADMS Denver 2021).[95]

Henn completed the literature review search. Henn completed the grading of literature quality, which was simultaneously completed by Wyon, with discrepancies mediated by Smith. Henn wrote most of the publication article, and feedback on the drafts was given by Wyon, Smith, and Ambegaonkar.

2.1 Introduction

When searching for literature relating to dancers and LBP it is necessary to examine data from LBP-specific studies, but also general dance injury studies, where an account of injuries and pains accrued by dancers within a set period are reported. Studies with this design often combine LBP complaints with other bodily areas, such as a 'trunk injuries' categorization. In these studies, LBP or low back injury (LBI) are not the primary focus of the research, but LBP data were still reported. "Low back pain" may also be termed "lumbar pain", "mechanical low back pain", "lumbar lesions", or otherwise combined with general spinal complaints. Differing injury definitions and reporting metrics within LBP studies have led to widely varied prevalence values. The cost and emotional impact of LBP is substantial, with studies on the general population reporting consequential negative effects on all aspects of their lives. The influence of LBP on dancers specifically is understudied, although the effects of general injury on the wellbeing of dancers has been studied since the 1990s.

The published literature on LBP in dancers is too varied to establish prevalence despite the significant impact LBP has on those afflicted. The variety of injury definitions and reporting methods require further investigation. Therefore, a systematic review was performed to determine prevalence of low back pain and injury in ballet, modern, and hip-hop dancers. A secondary aim was to identify whether there are trends in the data for dance genre, level of mastery, sex, and age. The literature review was completed using the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) method. The PRISMA method requires the reviewer to describe their selection process for articles within systematic reviews and meta-analyses and this method provides a checklist to guide researchers to a high standard of reporting. The systematic review also included assessments of the literature's quality using the Newcastle-Ottawa Quality Assessment Scale[96] and the Academy of Nutrition and Dietetics

(Academy) (ADA) Scoring System to grade the quality of scientific evidence.[97] These additional assessments were used to evaluate the strength and potential risk of bias of included studies.

2.2 Methods

2.2.1 Literature Search

This review was conducted between November 2017 and March 2018 using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method. A search was conducted of titles and abstracts in the PubMed (1966 to March 2018), MEDLINE (1946 to March 2018), SPORTDiscus (1983 to March 2018), Web of Science (1900 to March 2018), and the Journal of Dance Medicine & Science online archives (1997 to March 2018) databases using six permutations of the MeSH keyword “back pain” or “injury” and text words, as shown in Table 2.1.

Table 2.1: Search methodology keywords and fields used to locate articles

In title:	All fields, MeSH terms:
dancers	"back pain"
dancers	back pain
dancers	lumbar pain
dance	back pain
	dancers lumbar injury
	dancers “back injury”

Please note that both ‘injury’ and the plural term ‘injuries’ was included automatically by the search engines, or manually searched when not automatically included by the databases’ search engines.

A hand search of the reference lists of identified studies was conducted. A single investigator conducted the search actions and initial screening processes. Three articles that did not have an accompanying English translation were assessed with the help of translation applications: two in Portuguese[98,99] and one in German.[100]

2.2.2 Inclusion and exclusion criteria

Inclusion criteria were:

- The article had to address low back pain or injury in a ballet, modern, or hip-hop dance population.

- The “Ballet” genre included sub-genres classical, contemporary, and neo-classical ballet dance.
- “Modern” dance included sub-genres related to both classical modern (e.g., Graham technique) and newer post-modern.
- “Hip-hop” incorporated studies on its subgenres, most notably breaking, locking, and popping.

Exclusion criteria were:

- Participants from dance genres other than ballet, modern, or hip-hop dancers,
- Participants who were not specified or separated by dance genre,
- Not testing for back pain or injury (performance measures alone were not satisfactory),
- Examining back pain as related to a specific pathology,
- Duplicated data published in different publications,
- Case studies or series,
- Non-primary sources (i.e., literature reviews),
- Grouping the lumbar spine with other areas of the body,
- Articles without English translated titles (those articles with titles translated to English were included, even if the article itself required some translation).

The electronic database search yielded 639 articles, combined with 41 additional records identified through other sources, such as references lists, to produce 680 total articles. Three hundred and thirty articles remained after duplicates were removed, excluding 290 of the remaining articles for not meeting inclusion criteria (Figure 2.1). Differences in the categorization of “genre name” were addressed by the inclusion of sub-genres; for example, Graham or Horton were classified as modern dance, and Breakers, Poppers/Lockers, or New Schoolers were categorized as hip-hop. In contrast, studies that used the umbrella term “dance”, instead of specifying a main discipline or exposure hours, were excluded.

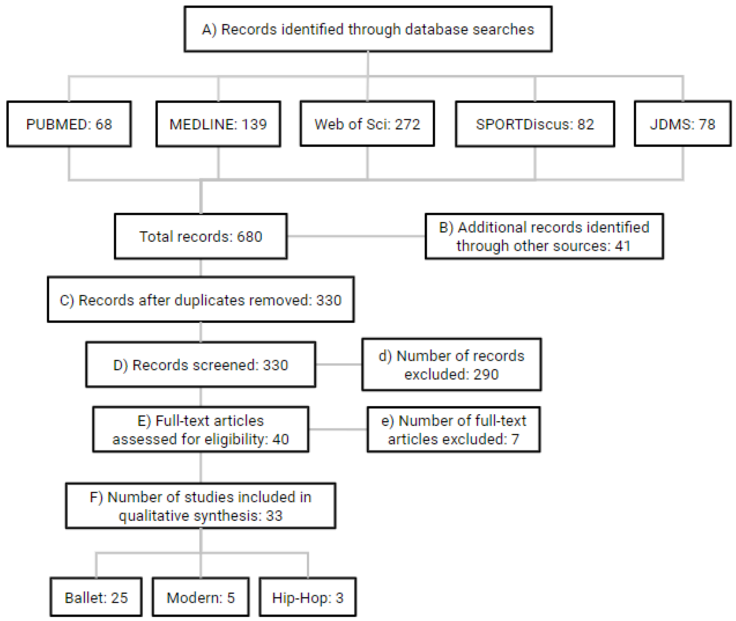


Figure 2.1: PRISMA flow diagram detailing the article search strategy in studies examining low back pain and injury in ballet, modern, and hip-hop dancers

2.2.3 Quality appraisal

After the initial screening of the 330 titles and abstracts, two researchers independently performed a full-text assessment of the remaining 40 articles, leading to the exclusion of seven more articles. Studies were assessed for their quality based on the Academy of Nutrition and Dietetics (Academy) Research Committee's 2013 adaptation[97] of Greer et al.'s original evidence grading strategies,[101] referred to 'ADA scoring system'. There were five grades given to the articles once examined: Good I, Fair II, Limited III, Expert Opinion Only IV, Grade Not Assignable V. A data-extraction sheet was utilized for full-text assessment, the results of which were compiled into a spreadsheet and then processed. A third researcher acted as a third reviewer for any disputed scores. Risk of bias was measured using a modified Newcastle-Ottawa assessment.[96]

2.3 Results

2.3.1 Included Studies

The final articles included 25 ballet articles[9,11,59,98-100,102-120], five modern dance[121-125], and three hip-hop[13-15] for a total of 33 articles. Sixteen articles studied at least one population of current professional ballet dancers. The incidence of LBP and LBI varied extensively, even between the scarce modern dance and hip-hop results. Summary tables of articles examining low back pain and injury (LBP/I) that were included in this study can be found in Table 2.2, Table 2.3, and Table 2.4 for ballet, modern, and hip-hop dancers, respectively.

Table 2.2: Summary of articles examining low back pain and injury in ballet dancers

	Article Title	First Author & Year	Design	Collection Methods / Intervention	Level of Evidence	Sample size, mean age/range	Terms used	Level of Mastery & Average Dance Participation	Relevant Outcomes: Total with LBP/I	Males with LBP/I	Females with LBP/I	Notes & Limitations	Data Reported As	GRADE score
1	Characteristics and prevalence of musculoskeletal injury in professional and non-professional ballet dancers	Costa et al. 2016	Retrospective case-control study	Questionnaire; prof vs non-prof dancers to assess presence, location, and mechanisms of injury Non-random sampling: convenience sample	3	n = 110 (88 F), 17.6+/-9.3 years average	"lumbar lesions"	Professional; 5.8+/-1.0 hours/day Student/Pre-Professional; 2.6+/-1.7 hours/day	12/53, 22.6% Professional women seemed the most affected by injury 3/57, 5.3% This study observed a low frequency of LBP, contrasting other studies	10/22, 45.5% -	2/31, 6.5% -	All 110 completely answered questionnaires were included. Relied on dancer memory. Most injuries occurred in relation to jumps; suggest 'taking into consideration the dancers' movements.'	people with injury	Fair II
2	National survey to evaluate musculoskeletal health in retired professional ballet dancers in the United Kingdom.	Smith et al., 2017	Retrospective cross-sectional study	Questionnaire; online national survey of retired prof ballet dancers in the UK for current MS issues & location, and cause of retirement Non-random sampling: snowball sample	3	n = 46 (14 F but not all reported), 50 years IQR 42-56	"Low back [muscle and joint pain]"	Retired Professional; no activity level given	32/46, 71% Retired dancers said were most affected by muscle and joint pain. Retired dancers seem to still be experiencing pain post-dancing professionally	-	-	Not all data reported/completed, bias of non-reporting. These are retired professionals, so training and activity level may have varied since they were dancing. Relied on dancer memory. Low response rate.	people with pain	Fair II
3	Musculoskeletal injuries in young ballet dancer	Leanderson et al., 2011	Retrospective, open cohort study;	Medical records; assessed records Aug 1988-June 1995 for diagnosis, location, and type of injuries Non-random sampling: convenience sample	2	n = 476 (297 F), 10-21 years	"low back pain"	Student; 6 hours/week in 4th grade, 10.5 hours/week in 5th/7th grades, 15 hours/week in 9th,10th, and 11th grades	45/476, 9.5% recorded injury records as they happened, but this study takes place in 2006-7, when they went back and assessed the records. They suggest that injury incidence increases with age	22/179, 5.1%	23/297, 5.3%	No exclusion criteria applied. Records were a bit old at the time of assessment, but they defend that the dance training has "most likely not changed significantly"	number of pains	Fair II
4	Injury patterns in elite preprofessional ballet dancers and the utility of screening programs to identify risk characteristics.	Gamboa et al., 2008	Retrospective descriptive cohort study	Screenings, Medical records; took place over 5 years: screened at the beginning, and injury data collected at the end of each year Non-random sampling: convenience sample	Prognosis, level 2b	n = 359 (288 F), 14.7+/-1.9years average, 9-20 years	"history of low back pain"	Pre-Professional; ~20 hours/week of ballet (ten 1.5-hour classes, three 1-hour rehearsals, one 2-hour rehearsal; 2 hours cross training and Pilates mat per week)	injured: 73, 44% non-injured: 125, 27% Retro review of physical therapy records at the end of the school year; compared injured and non-injured groups.	-	-	A broad-based screening program did not identify robust physical factors predictive of injuries in elite pre-professional adolescent dancers. The rate of injuries in dancers may be best understood when measured as number of injuries per 1000 hours of dance.'	people with pain	Good I

5	Verletzungen und Uberlastungserscheinungen im professionellen Ballett	Arendt et al., 2003	Retrospective cohort study	Questionnaire, Medical Records; A personal survey with training attention, a problem-oriented clinical-orthopaedic examination and, if available, a review of the medical documents; compared subjective complaints to medically treated injuries Non-random sampling: convenience sample	3	n = 77 (42 F), 20-34 years	"lumbar spine"	Professional; 45-50 hours/week for most dancers; does give data for above and below this range	499/567, 88% 'common discomfort described in the lumbar spine' out of the 285 F injuries and 282 M injuries over a 5-year period	-	-	They suggest a link between 'anatomical and technical deficiencies' and LBP	number of injuries	Fair II
6	The prevalence and impact of low back pain in pre-professional and professional dancers: A prospective study.	Swain et al., 2018	Prospective Cohort Study	Questionnaire; initial questionnaire for LBP history, then monthly prevalence of LBP & impact was collected over 9 months Non-random sampling: convenience sample	2	n = 168 (100 F), 11-25 years pre-professional: n = 95, 11-18 prof: n = 29, age range unavailable student: n = 77 & n = 19, 17-25	"any LBP", "activity limiting LBP", and "chronic LBP"; "History of LBP"	Student, Pre-Professional, Professional; mean dance hours/month ranged between 49.9 and 85.3 (SD range: 21.4 to 44.4).	93/119, 78% 62/119 52% 29/119 24% Table 1 gives their descriptive data: 93 had 'any LBP', 62 had 'activity limiting LBP', and 29 had 'chronic LBP'	~~15/19, 79%~~ 15 M had history of LBP, but data was missing for 11 cases	~~65/100, 74%~~ 65 F had history of LBP, but data was missing for 11 cases	No significant relationship was also identified between monthly dance hours and the monthly prevalence of any LBP or AL LBP' 'The current study was unable to find any overall association between the experience of LBP and the participation data collected'	people with pain	Fair II
7	Analysis of the relationship between low back pain and muscle strength imbalance in ballet dancers	de Aquino et al., 2010	Cross-sectional cohort study	Questionnaire & Screenings; questionnaire to divide into Pain and No Pain groups, and then submitted to test battery Non-random sampling: convenience sample	3	n = 42 (42 F), 16.4years average, 13-25 years	"mechanical lumbar pain"	Pre-Professional; 3.9 +/- 1.5 hours/week	21/42, 50% 'For the Pain group, the dancers should present chronic low back pain (reports of symptoms recurrent for more than 12 weeks) and of mechanical origin.' of which there were 21	-	21/42, 50%	The main movement that aggravated the low back pain in the dancers of the Pain group were the hyperextension of the trunk (85.7%) and the more frequent relief movement was the anterior flexion of the trunk (57.1%).' there were also imbalances in ABD x FQ that associated significantly with LBP	people with pain	Fair II

8	Validation of a Pain Questionnaire (SEFIP) for dancers with a specially created test battery	Ramel et al., 1999	Cross-sectional study	Questionnaire & Screenings; did a survey, then did a test battery, and compared the two Non-random sampling: volunteer sample	3	n = 28 (17 F), 27.6 years average, 19-43 years	"low back pain"	Professional; no activity level given	17/28, 60.7% Both the test battery and their SEFIP exam found 17 dancers with LBP, but it was not the same 17 dancers (one dancer reported pain when the TB found none, and vice versa)	-	-	Did not give data for amount of dancing per week 'Overall, the SEFIP questionnaire shows good agreement with the actual pain found on physical examination.'	people with pain	Fair II
9	Life history and point prevalence of low back pain in pre-professional and professional dancers.	Swain et al., 2017	Cross-sectional study.	Questionnaire; measured lifetime and point prevalence of LBP Non-random sampling: convenience sample	3	n = 110 (91 F), 17.8 years average (17.9 F & 17.1 M)	"lifetime history of low back pain:	Student, Pre-Professional, Professional; 13-18.5 hours/week for students, 24 hours/week for Pre-Professional, Prof activity level not given	81/110, 74% 'A 74% lifetime prevalence of LBP was reported by dancers. Point and 12-month prevalence were 24 and 64%, respectively.'	15/19, 78.9%	66/91, 72.5%	No significant association was observed between LBP and any demographic or physical variables.'	people with pain	Limited III
10	Trunk Dynamics Are Impaired in Ballet Dancers with Back Pain but Improve with Imagery	Gildea et al., 2015	Non-RCT, cohort study.	Interview; split into those with and without LBP, then Questionnaires, then dampening was measured in both groups, and then again after using imagery to see if the dampening improved Non-random sampling: volunteer sample	2	n = 30 (19 F), 24.4 years	"low back pain"	Professional; "on full workloads", no activity level given	22/30, 73% 'Of the 30 dancers, 22 dancers reported pain in the lower back or pelvic/hip region.' 14 reported LBP within the preceding 6 months, and 8 reported pain before that (0.5-13 years)	-	-	Made assumptions about simplification of the trunk muscles to enable estimation of trunk parameters. Convenience sampling limited the size of pain-free group 'Trunk damping, but not stiffness, is modified in dancers with a history of LBP.' & 'Dancers with a history of LBP can use imagery to modify trunk mechanical properties.'	people with pain	Good I
11	Morphology of the abdominal muscles in ballet dancers with and without low back pain: A magnetic resonance imaging study.	Gildea et al., 2014	Observational study	Questionnaire; separated into LBP and no LBP groups, then assessed via MRI for thickness of TA and OI ab muscles Non-random sampling: volunteer sample	3	n = 31 (17 F), F: 23.3 years average M 24.4 years average	"pain in the region of the lower back"	Professional; in the Int'l Phys Act Questionnaire, all dancers scored 'high' physical activity category	23/31, 74% Three groups for comparison post-questionnaire; no history of hip region or LBP (n = 8); history of / or current LBP (n = 13); history of / or current hip region and LBP (n = 10) ...thus 23 with LBP (regardless of hip pain).	-	-	The preliminary evidence of compromised behaviour of TrA muscles in LBP provides a foundation...' to move forward with more research. 'Participants with LBP also completed a Roland-Morris Disability questionnaire and Oswestry Disability questionnaire. Except for pain, there was no difference in demographic data among groups (ANOVA).'	people with pain	Fair II

12	Recurrent musculoskeletal pain in professional ballet dancers in Sweden: a six-year follow-up	Ramel et al., 1999	Cohort study	Questionnaire; Nordic Musculoskeletal Questionnaire to assess pain was administered in the middle of the fall season in 1989 and the middle of the spring season in 1995 Non-random sampling: convenience sample	3	n = 51 (34 F) 1989: 26 (22-31) 1995: 32 (28-37)	"pain...reported in the low back"	Professional (1989) Individual demand based on median hours of work: High 7, Medium 15, Low 18, No answer 11 Professional (1995) Individual demand based on median hours of work: High 7, Medium 15, Low 18, No answer 11	last 12 months: 69% last 7 days: 26% ~~incapacitating last 12 months: 28%~~ (1 missing answer) last 12 months: 82% last 7 days: 37% incapacitating last 12 months: 33%	- -	- -	Missing responses from their questionnaire. 'Highly selected group' so less generalisability. 'In spite of an increased 12-month pain prevalence over the years, the incapacitating pain for the persons in this study did not increase. These dancers somehow lived and worked with their pain, in spite of an increased number of performances over the years.'	people with pain	Limited III
13	Injuries in a Professional Ballet Dance Company A 10-Year retrospective study	Ramkumar et al., 2016	10-year retrospective study	Medical records; Data regarding the dancers' age, gender, location of injury, and diagnosis were collected from workers' compensation claims, company records, and medical records maintained by the treating doctors. Non-random sampling: convenience sample	3	n = 153 (81 F), 27.5 years	"lumbar strain...injury"	Professional; 27.5 hours/week excluding performance and dress	117/574, 20% frequency of lumbar spine injury ~20%; most common diagnoses in prof ballet were lumbar strain ~20%...lumbar spine strain was 117 out of 574 total injuries	-	-	Disproportionate occurrence of injuries over a season was not accounted for. Could not distinguish overuse vs. traumatic (except fractures). 'The data reveal that a dancer experiences at least one new injury every year,'	number of injuries	Good I
14	Overuse Injuries in professional ballet: injury-based differences among ballet disciplines	Sobrino et al., 2015	Cross-sectional study	Medical records; Data, including type of injury, were obtained from specialised medical services at the Trauma Service, Fremap, Madrid, Spain. Attempt at random sampling	3	n = 145 (? F), 25.79 +/- 5.69 years	"Mechanical low back pain" & "lumbar muscle injury"	Professional; no activity level given	3/76, 3.95% 486 injuries were evaluated, 366 total overuse injuries, with 82.6% of the total injuries for classical ballet being overuse as opposed to traumatic/other. In total there were 76 classical ballet injuries (25 M 51 F) and 3 of these were Mechanical low back pain 3.95% (0 M, 3 F) Also, 1 (1M, 0 F) had Lumbar muscle	0/25, 0% 1/25, 1.32%	3/51, 5.88% 0/51, 0%	Did not give activity level. Prevalence of overuse injuries...in classical ballet and among women.	number of pains	Good I

									injury out of the 76 injuries					
15	The effect of spinal and pelvic posture and mobility on back pain in young dancers and non-dancers	McMeeken et al., 2002	Cross-sectional study	Questionnaire; dancers vs non-dancers received a questionnaire concerning the type and amount of regular activity and history of LBP; then did videotape motion analysis of trunk posture and movement Non-random sampling: volunteer sample	3	n = 120 (82 F) (41 dancers (? F)), 17.2 +/- 3.6 years	"Low back pain episodes in the last year"	Student, Pre-Professional; at least 6 hours per week; non-dancers: one did 5 hours/week and nine did less than 3 hours/week	15/41, 36.6% Visual analogue scales used for intensity. Their Table 6 shows that 15 dancers had pain episodes in the last year, and that the paid lasted average 14 days with max intensity 66.6+/-23.9 / 100	-	-	They did not separate dancers by gender. 'no links between low back pain and sagittal pelvic tilt and lumbar postures. ...Our study did not demonstrate that greater spinal mobility was a useful predictor of the risk of back pain in dancers.'	number of pains	Fair II
16	A prevalência de dor em bailarinas clássicas The prevalence of pain in classical ballet dancers	Batista et al., 2010	Retrospective cross-sectional study	Questionnaire; "EVA" visual analogue scale questionnaire gathered data on location of pain for pointe dancers in Cubatão Non-random sampling: convenience sample	3	n = 30 (30 F), 20.4 +/- 4.5 years	"dor da regiao lombar"	Student; 18.7 hours/week	12/30, 20.30% They also looked at intensity of pain via EVA	-	12/30, 20.30%	It is important to emphasize that the modalities jazz and modern dance were not considered as other types of activities because they are part of the curriculum of the school where the research was carried out'	people with pain	Limited III
17	Ballet Injuries: Injury Incidence and Severity Over 1 Year	Allen et al., 2012	Prospective, descriptive single-cohort study.	Medical records; in-house medical team recorded time-loss injuries Non-random sampling: convenience sample	2	n = 52 (27 F), F: 25+/-6 years M: 23+/-5 years	"lumbar pain undiagnosed, lumbar muscle spasm/strain/tear"	Professional; 31.5 - 35.5 hours/week	30/355, 8.5% FEMALES: lumbar muscle spasm/strain/tear 11 instances, lumbar pain undiagnosed 3 instances of 172 total injuries MALES: lumbar muscle spasm/strain/tear 13 instances, lumbar pain undiagnosed 3 instances of 183 total injuries	16/183, 9%	14/172, 8%	Reliability and validity of the injury surveillance tool were not established.' 'Prof ballet dancers have a high proportion of ...lumbar spine and overuse injuries. Gender differences in injury incidence and profile were identified.'	number of pains	Good I
18	Musculoskeletal injuries in the Norwegian National Ballet: a prospective cohort study	Byhring et al., 2002	Prospective cohort study	Questionnaire, Medical records; history questionnaire, and then 19-week prospective study of injuries as registered by medical staff. Non-random sampling: convenience sample	2	n = 41 (27 F), 26.7 years 19-40 years	"low back"	Professional; 30-40 hours/week	1/10 time away from work injuries, versus about 8 out of the 64 total injuries. Fig. 1 does show complaints of the low back, but only graphically, so it is difficult to assess the exact number of injuries (8 low back?). Later, they explain out the 64 injuries, 10 resulted in time off, and one of those ten was a low back injury	-	-	The study sample did not differ from the whole population regarding gender, age, and professional status' & 'it is concluded that there is a high incidence of MS injuries in the Nor Nat'l Ballet'	number of injuries	Fair II
19	The injury panorama in a Swedish professional ballet company	Nilsson et al., 2001	Combined retro- and	Questionnaire, Medical records; injuries were	2; 3	n = 98 (50 F), 26.6 years 17-47	"lower back, gluteal region...overuse"	Professional; 48 hours/week	70/390, 17.9% Study showed T/O: proportion of these	35/182, 19.2%	35/208, 16.8%	The injury patterns in the retrospective and prospective	number of injuries	Fair II

			prospective study	recorded through medical professionals over 5 consecutive years and a retrospective recording of the first two years was made through a form that was designed to register the diagnosis, site of injury, injury mechanism, and type of injury. Non-random sampling, but they did follow the company over five years, making it more representative than most convenience samples		years, 390 injuries			injuries that were traumatic versus overuse. Only the overuse data were used.			parts of the study were similar. Furthermore, the present study demonstrates a difference in injury pattern between male and female dancers.'		
20	Ballet dancer's turnout and its relationship to self-reported injury.	Coplan 2002	Retrospective cohort study.	Questionnaire, Screenings; divided into LBP or no LBP, then measure first position turnout and passive ext rotation ROM Non-random sampling: convenience sample	2	n = 30 (27 F), 16-50 years	"low back injury"	Student; no activity level given	3/22, 13.6% Twenty-two total injuries of the following kind were reported: knee (n = 8 or 36%), shin (n = 5 or 22.7%), low back (n = 3 or 13.6%), ankle (n = 3 or 13.6%), hip (n = 1 or 4.5%), and foot (n = 1 or 4.5%).	-	-	Compensated turnout was greater in injured groups. No data were collected describing the hours of practice or level of experience and performance of the subjects. A lack of formal diagnosis of injury and the limited number of subjects. The survey relied on the self-reported history of injury and therefore the memory of the dancer.	number of injuries	Fair II
21	Lumbosacral pain in ballet school students. Pilot study.	Drężewska et al., 2013	Combined retro- and prospective study	Questionnaire, Medical Records, and later, Screenings. The questionnaire established who did and did not have back pain and was corroborated by medical history forms; the VAS was used for subjective pain intensity, and they screened after that. Non-random sampling: convenience sample	2	n = 71 (45 F), 16.5 years average (15-18 range)	"with lumbosacral pain"	Pre-Professional; 19.7 hours/week with 10-30 hour/week range	44/71, 62% Gender split was not statistically significant	-	-	Age and Years Dancing "Dance Seniority" were statistically significant; pain increased with age and seniority LBP increased as BMI was below normal	people with pain	Fair II
22	Traumatic injuries in professional dance-past and	Wanke et al., 2014	Retrospective cohort study	Medical records; work accident	2	n = 241 accidents (participant	“traumatic injuries to the lumbar spine”	Professional; no activity level given	1994/95: 9/155, 5.8%	-	-	Dramatic increase in LBI from 1994/95 to 2011/12,	number of injuries	Fair II

	present: ballet injuries in Berlin, 1994/95 and 2011/12.			reports from three theatres Non-random sampling: volunteer sample		numbers not given), 1994/95: 28 years average 2011/12: 29.5 years average			2011/12: 17 or 18 out of 86, reported as 20.3%, although the nearest whole accident is either 19.8% or 20.9%					
23	Kinematics of the lumbar spine during classic ballet postures	Feipel et al., 2004	Retrospective cross-sectional study	Questionnaire; self-administered of their own design. Non-random sampling: convenience sample	3	n = 25 (17 F), 21 +/- 4 years average	"current low-back pain"	Professional, Pre-Professional; at least 20 hours/week of dance	10/25, 43%	-	-	Participants who danced less than 20 hours/week or less than 6 years total ballet experience were excluded from their study	people with pain	Fair II
24	The association between body-built and injury occurrence in pre-professional ballet dancers - separated analysis for the injured body-locations	Zaletel et al., 2017	Retrospective cross-sectional study	Questionnaire; self-administered of their own design that was verified by test-retest for reliability. Non-random sampling: convenience sample	3	n = 24 (24 F), 16-18 years	"lumbar region injury"	Pre-Professional; 20-25 hours/week	8/60, 13.3% Occurred during training: 7/8, 88% Occurred during performance: 1/8, 12%	-	8/60, 13.3%	Their questionnaire asked for injuries in the last year only.	number of injuries	Fair II
25	Ballet injuries. An analysis of epidemiology and financial outcome.	Garrick et al., 1993	Retrospective cohort study	Medical records; workers' compensation insurance records for 3 years of a ballet company Non-random sampling: convenience sample	2	n = 104, age not reported	"injury to lumbar region" that resulted in medical expense	Professional, Pre-Professional; no activity level given	71/309, 23.0%	-	-	Reported sparse demographic data	number of injuries	Fair II

Abbreviations used:

- LBP: Low back pain
- LBI: Low back injury
- LBP/I: low back pains or injuries

Table 2.3: Summary of articles examining low back pain and injury in modern dancers

	Article Title	First Author & Year	Design	Collection Methods / Intervention	Level of Evidence	Sample size, mean age/range	Terms used	Level of Mastery & Average Dance Participation	Relevant Outcomes: Total with LBP/I	Males with BP	Females with BP	Notes & Limitations	Data Reported As	GRADE score
1	Injuries in students of three different dance techniques.	Echegoyen et al., 2010	Prospective cohort study	Medical records; a sport physician recorded the data concerning injuries (at least one absence from dance class/rehearsal). Non-random sampling: convenience sample	2	n = 444 (F?); 23.10 +/- 3.04 years for modern, 23.85 +/- 3.05 years for Mexican folkloric, and 22.5 +/- 3.04 years for Spanish dance.	"back pain"	Student; training 11.6-13.3 hours/week with 1.6 hour/week rehearsal	54/620, 8.70%; 1168 total injuries over 3 years, 620 modern injuries.	-	-	Modern dance had 2x as many injuries as Mexican Folkloric, and ~5x as many injuries as Spanish dance...that is a little more than 1 injury for each modern dancer per 3 years.	number of pains	Good I

								Student, Self-Reported (324 hours/10 months = 32.4hours/month, ~8 hours/week)	6/70, 8.6%	3/14, 21.4%	3/56, 5.4%	The resulting frequency was too low for statistical analysis for this size of research; thus, they examined trends. Cautioned about generalizing for the greater population since the goal of this study was feedback to the conservatory specifically.	SELF-REPORTED; number of injury	
2	Self-reported and reported injury patterns in contemporary dance students.	Baker et al., 2010	Combined retro- and prospective study	Questionnaire, Medical records; questionnaire adapted Dance UK's injury questionnaire and medical records from Injury Zone UIK Sport electronic athlete medical record system) Non-random sampling: convenience sample	3; 2	n = 57 (47 F); F: 20.0 +/- 2.51 years M: 21.0 +/- 3.00 years in ~6.5 months, they took 180 hours contemporary and 144 hours ballet	"Lower back injuries"	Student, Reported (324 hours/10 months=32.4hours/month~8 hours/week)	9/63, 14.3%	1/11, 9.1%	8/52, 15.4%	This study supports seasonality of injuries. Jumping seemed to be a main method of injury. Relies on dancer recall.	REPORTED; number of injuries	Fair II
							"Lower back Injuries"	Graham technique (no activity level given)	38/229, 16.7%	-	-			
3	Technique as a consideration in modern dance injuries.	Solomon et al., 1986	Retrospective cross-sectional study	Questionnaire; a questionnaire they created; no details given. Non-random sampling: convenience/snowball sampling	3	n = 164 (127 F); 26.15 ± 6.43 years average, 16-48 years	"Lower back Injuries"	Horton technique (no activity level given)	49.5/229, 21.6%	-	-	Relies on dancer recall; snowball sampling limits generalizability. Did not separate their professional and non-professional results.	number of injuries	Fair II
4	Assessment of Compensated Turnout Characteristics and their Relationship to Injuries in University Level Modern Dancers	van Merkensteijn et al., 2015	Retrospective cross-sectional study	Questionnaire; self-reported injury of their own making Non-random sampling: convenience sample	3	n = 22 (20 F); 21.27 +/- 1.279 years average	"Low back pain"	Student; 20 hours/week plus time for various supplemental training	6/22, 27.3%	-	-	Asked for past 2 years of injury data, questionnaire was not verified. Concluded that all dancers compensated turnout, but to a lesser degree than previous research.	People with pain	Fair II
5	Injuries in Professional Modern Dancers: Incidence, Risk Factors, and Management	Shah et al., 2012	Retrospective cross-sectional study	Questionnaire; large scale survey, with a previous publication detailing the design (Weiss, 2008) Attempt at obtaining full sample size, but response rate and underrepresentation of free-lance modern dancers inhibits representativeness	3	n 184 (173 F); 18-55 years, 30.1 +/- 7.3 years average	"Low back injury"	Professional; 8.3 +/- 6 hours/week in class, 17.2 +/- 12.6 hours/week in rehearsal, 8.2 +/- 6.6 hours/week various supplemental training	40/230, 17%	-	-	Injury data was from preceding 12 months. High incidence of injury overall (82%) but does rely on self-reporting and recall of participants.	number of injuries	Good I

Abbreviations used:

- LBP: low back pain
- LBI: low back injury
- LBP/I: low back pain or injury

Table 2.4: Summary of articles examining low back pain and injury in hip-hop dancers

	Article Title	First Author & Year	Design	Collection Methods / Intervention	Level of Evidence	Sample size, mean age/range	Terms used	Level of Mastery & Average Dance Participation	Relevant Outcomes: Total with LBP/I	Males with BP	Females with BP	Notes & Limitations	Data Reported As	GRADE score
1	Pain Prevalence Among Female Street Dancers	Grčić et al., 2017	Retrospective cross-sectional study	Questionnaire; used a basic health and data questionnaire and the SEFIP Non-random sampling: volunteer sampling	3	n = 137 (137 F); 19.7 years average	"Lower back"	Novice 3-6 hours/week Student 7-10 hours/week Pre-Professional 11-15 hours/week Professional 15+hours/week	34/73; 46.6% 19/34, 55.9% 9/16, 56.2% 12/14, 85.7%	- - - -	34/73; 46.6% 19/34, 55.9% 9/16, 56.2% 12/14, 85.7%	LBP was the most common issue. Street dancers do not have the same supervision, so this may make them more injured. Relied on dancer recall. 'The results of this research suggest that the progression of back pain is indeed connected to the increased hours of training per week.'	people with pain	Fair II
2	Injury incidence in hip hop dance	Ojofeitimi et al., 2010	Retrospective cross-sectional study	Questionnaire; A Web-based survey was conducted over a 6-month period. attempted Random Sampling	3	n = 232 (169 F); range 13-44 years F: 24.7 +/- 5.5 years average M: 23.4+/- 5.4 years average	"Trunk: Lumbar/Pelvis...Injury"	"Student, Teacher, Professional"; activity level not provided	Physical Complaint 50/738 (7%) Time Loss 38/506 (8%)	- -	- -	This study did give the years of dancing but did not give current activity level. Does break down results by sub-genre: Breakers, Poppers/Lockers, Newschoolers	PHYSICAL COMPLAINT, number of injuries TIME LOSS, number of injuries	Fair II
3	Musculoskeletal injuries in break-dancers	Cho et al., 2009	Combined retro- and prospective cross-sectional study	Questionnaire, Screenings; questionnaire was for the basics, and then they did routine radiographs for certain places, and then additional radiographs if a dancer had pain in an area that was not part of the routine. 'Diagnosis was based on findings from medical histories, physical examinations and radiologic examinations,' No sampling; did not describe their sampling technique at all.	2	n = 42 (0 F); 22.3 years average, 16-3 years.	"lumbar spine...injury"	Professional Student Both (full total) 1-8 hours of training per DAY, average 4.1 hours	16/133, 69.6% of the professional group had this injury 5/60, 26.3% of the student group had this injury 21/193, 50.0% of the total group had this injury	16/23 (69.6%) 5/19 (26.3%) 21/42, 50.0%	- - -	Had a "major skills" chart that tracked central moves and who had these abilities, but that there were no major differences between amateurs and professionals. Relied on dancer memory. 'A limitation of our study was the inability to clarify the correlations between major skills, the specific motion and the injury sites, owing to the small study sample.'	people with injury	Fair II

Abbreviations used:

- LBP: low back pain
- LBI: low back injury
- LBP/I: low back pain or injury

2.3.2 Study Design and Risk of Bias

Twenty-five[11,13-15,59,98-100,103-106,109,110,112-115,118-121,123-125] of the 33 studies collected self-reported data via questionnaires. Thirteen[9,45,100,102,103,106-108,111,113,116,117,122] studies included the use of medical records and seven[14,98,104,106,107,109,115] used physical screenings to determine incidence of pain or injury to the low back. Thirteen studies[14,98,100,103,104,106,107,109,110,112,113,115,121] used multiple data collection methods, often both a questionnaire and the use of medical records. Few studies measured back pain identically, although most used a modified retrospective survey approach across a set amount of time (e.g., “Have you had back pain within the last week? Month? Year?”). The injury definitions of “low back pain” or “low back injury” varied, with studies describing pain as “mechanical low back pain”,[98,117] or defining injuries to this area as “lumbar lesions”.[105] Studies that examined the duration of pain over the course of a dancer’s career used the terminology “lifetime history of low back pain”.[118]

Table 2.5: Risk of bias reporting summary (modified Newcastle-Ottawa Method) in articles examining low back pain and injury in dancers

Stars (out of 10)	Number of studies
7	9
6	9
5	10
4	4
3	1

A summary of the results of the risk of bias assessment can be found in Table 2.5. An adapted Newcastle-Ottawa method[96] specific to cross-sectional studies was used, which grades each study out of ten possible stars (points): five for population selection method, two for comparability, and three for the outcome methods. Only five studies scored less than five, however, no study scored higher than seven. Twenty-nine studies relied on non-random sampling methods: convenience sampling (twenty studies),[9,98-100,102-108,111,113,114,116,118-122] snowball sampling (two studies),[11,124] volunteer sampling (seven studies),[13,59,109,110,112,115,125] or a combination; one study did not describe their sampling technique at all.[14] The lack of random sampling techniques limited the robustness of the reviewed research and prevented any study from gaining a full score.

2.3.3 Data Reporting

Conclusive results for the prevalence of LBP and/or LBI were unable to be calculated because of the difference in data reporting between studies. Sixteen studies[11,13,14,59,98,99,105-107,109,110,114,115,118,119,125] reported how many dancers of the total population studied complained of LBP/I, while the other seventeen studies[9,15,100,102-104,108,111-113,116,117,120-124] reported what percentages of their total pains/injuries were LBP/I.

2.3.3.1 Ballet Dancers

Twenty-five studies[9,11,59,98-100,102-120] examined LBP/I in ballet dancers. Of the 25 articles, six scored grades of “Good I”, sixteen scored “Fair II”, and three scored “Limited III” using the ADA scoring system. Risk of bias scores ranged from 3-7/10 and averaged 5.6/10. Sample sizes ranged from 24 participants[120] to 476 participants,[111] with three studies[98,99,120] having female-only populations, and seven studies[102,105,111,113,117-119] dividing their LBP/I results by sex. Quantifiable activity level was not reported for seven studies,[9,11,59,113,115,116,119] and those that did provide activity level, typically in hours per week, varied substantially from one another (the range for those that reported activity level in hours per week was 3.9+/-1.5 hours/week to 40-50 hours/week).

Eighteen[11,59,98-100,103-106,109,110,112-115,118-120] of these studies used questionnaires as a data collection tool. Studies could not be meta-analysed due to the differences in both collection methods and data reporting (Table 2.6). Collectively, the studies indicate that ballet dancers experience LBP, with an average of 57% LBP prevalence (range: 20.3%-79%), as well as LBI (range: 5.3%-22.6%). The number of ballet dancers with LBP specifically in these studies trended towards two out of every three dancers experiencing LBP (median: 62%, mean: 57%).

Table 2.6: Reporting methods in studies examining low back pain and injury reports in ballet dancers

Data reported as: *	Low back pain or injury values:	Range:
People with low back pain (12)	71%, 32.3%, 78%, 50%, 60.7%, 74%, 79%, 73%, 74%, 33%, 20.3%, 62%, 43%	20.3% - 79%
Number of pains in the low back (4)	9.5%, 5.19%, 36.6%, 8.5%	5.19%-36.6%
People with low back injuries (1)	22.6%, 5.3%	5.3% - 22.6%
Number of injuries to the low back (8)	88%, 20%, 2.1%, 17.9%, 13.6%, 5.8%, 20.3%, 13.3%, 23.0%	2.1%-88%

* *parentheses indicate number of articles who reported in this way.*

2.3.3.2 Modern Dancers

Five studies[121-125] examined LBP/I in modern dancers. Of these articles, two scored "Good I" and three scored "Fair II" using the ADA scoring system. Risk of bias scores ranged from 4-7/10 and averaged 5.6/10. Sample sizes ranged from 22 participants[125] to 444 participants,[122] with one study[121] dividing their LBP/I results by sex. Quantifiable activity level was not reported for one study.[124]

Four[121,123-125] of these studies used questionnaires as a data collection method. Studies could not be meta-analysed due to the differences in both collection methods and data reporting (Table 2.7). The five studies, which all examined a population of modern dance students, seem to agree that LBP/I exist, although there is a serious dearth of studies. The results from these studies trend towards being lower than those of the ballet studies, with LBP prevalence being reported as 27.3% of dancers and LBI prevalence ranging from 8.6%-21.6% of total injuries.

Table 2.7: Reporting methods in studies examining low back pain and injury reports in modern dancers

Data reported as:*	Low back pain or injury values:	Range:
People with low back pain (1)	27.3%	N/A
Number of pains in the low back (1)	8.70%	N/A
People with low back injury (0)	-	-
Number of injuries to the low back (3)	8.6%, 14.3%, 16.7%, 21.6%, 17%	8.6% - 21.6%

* *parentheses indicate number of articles who reported in this way.*

2.3.3.3 Hip-Hop Dancers

Three studies[13-15] examined LBP/I in hip-hop dancers. All three articles scored "Fair II" using the ADA scoring system. Risk of bias scores ranged from 5-7/10 and averaged 6.3/10. Sample sizes ranged from 42 participants[14] to 232 participants,[15] with one study[13] having an all-female population, and another study[14] having an all-male population. Quantifiable activity level was not reported for one study.[15]

All three of these studies used a questionnaire as their data collection method. Studies could not be meta-analysed due to the differences in both collection methods and data reporting (Table 2.8). The three studies seem to agree that LBP/I exist, with a mean LBP prevalence of 61.1% prevalence (range: 46.6-85.7%) and LBI prevalence of 49.0% (range: 26.3%-69.6%), which are much higher than the modern dance studies, with values closer to that of the ballet dance studies. The number of hip-hop dancers with LBP specifically trended towards two out of every three dancers experiencing LBP (median: 56.0%, mean: 61.1%).

Table 2.8: Reporting methods in studies examining low back pain and injury reports in hip hop dancers

Data reported as:*	Low back pain or injury values:	Range:
People with low back pain (1)	46.6%, 55.9%, 56.2%, 85.7%	46.6%-85.7%
Number of pains in the low back (0)	-	-
People with low back injury (1)	69.6%, 26.3%	26.3%-69.6%
Number of injuries to the low back (1)	7%, 8%	7-8%

* *parentheses indicate number of articles who reported in this way.*

2.4 Discussion

The primary findings of the present study indicate that not enough LBP/I data exist, particularly for modern and hip-hop dancers, and that clear injury definitions and more descriptive statistics surrounding participant demographic information (sex, exposure hours, primary dance genre) are needed to complete additional comparisons. Many studies used professional ballet dancers as their population of study, and very few studies had modern or hip-hop dancers as participants. There was a large range of prevalence values between studies, and a high risk of recall bias with many studies relying on questionnaires for data collection.

The current study found risk of bias scores to be relatively low, however, with no study scoring higher than seven out of ten, mainly due to the reliance on non-random sampling methods. This limitation was present in most dance research on LBP/I, and I hypothesize this is due to the convenience of having many dancers present as part of a dance company or university dance program; collecting data becomes simpler and the participation rate presumably higher when the participants are in the same place at the same time, or participation in the study can be supported by a company or program director. However, this convenience pitfall also reduces the robustness of the research and should ideally be reduced in future research to adequately address risk of bias. This will lend confidence to the acquired results, and I predict that a reduced risk of bias will affect the large range of results for LBP/I in dancers over time.

2.4.1 Differences in data collection and presentation

Despite the limited robustness and large range of results, ballet and hip-hop dancers have a moderate risk for LBP/I. Direct comparison between studies was not possible due to heterogeneity across studies. Data collection methods for pain/injury data varied, with sixteen studies reporting the number of pains/injury and seventeen studies reporting the number of people with pain/injury across all three dance genres in the present reviews. For example, twelve ballet studies surveyed how many dancers had back pain, while four ballet studies surveyed how many instances of back pain occurred in a certain time frame; this made processing the data difficult without subdividing it for purposes of pooled statistical comparison. Vast differences in collection and reporting methods prevented even the most general comparisons to be made about the prevalence of back pain. Variation in types of questionnaires, screening methods, collection methods, interview questions, and differing injury definitions made determining prevalence difficult.

Baker et al.[121] discussed the contrast between self-reported and reported injuries in contemporary dance students and suggest that there is a difference in how dancers and physiotherapists classify injury. However, Ramel et al.[115] administered a Self-Estimated Functionality Inability because of Pain (SEFIP) survey for areas of pain to ballet dancers, and then completed a test battery to confirm the results of the survey. They found that there was good agreement between where the dancers cited pain on the survey and where medical professionals identified areas of pain or weakness during the test battery.

Additionally, some research included in the current study did not specify any quantitative level of dance activity, which further complicates directly comparing any of the studies. For example, Ramkumar et al.[116] reported that their professional ballet population danced an average of 27.5 hours per week (injury incidence of 0.65 per 1000 hours), excluding dress rehearsals and performances. Alternatively, Arendt et al.[100] found that most of their professional ballet population danced 45-50 hours per week (number of weeks per year was unspecified in the study, but assuming a 44 week contract, injury incidence per 1000 hours would be 3.27-2.95). Each studio, university, conservatory, and professional dance company has differing schedules and demands, so it is unsurprising that the level of activity might differ, even amongst professional ballet dancers. As developing research suggests, there may be a correlation between hours of dance activity and rate of injury.[126] Thus, noting the dance exposure hours instead of, or in addition to, the experience level of a given dance population will allow for more direct comparisons between populations.

Overall, dancers appear to be at significant risk for LBP, and an increased risk of LBI, although the risk seems higher for dancers who specialize in ballet and hip-hop rather than modern dancers. Of greatest concern to professionals is identifying if their dancers have increased risk. By addressing trends in LBP/I within levels of mastery, age, and sex, it may be possible to determine those dancers who may be at risk of LBP/I before the onset of LBP/I.

2.4.2 Secondary Objectives

2.4.2.1 Level of Mastery

Secondary objectives of this review included assessing trends in LBP and LBI along the dancers' level of mastery. Overall, research across varied sport populations seem to agree that athletes who have increased exposure or intensity during participation have more injuries than those who do not.[127] Studies of athletes like gymnasts seem to suggest that LBP is linked to increased exposure hours,[4] leading to the hypothesis that dancers may also see this trend. No trends could be definitively stated for LBP/I and level of mastery from the current study. From the limited amount of research available, professional hip-hop dancers seem to be at more of a risk than those with less mastery, yet both ballet and modern dance results were too inconsistent to present any trends.

When possible, the original researchers' categorizations for mastery/experience were used. Otherwise, three arbitrary categorizations were used, based on the amount of dance (rehearsals, classes, performances) completed on an average week that fit most full-text articles: Student (<15 hours per week), Pre-Professional (>15 hours per week), and Professional (hired by a "professional company"). Ten studies did not provide a measure of dance exposure or typical workload, thus were unable to be categorized. The studies that did specify exposure varied in their classification of these exposures; for example, professional dancers were reported to have between 27.5[116] to 45-50[100] hours of ballet training per week, or giving no measures other than stating they were "professionals with a full workload".[110]

Some studies reported upon a "teacher" category that was separate from both students and professionals. Previous authors have indicated differing demands on the body between dance classes, rehearsals, and performance,[128] and researchers providing the ratio of these three items could allow for comparison across multiple studies in the future. Further research should include demographics that give a sense of the rigor and duration of dancing, rather than labels like 'student' or 'professional', to account for the differences in dance programs, performance seasons, and dance genres. This supports the need for dance activity levels and exposure hours to be included in future research.

2.4.2.2 Age

Reviews of sport literature agree that children and adolescents seem to be at risk for sport-related injuries,[129] with theories that physical and physiological differences many account for these high rates and decreasing their vulnerability with age and maturation.[130] However, for LBP specifically, the specific sport population being studied changes the relationship between LBP/I risk and age. Several studies have found that young athletes generally are at a higher risk of LBP than adults, although the causes may differ.[131] This finding contrasts with sports that have sex roles, like rhythmic gymnasts, Dance Sport, and similar disciplines, where there is an increased their risk of LBP with age.[132-135] Studies did not specify the age range of those dancers who either became injured or had endured/still endure back pain, thus any trends between age and risk for LBP/I were unable to be discerned. Demographics for the general population were provided, but none for those dancers that presented with LBP or LBI. This observation again calls for more research into age and LBP/I for dance in general, and specifically ballet, modern, and hip-hop dance.

2.4.2.3 Sex

None of the eligible hip-hop dance studies provided separate data on males and females with LBP/LBI. Additionally, the current study was unable to discern clear sex trends amongst the modern dance studies, as only one reported data separately. Sport research does not seem to have analogous low back pain or injury research; most studies compare males and females from different sports. Oftentimes, sport injury reporting aggregates multiple sports (such as combining dancers and gymnastics into the same population) or multiple injury sites together (such as reporting "[general] back injury", instead of being specific about which region of the back was injured).[136-138] This makes the identification of sex role trends in LBP/I from existing research challenging. Most studies seemed to report similar rates of LBP/I, and differences that were not statistically significant in most cases.

Aggregating multiple sports or injury sites would negate any differences between males and females in the same sport or in sports that have "sex roles". Miletic et al.[135] found that male international Dance Sport dancers had more hip pain than female dancers, suggesting differences in male and female roles. Male and female gymnasts seem to display anthropometric differences[139] and may be considered to have "sex roles", as male and female gymnasts participate in different gymnastic events. For dance research, Dance Sport seems to indicate anthropomorphic sex differences as well,[140] but injury results reported by sex are scarce, as standardized measures and overall research into Dance Sport injuries are lacking.[141]

Dance research also lacks standardization. Baker et al.,[121] indicated that three of their 56 female injuries had “lower back injuries” and three of their 14 male injuries had “lower back injuries” as reported by the dancers. However, eight of 52 injuries and one out of 11 injuries were reported by physiotherapists for that same period. Because the dance students and the physiotherapists in that study were not perfectly aligned in their injury definitions, it is difficult to make definitive statements on the role that sex plays in putting modern dancers at risk for LBP/LBI.

Seven of the 25 ballet studies differentiated between males and females; those studies which did found very little discrepancy, which was unexpected, due to the popularity of sex roles in ballet, as many ballet pieces traditionally have a male and female role with different physical requirements. However, due to the typically larger number of females in ballet performances as compared to males, the male sample sizes were noticeably smaller than their female counterparts. More research into sex differences should be included in future studies of injury and pain in dancers of any genre, but especially if that dance discipline tends to have differences in expectations for a “male role” and a “female role”.

2.5 Limitations & Future Recommendations

There are limitations to this study. Dance Sport, Flamenco, and other such dance populations were not included in this study, although some research into those dance genres does exist. Studies that focused on degenerative pathologies, such as spondylosis or degenerative disk disorders, were excluded; the causes of low back pain in dancers are assumed to be multi-faceted, and thus are not addressed in most of the research into back pain and injuries. While the researchers recognize that degenerative pathologies most likely constitute some of the dancers who claimed to have back pain or injury within the included studies, a skew in these data may have occurred due to the exclusion of chronic diseases.

Future studies should include the time frame over which subjects are assessed for pain/injury, and researchers should obtain both the number of complaints and how many people have these complaints to aid comparison across multiple studies on this topic. For example, reporting that 30 injuries out of 100 injuries that occurred in a dance performance season were LBI, as well as reporting that 20 out of the 30 total dancers who participated had LBI. While this may seem redundant at initial glance, reporting both values aids in comparison across studies when trying to identify prevalence.

As noted, most studies used in this review included pain or injury questionnaires. Questions such as, “Have you had back pain in the last year?”, asked dancers to recall experiences, relying on their memory which can be unreliable, particularly as the level of detail pertaining to injuries increases.[142] Level of evidence would increase if reliance on memory decreased, however, the discrepancy between self-reporting and medical record reporting needs to be addressed; and the validity of performing either a questionnaire or viewing medical reports when trying to assess the "true" prevalence of back pain should also be considered. Including who is reporting the injuries, a clear injury definition, and specifics as to how the data were obtained can add transparency to data collection, as the discrepancy between dancer self-reported injuries and clinician-reported injuries has been noted in dance previously.[105,107]

Furthermore, studies would benefit from apportioning their data by dance exposure hours or similar measurement rather than arbitrary categories like "professional" or "pre-professional", since agreement on these terms is low even within the same dance genres. Further research in genres other than ballet, including modern and hip-hop dance are required to provide a comprehensive understanding of LBP/I.

To better compare outcomes of future research in dance, I suggest the following best practices:

Data collection and presentation

- Use clear injury definitions based on current best practices.
- Report both the number of complaints and how many people have these complaints.
- Include non-ballet dance genre populations.
- Report dancing time in objective epidemiological measurements, such as exposure hours (e.g., per 1000 hours).
- Address possible discrepancies between self-reported and others-reported injuries, if applicable.
- Describe who reports the injuries (e.g., self-reported or clinician) and acknowledge possible discrepancies between these approaches.
- Include the time frame used for assessing pain/injury and limit the length of time participants are asked to recall information if using a questionnaire format.
- Gather data on both low back pain (LBP) and low back injury (LBI).
- Record sex differences, particularly if the dance genre utilizes sex roles.

2.6 Conclusion

The included studies in this review suggest that the prevalence of LBP/I is relatively high in ballet dancers (LBP range: 20.3%-79% of total dancers are affected; LBI range: 2.1%-88% of total injuries), not as likely in modern dancers (LBP reported by one study as 27.3% of total dancers are affected; LBI range: 8.6%-21.6% of total injuries), and possibly a higher risk in hip-hop dancers (LBP range: 46.6%-85.7% of total dancers are affected; LBI range: 26.3%-69.6% of total dancers are affected), although not enough high-quality research exists on the subject to date. Future studies need a higher level of evidence and a reduced risk of bias. The current study's results also suggest that ballet dancers are at risk for LBP/I independent of sex, age, or level of mastery. Currently, there is not enough evidence to draw any definitive conclusions about modern dancers or hip-hop dancers and their relationship to LBP/I.

3 Thesis structure, aims, and hypotheses

The impetus for this thesis grew out of personal experience as a lifelong dance practitioner with a background in both dance and kinesiology. Informal anecdotes from dancers and dance educators about the commonality of this condition and the debilitating impact that LBP can have on dancers inspired the investigation. Research was needed to fill the gap between the anecdotes and experiences of dancers with low back pain and the existing literature. Through the literature review, it was hoped that a metanalysis or other aggregate measure could be performed to establish LBP prevalence for all three dance genres. However, existing research centred on professional ballet dancers, with very few studies examining LBP in modern or hip-hop dancers. Additionally, the differing injury definitions used in published literature resulted in a large range of prevalence values and prevented comparison across studies.

The key aim of this thesis was to investigate LBP in ballet, modern, and hip-hop dancers, and provide practical recommendations based on the findings. Ballet, modern, and hip-hop dance genres were chosen specifically because ballet and modern (also called contemporary) dance represent genres commonly present at professional and collegiate levels. Hip-hop dance was also included because despite its popularity as an artform, there is a dearth of published dance science literature that includes this population.

This thesis is organized into chapters. The content of each study builds upon the results of the study that precedes it, demonstrating a thorough and well-designed research plan. Prior to beginning novel research, a systematic literature review (Chapter 2) was conducted that focused on identifying what studies have already been published on the topic of LBP in dancers.

Therefore, Study 1 (Chapter 4) utilized a questionnaire to assess how many dancers have been afflicted with LBP to establish prevalence as well as impact and care-seeking behaviours. The questionnaire recorded what dancers with LBP perceived the impact of LBP to be on their daily lives and dancing, and what dance movements they feel increase their LBP. Lastly, the questionnaire inquired how afflicted dancers manage their LBP, and if there are any differences in self-reported LBP severity, functionality, and care-seeking behaviours amongst the dance genres.

Study 2 (Chapter 5) gathered observational data on dancer exposure to movements that the first study had identified as increasing LBP. The COVID-19 pandemic necessitated that this research project was conducted using online dance videos, rather than in-person observations. Data collection entailed recording counts of movements (total number and frequency, measured in movements per minute) of **spinal** (spinal flexion, spinal extension, spinal rotation, and spinal lateral flexion), **impact** (jumps, leaps, and falls), and **partnering** (supports, lifts, and leans) dance movements within seven dance environments:

- ballet class,
- ballet performance,
- modern dance class,
- modern performance,
- hip-hop breaking,
- hip-hop cyphers, and
- hip-hop battles.

Study 2 also quantified the demands of the three dance genres and identified whether different dance genres have similar movement demands or work-to-rest ratios. The aim was to determine if some dance environments have more exposure to movements that increase LBP than others.

Study 3 (Chapter 6) tested the effect of speed on three spinal extension movements, one from each dance genre studied: the ballet arabesque, the modern dance attitude with body roll, and the hip-hop dolphin dive. Study 3 built on Studies 1 and 2 by combining the type of movement most often described as having increased dancers' LBP from Study 1 with the speeds from the Study 2 dance environment that was noted to have the highest number of said movements. In Study 1, dancers self-reported that the spinal extension movements like the arabesque can increase their low back pain. Yet previous studies have compared the execution of the arabesque movement between dancers with and without low back pain using detailed multi-segment motion capture and found little significant difference.[51,62] Therefore, research was needed to investigate why this type of movement may increase low back pain in any dance population, rather than differences in execution of the movement between pain and non-pain groups.

No previous studies have published research on speed and the arabesque movement, particularly as it relates to LBP. However, data from Study 2 showed that the tempo (speed) of movements varied within the performance environments. Therefore, Study 3 used an inertial sensor system to examine the possible effect of speed on the angular displacement, angular velocity, and angular acceleration of the lumbar and thoracic spine and gesture leg (foot) during the three spinal extension movements. It was hypothesized that as the tempo of the music (and thus the speed of the movement) increased, the angular velocity and angular acceleration would also increase, generating increased forces and increased angles (angular displacement) at the low back, and potentially causing an increased risk of impingement and pain.

Finally, the last chapter (Chapter 7) puts forth a discussion of the findings of these studies, as well as practical applications of this research for dance populations. The final chapter considers the limitations of this research, while also making suggestions for improving future research, and defines the ways in which this thesis has contributing to dance science as a field of research.

The aim and null hypothesis of each study are summarized below:

Study 1 (Chapter 4):

Aim: This study utilized a questionnaire to assess the impact and management of LBP in ballet, modern, and hip-hop dance populations.

Null hypothesis: Dancers are not affected by, and thus do not need to manage, LBP and there is no difference in any aspect of LBP severity or management amongst dance genres.

Study 2 (Chapter 5):

Aim: This study used archival footage from online video recordings to observe how many spinal, impact, and partnering movements dancers encounter in seven dance environments, with a focus on movements (as self-reported in Study 1) that increase LBP.

Null hypothesis: Dancers are not exposed to movements that increase LBP. The total number and frequency of each movement type, work times, and rest times are the same across dance environments.

Study 3 (Chapter 6):

Aim 1: This study investigated the impact of tempo (speed) on the joint angles, angular velocity, and angular acceleration of the thoracic and lumbar spinal segments during movements that cause the spine to extend within three different dance vocabularies: ballet, modern dance, and hip-hop.

Null hypothesis: There are no patterns of effect for speed on joint angles, angular velocity, and angular acceleration of the thoracic and lumbar spinal segments during spinal extension movements: piqué first arabesque, attitude with body roll, or dolphin dive movements.

4 Perceived Severity and Management of Low Back Pain in Adult Dancers in the United States (Study 1)

Part of this chapter has been previously published as a conference proceeding[95] and as a full study reference (Henn et al., 2022).[94]

Henn created the survey; Wyon gave feedback. Henn disseminated and processed the pilot study. Henn disseminated the full-scale study and processed the data with Wyon. Henn wrote most of the article, and feedback on the drafts were given by Ambegaonkar, Wyon, and Smith.

4.1 Introduction

The lack of consensus in the literature has made it clear that although LBP afflicts some dancers, the variety of reporting methods and study designs have prevented comparisons; a wider LBP prevalence has not been established. As identified in the literature review, studies on LBP in dancers use a variety of reporting methods to assess LBP. Self-report (e.g., questionnaires) and medical records were identified as two of the most common methods used to assess LBP in dancers. While participation bias exists for most injury surveys, obtaining self-reported accounts from participants is crucial to comprehensively examine the impact of a condition. Some studies have focused on tool validation for pain in dancers, using tools developed in other disciplines and applying them to dance populations. Dance-specific tools do not seem to have been developed yet. Many studies on LBP intensity note that they measured intensity, but do not always publish the mean, median, or pain scale, or they studied a non-dance population.

There were three objectives to this study: (1) to determine if LBP negatively impacts functioning of dancers' normal day-to-day activities/dancing, (2) to examine if dancers are managing their LBP through medical care-seeking behaviours, and (3) to examine if LBP severity, typical functions, and care-seeking behaviours differ by dance genre.

4.2 Method

4.2.1 Study design

Data were collected using the Online Surveys program (formerly BOS; Jisc, Bristol, United Kingdom); the survey content was custom-created based on current best practices and other questionnaires, as a dance-specific, LBP function and care-seeking questionnaire was unable to be located in the published literature. The online survey with 24 content questions (20 multiple choice, two rating scale, and two open-ended) was created to examine LBP history, impact, and management strategies (Appendix 4.1). There were five demographic questions asking for age, years dancing, country that they dance in, primary dance genre, and years dancing in their primary genre. The demographic questions enabled the researchers to screen for exclusion criteria. The primary dance genre question was multiple choice, and provided four options: ballet, modern, hip-hop, and other. Ballet and modern dance are popular genres at dance institutions, and hip-hop dance was included in an attempt to increase LBP research on this population, an issue identified in the literature review of this thesis.

Five questions examined dance exposure (engagement in a dance activity) and dance experience, asking for hours of dance per week during a normal week, hours of dance per week in the week preceding survey completion, maximum hours danced in a single day in the last four weeks, rest days per week in the last four weeks, and hours of rest during a normal day. There was one stress-related question that asked on a scale of 1-5, how stressed did the dancers feel on an average day. There were four LBP history questions that asked if they had LBP, where they perceived their LBP originated from if they had LBP, if their LBP limited their activities of daily living in the past four weeks, and if their LBP limited their dancing in the last four weeks. The MeSH definition of low back pain[143] was used, which defines LBP as an acute or chronic pain in the lumbar or sacral regions of the back. An anatomical diagram highlighting the area of pain was included as suggested by Dionne et al..[16] The recall timeframe for LBP in most questions was limited to four weeks to prevent recall bias.[16] As LBP tends to recur,[17-20] three questions were included to assess self-reported lifetime occurrence of LBP, despite the risk of recall bias.

There were three LBP coping strategy questions that asked if participants had ever sought professional help for LBP, how often in the last four weeks did they seek help for LBP, and if they had ever been diagnosed with LBP by a medical professional. And lastly, those who had experienced LBP were asked six questions about the impact of their LBP on their lives. Participants were asked if LBP is on their mind at least once per day, do they perceive their LBP to regularly inhibit their non-dance life, has their LBP inhibited their non-dance life in the last four weeks (open ended), how intense is their LBP on a scale of 0-10, have they received any diagnostic imaging related to LBP, and were there any dance movements that increased their LBP (open ended). Some questions were modified to assess dance-centric functions in addition to overall activities of daily living (ADL). ADL were defined as: ‘Day-to-day activities that are basic activities of everyday life and self-care, such as dressing yourself, walking, sleeping, standing, eating; in this case, everyday non-dance activities’.

4.2.2 Participants

Inclusion criteria were dancers from dance companies or university dance programs of any proficiency, including teachers, 18 years and above. Exclusion criteria were dancers younger than 18. Ethics permission was granted by the Institutional Review Board of the University of Wolverhampton (ethics approval code 16/19/EH1/UOW, Appendix 4.2). Participants completed an informed consent prior to beginning the survey. This informed the participants of the nature of the research, the ability to withdraw at any time, and confirmation they were 18 years of age or older.

4.2.3 Survey Pilot Testing for Validity

The content of the survey was validated using a pilot test. Advertisements were posted on a university dance group social media page on 27 April 2019, with a requested completion date of 10 May 2019. Participants anonymously accessed the survey via a hyperlink and were asked to complete the survey in full. Six participants completed the pilot study, with a median age of 29.6, a median of 25.8 years dancing, and a median of 12.8 years dancing in their primary dance genre (four modern, one hip-hop, one tap dance). No ballet dancers participated in the pilot study and the training load was relatively light (0-10 hours per week). After reviewing the survey responses to the pilot study, two questions (#10, #11) pertaining to rest had used unclear wording, with some respondents interpreting the question to include hours sleeping (i.e., 24 hours of rest). Thus, the language of these questions was updated to exclude sleeping for clarity. The pilot version of the survey was identical to the survey used in the larger study, except for the wording of questions 10 and 11.

4.2.4 Procedures

To assess a range of professional and student dancers and teachers, the survey was disseminated via Facebook, added to the electronic newsletter for the International Association of Dance Medicine & Science, and emailed to 150 university dance programs in the United States. The university contacts were encouraged to share the study with any local or affiliated dance companies to “snowball” participants, which is a survey technique of asking participants to share the survey with anyone they think fits the inclusion criteria of the study to receive more participants. Twenty-two of the dance programs confirmed they would share with their students, teachers, and nearby dance companies. Although “snowballing” participants increased the reach of the survey, the response rate is unknown. The survey was open for two months and sent out in two rounds: 20 May 2019 - 20 June 2019 and 16 August 2019 - 16 September 2019.

A second reminder email was sent out to the remaining dance programs who had not confirmed dissemination near the close of the survey.

After the first data extraction process, participants were removed whose primary location of dance activities was outside the United States (n=7) as these numbers were lower than the total numbers of United States respondents (n=290). The raw data were then transformed into a format appropriate for statistical processing (e.g., six years and three months = 6.25 years). Duplicates were removed by closely comparing possible matches between summer temporal data and fall temporal data for identical answers; one fall entry was removed as a result (final count was 289 participants). Some questions on the survey addressed participants with a history of LBP specifically and asked those participants without a history of LBP to skip these questions. Therefore, some questions were reported as percentages of total responses as opposed to percentage of total participants who responded.

4.2.5 Data Analyses

Data analyses were two-fold, as the survey recorded both quantitative and qualitative data. All quantitative data were processed in Jamovi.[144] First, all data were examined for normality using basic frequency analysis. Parametric tests (e.g., t-tests) were used if data were normally distributed. If data were not normally distributed, non-parametric tests (e.g., chi-square tests, Kruskal-Wallis, and Mann-Whitney U tests) were used as appropriate. T-tests were used to compare those with a history and those without LBP history. While the Bonferroni correction has its own limitations, a Bonferroni-adjusted alpha (α_B) of 0.004 was used to determine significance for all tests due to multiple comparisons being performed.

Qualitative data were compiled using the conventional content analysis (CCA) method described by Hsieh and Shannon.[145] For these open-ended questions, participants were encouraged to provide as much information as they wished. Codes were derived from the responses, compiled into categories, and the number of responses for each were tabulated. Participants could indicate multiple codes within one response. The questions were phrased as, “Has your low back pain inhibited other non-dance aspects of your life within the last four weeks specifically? Please tell us about your experiences,” and “Are there any dance movements that increase your low back pain?” The main variables of interest included history of LBP (frequencies), perceived source of LBP (frequencies), pain intensity (Likert scale 0-10), interfering with ADL (frequencies), interfering with dancing (frequencies), interfering with specific non-dance movements (open-ended, CCA), movements that exacerbate LBP (open-ended, CCA), care-seeking due to LBP (frequencies), and who the participants sought care from (frequencies).

4.2.6 Validity considerations

Some considerations in the validity of this study's design include having the survey open in two rounds, limiting the survey to United States' dancers, and participation bias. The survey was open for two time periods to increase completion, and results were carefully compared to ensure anyone who completed the survey twice had the duplicate entry removed. However, despite the concerted effort to avoid this error, it is possible that internal validity may be compromised in an unanticipated way. To increase external validity, the survey was limited to dancers based in the United States, as the low numbers of global participants would have compromised the external validity of the results; limiting the survey's reach post-data collection ensured that the results were valid for the population of study. Lastly, as detailed further in section 7.3, possible participation bias for dancers with LBP may pose a threat to validity, and it is a limitation of this study.

4.3 Results

4.3.1 Demographics

Twenty-two university dance programs and one dance company formally responded to the invitation to disseminate the survey to their dancers and teachers. All dance programs and the dance company were located in the United States. The median age of participants was 20 years of age (range: 18-69 years), with 219/289 (76%) participants aged 18-21 who completed the survey. Participants had a median of 16 years of overall dance training (range: 1-65 years) with a median of 10 years training in their primary dance genre (range: 1-55 years). Modern/contemporary dance was the most popular genre (172/289 participants, 59.5%), followed by ballet/classical dance (86/289 participants, 29.8%), other (23/289 participants, 8.0%), and hip-hop dance (8/289 participants, 2.8%). Dancers who selected 'other' listed multiple genres, genre fusions, or single genres. The genres included African, ballroom, belly dancing, drill team, flamenco, jazz, musical theatre, and tap. Hip-hop dance had only eight participants and was therefore combined into the category "other dance genre" to total 31/289 participants.

4.3.2 History of LBP

Participants reported an 88.9% (n=257/289) lifetime prevalence of at least one occurrence of LBP (Table 4.1). 32/289 participants (11.1%) reported no history of LBP. Of the participants that had LBP, 132/259* attributed their LBP as originating from dance (*two dancers indicated they did not have a history of LBP, but then indicated a source for their LBP, contradicting themselves), 28/259* indicated a non-dance source, and 99/259* were unsure where their LBP originated. Only 89/257 (30.8%) of dancers with LBP were diagnosed with LBP by a medical professional, compared to the 257 that self-reported having experienced LBP. Lifetime LBP, ADL-limiting LBP, dance-limiting LBP, and dance exposure were similar across dance genres (Table 4.2).

Table 4.1: Dancers with a history of low back pain by dance genre

Have you experienced low back pain before?	Primary dance genre: All genre totals	Modern / contemporary dance	Ballet / classical dance	Other
I do not have/have not had low back pain	**32** (11.1% of total)	17 (9.9% of modern dancers) (5.9% of total)	12 (14.0% of ballet dancers) (4.2% of total)	3 (9.7% of other dancers) (1.0% of total)
Yes, I have had pain in the dark grey shaded area of this image	**257** (88.9% of total)	155 (90.1% of modern dancers) (53.6% of total)	74 (86.0% of ballet dancers) (25.6% of total)	28 (90.3% of other dancers) (9.7% of total)

Table 4.2: Care-seeking among dancers with low back pain in a 4-week period

		Dancers with low back pain (LBP) that limited activities of daily living (ADL)			Dancers with low back pain (LBP) that limited dancing		
	Total # of dancers in genre	Number of dancers who reported LBP	Number of dancers with ADL limiting LBP	Number of dancers who sought care at least once	Number of dancers who reported LBP	Number of dancers with dance limiting LBP	Number of dancers who sought care at least once
Modern	172 (100%)	135 (78.5%)	43 (25.0%)	37 (21.5%)	129 (75.0%)	51 (29.7%)	36 (20.9%)
Ballet	86 (100%)	61 (70.9%)	22 (25.6%)	14 (16.3%)	61 (70.9%)	28 (32.6%)	14 (16.3%)
Other	31 (100%)	24 (77.4%)	7 (22.6%)	8 (25.8%)	23 (74.2%)	10 (32.3%)	8 (25.8%)
Total	**289 (100%)**	**220 (76.1%)**	**72 (24.9%)**	**59 (20.4%)**	**213 (73.7%)**	**89 (30.8%)**	**58 (20.1%)**

Abbreviations used:

- LBP = Low back pain
- ADL = Activities of daily living

4.3.3 *Impact of LBP*

In the four weeks preceding survey completion, 220/289 dancers (76.1%) responded that they experienced LBP, and 72/220 of these dancers expressed that their LBP inhibited their ADL and 89/220 reported their LBP limited their ability to participant in dance fully. Dance activity levels, including number of rest days taken, had no significant association with lifetime self-report of LBP, nor with negative impact of LBP on ADL or dancing ($p>0.004$ for all measures). Of the dancers that had experienced at least one episode of LBP in their lifetime, 137/270 participants (50.7%) noted their LBP was on their mind often, at least once per day. Almost as many, 111/270 dancers (41.1%), agreed with the statement that their LBP did inhibit their non-dance life regularly. Most dancers rated their average LBP intensity low (Figure 4.1), with the most reported pain intensity being two on an 11-point scale (n=270) between 0 (“no pain”) and 10 (“intense, debilitating pain”), with median pain intensity being four (IQR: 3.0). When comparing dance genres, modern dancers had a median pain intensity of four (IQR: 4.0), ballet dancers had a median pain intensity of three (IQR: 3.0), and ‘other’ dancers had a median pain intensity of three (IQR: 3.0).

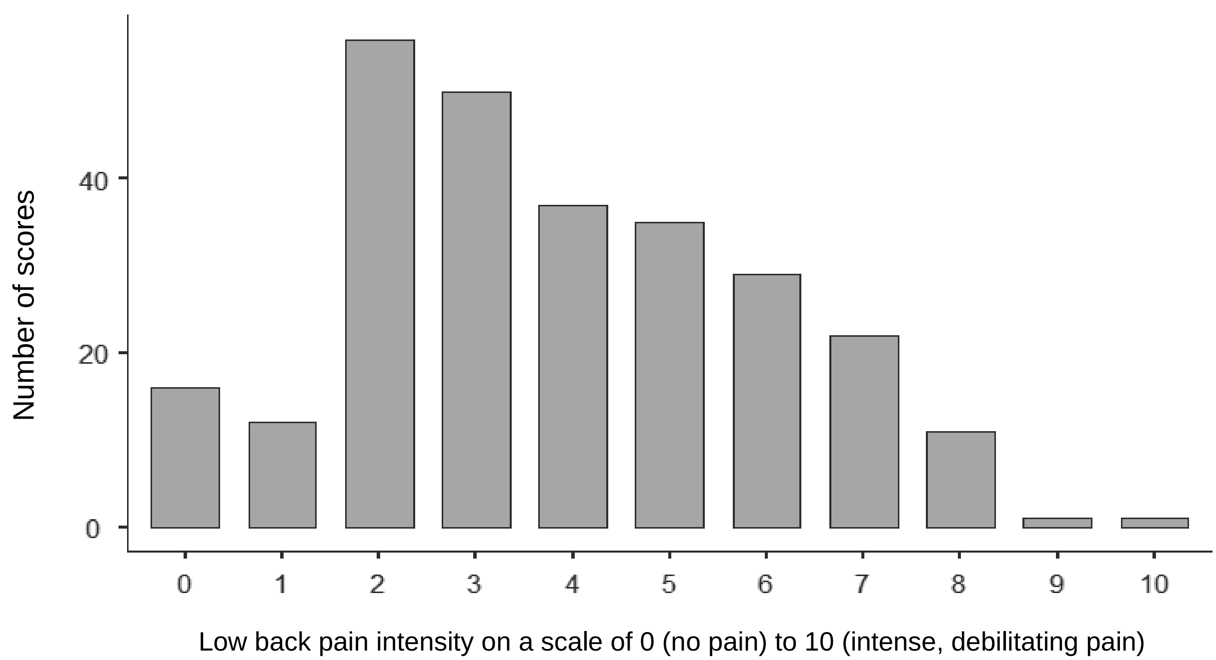


Figure 4.1: Frequency histogram of low back pain intensity for all dance genres, on a scale of 0 to 10

Derived from the open-ended responses, dancers reported that sitting, such as when driving a car, was the functional movement that was most inhibited by LBP (41/200 responses), followed by standing/walking (34/200 responses), and then prolonged lying down, such as when sleeping (20/200 responses) (Table 4.3). Responses from 130 modern dancers, 64 ballet dancers, and 21 other dancers indicated two categories of dance movements that increased their LBP: spinal movements and trunk stabilization when activated, loaded, or during impact. Dancers overwhelmingly reported that the most painful dance movements involved spinal extension, specifically arabesques and arching backwards (113/303 responses), followed by spinal flexion activities like curving forward or bending over (41/303 responses), spinal rotation (19/303 responses), and high kicks or lifting their leg (15/303 responses) (Table 4.3).

Table 4.3: Codes and categories for qualitative data assessing low back pain impact on function

Category	Codes
Staying in one position for prolonged time	driving, sitting walking, standing sleeping, laying down kneeling, gardening
General physical activity	working out, dance, yoga, house chores
Bending	squatting, getting up, getting dressed
Lifting heavy objects	carrying objects, bending to pick up objects
Spinal Movements while Dancing	spinal extension spinal flexion spinal rotation spinal lateral flexion
Stabilizing Trunk Through Various Loads while Dancing	when the leg moves into extreme range (high kicks, legwork, splits, *penché*) impact or interaction with the floor (“floorwork”) core and weight-bearing (crunches, flat backs, lifting, partnering, pelvic articulations)

4.3.4 Care-Seeking and Management of LBP

In the four weeks preceding survey completion, nearly all the dancers that sought help also had LBP in the same period (59/60). The dancers that sought help three or more times nearly always had LBP that limited their ADL (16/19) and their dancing (16/19). No trends emerged when examining medical care-seeking behaviours by dance genre (Table 4.2). Of the 257 total participants with a history of LBP, 90/257 (35.0%) had never sought medical assistance despite having had LBP and 171/257 (66.5%) sought care at least once in their lifetime. Median pain intensity for care-seekers was four (IQR: 3.75), indicating moderate pain on a 0-10 scale. Median pain intensity for dancers who had LBP but did not seek care was three (IQR: 3.00); pain intensity was higher for care seekers compared to non-care seekers, although it was not significant ($p=0.015$; $\alpha_B=0.004$). Dancers often visited more than one professional to manage their LBP, with 60/171 (35.1%) of care-seekers utilizing more than one professional in their lifetime. The most common method was a chiropractor, with 94/171 participants having seen a chiropractor for their LBP, 77/171 having seen a medical doctor, including sport-specific doctors, 60/171 having seen a physiotherapist, 36/171 having seen an acupuncturist or other alternative method, and 11/171 having listed a method not on the provided list of options, including professionals in the fields of Pilates, naprapathy, and massage.

4.4 Discussion

Study 1 attempted a large-scale online survey to determine LBP prevalence in dancers, as well as how LBP impacts non-dance daily activities and the dance careers of those with LBP. Initially, the survey was conducted to determine prevalence of this issue globally. Unfortunately, the results of the survey had limited global reach, and thus Study 1 shifted focus to dancers only in the United States. The survey was created utilizing best practices in the field of LBP questionnaire research. However, bias is inherent in prevalence questionnaire research, as those dancers afflicted with LBP were more likely to participate, and LBP prevalence data should be interpreted with caution. While Study 1 may not have solidified the prevalence of LBP in dancers, the study gathered valuable data on the impact of LBP from the dancers' perspectives.

4.4.1 Primary Findings

The primary findings of the current study were that most dance respondents had LBP. Dancers were limited in both dancing and non-dancing activities due to their LBP, especially during sustained activities. Furthermore, LBP was prevalent in dancers regardless of dance genre. While some dancers sought multiple professionals to care for their LBP, a third of the affected dancers did not seek care for their LBP at all. Pain intensity and loss of function may influence care-seeking behaviours for dancers with LBP.

4.4.2 Movements Inhibited by LBP

The participants described several functional movements that were inhibited due to their LBP. Basic movements, such as sitting, walking, standing, sleeping, and bending, were inhibited in the participants in the four weeks preceding the study. Non-dancers with LBP experience similar difficulties.[23,25] There was no difference in LBP rates between dance genres, suggesting that the movements themselves increase LBP, regardless of the aesthetic influence of any specific dance genre. Spinal extension movements increased LBP in dancers more than any other response. Other researchers examining pre-professional dancers found that regardless of LBP history, most dancers had negative back pain beliefs, and associated extreme spinal extension (backwards port de bras) with being dangerous to their back even if they themselves did not experience LBP.[29]

In the current study, several other specific movements were grouped into a trunk stabilization category, where movements such as high kicks or leg lifts (e.g., penchés), jumping, lifting, or partnering were noted by some of the participants to increase their LBP. Professional ballet dancers with LBP have been shown to have less trunk dampening[110] and collegiate dancers with LBP have shown reduced trunk muscle endurance[146] when compared to those without. Multiple factors likely contribute to LBP in dancers, including spinal flexibility, strength, and shape.[147] The spine is biomechanically complex; the nature and distribution of loads within the spine and associated structures can be challenging to study during dynamic human performance and there is still plenty of scope for spinal research to understand spinal function and injury-related aspects.[148]

4.4.3 LBP Management and Care-Seeking

Over a third of the participants who sought care for their LBP sought out more than one type of professional care provider, possibly practicing “health shopping”, where those afflicted seek second opinions from a variety of sources, as is seen in general LBP populations.[25] The United States does not have universal healthcare; individuals pay for medical treatment, sometimes subsidized by private insurance. As of 2010 under a provision of the Affordable Care Act, adult children may be ensured under a parent’s plan as a dependent until they are 26 years of age. Professional dancers, particularly part time or in small companies, do not always have medical insurance,[149] due to a multitude of factors outside the scope of this thesis. Cost may be a factor in care-seeking behaviours unique to countries that do not have universal healthcare, especially as recurring episodes of LBP tend to cost more and last longer than the first instance.[150] As someone with LBP ages, this financial impact may be compounded, with Schofield et al. finding that Australians who retired early due to their back problems accumulated less wealth.[24]

It is possible that dancers' beliefs about the nature of their LBP may have some implications as to their selection of care provider(s). A recent survey has suggested that stakeholders perceive that some dance education curricula may not be equipping dancers with high enough levels of health literacy.[151] Many participants in the current study did not seek help from any care providers at all, despite having LBP. Dancers who sought care for their LBP three times or more nearly always had LBP that limited their function in some way. Care-seeking for LBP in the general population follows a similar trend, where patients with LBP who are more disabled and in more pain tend to seek help more often.[152] Whether dancers with LBP will increase care-seeking due to loss of function is still unclear. Rehabilitating pain or injury in dancers before it becomes debilitating may be one method to decrease avoidance of professional care. Managing or rehabilitating minor injuries or pains before they intensify to negatively impact dancing and threaten dancer self-identity is crucial for life-long issues like LBP.

4.4.4 Low Back Pain Intensity

The median LBP values from the current study are similar to other LBP intensity studies on the general population (79% of participants had mean pain intensity of less than 49 out of 100 at baseline[32]) and in athletes (pain intensity 4.2±0.6 – 4.5±0.8 on an 11-point scale at baseline in older, male recreational ice hockey players[33]). While not much data exists on LBP intensity in dancers, the values in the current study are similar to a prior published study on LBP in pre-professional ballet and contemporary dancers[119] and an undergraduate thesis study on hip flexor extensibility and LBP.[34] Advanced jazz and ballet dancers reported average LBP intensities of 2.70±1.89 on a 0 to 10 scale across a dance class, with pain intensity values taken before, during, and after dancing. However, the situational differences may prevent an accurate comparison. Dancers' LBP median pain intensity in the current study was found to be higher in care-seekers than non-care-seekers, although this result was not significant under the Bonferroni correction. More research into LBP care-seeking in dancers is needed to validate pain intensity as an influence on care-seeking.

4.5 Conclusion

While these results cannot be overgeneralized outside of the study's participants, the negative impact of LBP on dancers may be substantial and prevalent, both inside and outside of the dance studio. Most dancers in the current study suffered from LBP with low to moderate pain intensity. Results were similar across ballet, modern dance, and combined 'other' dance genre categories. Dancers reported that both dance and non-dance activities that were limited by their LBP. To manage their LBP, 35.1% (60/171) of care-seeking dancers sought out multiple care professionals, while 35.0% (90/257) of afflicted participants did not seek care for their LBP at all. Dancers may thus be more prone to secondary negative long-term sequelae that may harm their dance careers. And finally, these participants were clear that spinal extension movements like the arabesque increased their LBP. However, no published research exists that quantifies how often dancers are asked to perform these movements. Therefore, Study 2 expands on Study 1 by reporting the number of spinal extension movements that ballet, modern, and hip-hop dancers are exposed to in class, performance, and non-proscenium dance environments.

5 Counts of spinal, impact, and partnering movements using video analysis of YouTube ballet, modern, and hip-hop dance videos (Study 2)

Part of this chapter has been previously published as a full study reference (Henn et al., 2023).[153]

Henn recorded data for all seven dance environments and trained research assistant, Lanza. Lanza recorded ballet performance data. Both reviewers discussed any discrepancies with one another. Henn wrote most of both articles, and feedback on the drafts were given by Ambegaonkar, Smith, and Wyon.

5.1 Introduction

Even with the difficulty presented by establishing prevalence of LBP in dancers, LBP still has substantial impact on dancers' daily lives and dancing. In Study 1, the survey queried dancer participants, "Are there any dance movements that increase your low back pain?". As detailed in Chapter 4 of this thesis, dancers with LBP self-reported that spinal movements (188/303 responses from 257 participants) increased their LBP. The spinal movements that most exacerbated LBP were spinal extension (113/188; arching backwards, arabesque), following by spinal flexion (41/188; forward Graham-like contractions, cambré forward), spinal rotation (19/188; spiralling, twisting), neutral spine hip hinge (8/188, flat back), and spinal lateral flexion (7/188). However, it was still unknown how often dancers encounter spinal dance movements that could increase their LBP.

After the dancers identified these movements, a search of the literature revealed that research had not been published on how often dancers perform these specific movements in a typical dance setting, such as a dance class. The timing of this research also coincided with the COVID-19 pandemic, which necessitated safe ways to continue researching during the pandemic lockdown. I began researching archival videos of dance classes and performances of ballet, modern, and hip-hop dance through the YouTube.com video database. My research assistant and I recorded the number of spinal, impact, and partnering movements, the movement dynamics, and the temporal metrics, such as time dancing or time resting.

Movement documentation and analysis is not a new concept neither in sport nor in dance. Researchers have documented sport performance using time-match analysis, which focuses on movements that have inherent intensities (standing, walking, running, sprinting) as a method of documenting movement.[154] Time-match analysis research involves setting up video recording device(s) to record the match, which is later analysed.[154] More recent studies utilise global positioning system (GPS) monitoring to achieve the same goal, although their use may be limited when monitoring high speeds over short distances.[155] Researchers can use video analysis to examine dancers in their familiar settings without the influence of wearable equipment or a change in environment. The ability to pause, rewind, and slow down movements within a video recording allows researchers to thoroughly analyse dance movements.

In dance science, researchers have previously analysed professional ballet[156,157] and contemporary[157] dancers by counting discrete skills (plies, jumps, supports, assisted lifts, and lifts), changes in direction, movement of the centre of gravity, and which body part(s) were involved in each movement. The number of dance movements within a given period may not always correlate to metabolic or cardiorespiratory demands because dance movement counts do not always account for the effort used to execute those movements. However, movement counts do provide an estimate of the demands required of the dancer and thus provide information that dancers and support staff can use to inform support plans and tailor classes or cross-training programs to meet the needs of their dancers.

Two additional methods that have been used to quantify the demands of dance during video analysis are work-to-rest (WTR) ratios and percentage time dancing. WTR ratio, also called exercise-to-rest ratio, is a method of documenting exercise demands. The WTR ratio is calculated by dividing the time a dancer is dancing by the time not dancing, expressed as a ratio. Researchers typically report these ratios as percentage work (50% work) or a numerical ratio (1:1 work time to rest time). The time dancing can also be expressed as a percentage of the total time of the dance class or performance. Different WTR ratios can utilize different physiological energy systems if the physical demand reaches a certain intensity threshold.[158] Identifying the WTR ratios that dancers encounter can approximate what systems they are training and whether the systems being trained in classes are the systems needed for performance.

Previous studies on WTR in dance examined class, rehearsal, and performance in both ballet[156] and modern dancers.[128,159] Twitchett et al[156] identified that corps de ballet and soloists dancers had more rest than work during performance, ranging from 1:1.4 to 1:3.3, with principal dancers having ratios of 1:1-1:1.3. Researchers comparing ballet and contemporary dance performance WTR ratios found ratios of 1.6:1 and 2.2:1, respectively.[157] Wyon et al[128] found that the WTR during performance placed more demands on the aerobic and anaerobic systems than during class, with WTR ratios ranging from 1:1.6 to 1:3. Overall, the WTR ratios of dance classes seem to have more rest than their performance counterparts, although some ballet ranks may have more rest than work during performance.[102,160] The suggested WTR in dance classes has been advised to be 1:3.[161] Previous video analysis studies have found an average dancing time of 62.19±13.91% for ballet performances and 68.97±15.78% for contemporary dance performances.[157] Female corps de ballet dancers have been found to have a lower percentage of their time dancing (~38%) than the male principal dancers (~44%).[156]

The role of dance genre in movement exposures was also unclear. Dance genres may differ in their spinal movement counts, causing the risk of low back pain to also differ. Spinal movement counts can thus inform dancers and support staff of elevated risk of LBP for dancers within certain genres and dance environments. Ballet and modern dance are popular genres at American universities, where it is common for dancers to take classes and perform in both dance genres simultaneously. However, previous video analysis research on ballet and modern dance populations did not include a more detailed categorization of the spine beyond 'trunk' and specific trunk movement counts were not reported.[156,157]

While hip-hop as a dance major is less common in American university settings, the label "hip-hop dance" comprises many dance genres that evolved from a social dance and street dance tradition.[162] Thus, an non-proscenium, street dance performance is a more realistic setting to study hip-hop dance in the United States. To date, there have been no studies published on any type of hip-hop movement counts in any dance environment. There have been no studies that have reported the incidence rate of specific dance movements that exacerbate LBP in any dance genre. By documenting the spinal movements (e.g., spinal extension), it is possible to begin quantifying how often dancers are exposed to these movements.

The objective of Study 2 was to measure the exposure (total number and frequency) of spinal, impact, and partnering movements in ballet, modern, and hip-hop dancers as a surrogate measure of LBP-associated movements. Sixty-five total videos were examined of dancers in class, performance, and, for hip-hop specifically, non-proscenium performance environments. The secondary objective was to quantify dance genre demands and identify whether different dance genres have different movement demands or WTR ratios. The goal was to determine if some dance genres or performance environments are more exposed to LBP-associated movements than others. Both a male principal ballet dancer and a female corps de ballet dancer were analysed because demands on ballet dancers during performance vary depending on rank and role.[102,160]

5.2 Method

5.2.1 Study design

Ethical approval was obtained from The University of Wolverhampton (ethics approval code: 06/21/EH/UOW, Appendix 4.2). Sixty-five dance videos uploaded to YouTube.com were analysed for dance movements within seven dance environments: ballet class and performance, modern dance class and performance, and hip-hop breaking, cyphers, and battles. A hip-hop cypher was defined as a large group of dancers with one performer dancing at a time. Hip-hop battles were defined as “1v1s”, where two dancers take turns dancing. Counts of spinal movements (spinal flexion, extension, lateral flexion, and rotation), impact movements (jumps, leaps, and falls), and partnering movements (lifts, catches, and leans) were recorded in a data collection tool.

Videos were screened between December 2020 and February 2021, which the users had uploaded to YouTube.com between 11 January 2009 and 2 October 2020. These dates do not reflect when the videos were initially recorded, only when the owner uploaded them to the YouTube website at a specific URL. Searches were conducted in English through YouTube’s search bar feature on a desktop computer. Ballet and modern dance videos only were filtered for “Video” (to eliminate playlists) and “Long >20 mins” (to eliminate partial videos, as most dance classes and performances in these genres are longer than 20 minutes). Hip-hop videos were not filtered by length of video in this way because non-proscenium performance environments do not have a standardized length of time that is typical of these styles.

YouTube saves search data[163] which can influence search results and inject bias, thus all searches were performed in a Microsoft Edge InPrivate web browser, with the addition of the DuckDuckGo Privacy Essentials browser extension that blocks tracking features on the websites visited,[164] and without being logged into a YouTube account (or parent company Google[165] account, now called Alphabet, Inc.). Because search algorithms can change over time and impair repeatability, a full list of the videos and URLs used in this study are provided in Appendix 5.1.

Videos were identified through the following search terms, searched in English:

- “ballet dance class full”
- “ballet dance performance full”
- “modern dance class full”
- “modern dance performance full”

- “hip-hop dance cypher”
- “hip-hop dance battle”
- “hip-hop dance breakdancing”

The search terms ‘hip-hop dance class’ and ‘hip-hop dance performance’ are not necessarily authentic to a street dance form. Instead, searches using the terms ‘breaking’, ‘cypher’, and ‘battle’ were used, more broadly categorized as ‘non-proscenium performance’ for processing. The term ‘non-proscenium’ was chosen to differentiate the hip-hop performance spaces from the proscenium stage performances of ballet and modern dance, even if the hip-hop dancers were performing in a stage space (e.g., large-scale battle exhibitions).

For the purposes of this research project, a cypher was categorized as a small group dance demonstration and a battle as a “1v1” or group versus group call-and-response dance demonstration. The term “breakdancing” is incorrect,[162] yet a preliminary search using “breaking” yielded only two relevant results out of the first 20. Therefore, the inaccurate yet more publicly familiar term “breakdancing” was used in searches. Although “hip-hop” can be spelled “hip hop”, preliminary comparison of YouTube results was consistent for both spellings, thus the hyphenated version was used in all search results for consistency. To address the study objectives, 65 total videos of dancers were analysed in class, performance, and, for hip-hop specifically, non-proscenium performance environments. Both a male principal ballet dancer and a female corps de ballet dancer were analysed in five ballet performance videos to comprise the ten total entries in the ballet performance category.

5.2.2 Exclusion criteria

In the YouTube video database, many dance videos are uploaded with specific purposes in mind for viewers, such as recreational exercising or learning specific dance moves, particularly for hip-hop genres. These videos were omitted because they do not represent a typical dance class or performance. Ballet or modern dance performances with over-stylized movements, such as the excessive forward flexion of the male principal role in the ballet *Petruska*, were also excluded. In class videos, the dancing of students was assessed; instructor dancing and explanation were not included. While the search was performed in English, videos were not excluded if the instructors or dancers in the video spoke a non-English language. Exclusion criteria can be found in Table 5.1.

Table 5.1: Exclusion criteria for YouTube.com search results of ballet, modern, and hip-hop dance videos for a movement count study

Partial or abbreviated classes or performances
Hip-hop dance that was not in a battle or cypher environment
Workout videos, movement tutorials, or documentaries
Classes or freestyle that state they will focus on specific elements (i.e., jump strengthening class)
Commercially broadcast dance reality television shows (i.e., *Dancing with the Stars*, *World of Dance*, *So You Think You Can Dance?*)
Videos that declared an intentional mixing of dance styles or whose genres did not match the search terms
Videos that covered identical content or identical dancers, to decrease content overlap
Significant visual challenges (i.e., poor video quality that hindered movement identification)
Dances that constituted applications for awards, degrees, or entry into dance programs

5.2.3 Data Extraction

5.2.3.1 Spinal, Impact and Partnering Movements

The first ten videos for each search term that met the criteria were screened in full, except the first five ballet performances videos, which were screened twice to document two different roles within the same repertoire. The video analysis process documented specific dance movements in 30 second increments within spinal, impact, and partnering movement categories. The method of recording movements within a dance video used here was based on the methods used by Twitchett et al.,[156] with the modification of identifying specific spinal movements. The time dancing was rounded to the nearest 30 second interval for ease of processing (e.g., 23 seconds of dancing would be rounded to 30 seconds).

Although the cervical and sacral vertebrae are part of the spine, they were not recorded as spinal movements unless the trunk was included. Épaulment (the slight tilting of the head and spine in ballet technique) and gestural movements (clapping or miming) were not recorded as spinal movement due to their frequency and negligible impact on total spine movement and subsequent LBP risk. The movement definitions can be found in Table 5.2. Each reviewer had more than 20 years dance experience, and therefore these movement definitions and decisions of movement quality were of our own making, derived from dance experience. Reviewers dialogued throughout the review process to ensure consistency in movement definitions. Movements that were part of the same “support” were chained together (e.g., developpé-arabesque-penché en pointe). The movement was considered a “new support” when the position of the supporter changed, or the dancers moved out of the support movement entirely.

Table 5.2: Movement definitions used to record spinal, impact, and partnering movement counts from ballet, modern, and hip-hop YouTube.com dance videos

Spinal Movements	**Extension**: measured above hips and below neck, spine moves into extension **Flexion**: measured above hips and below neck, spine moves into flexion **Rotation**: measured above hips and below neck, spine rotates to one side (indicated by hips and chest facing different angles) **Lateral Flexion**: measured above hips and below neck, the spine flexes to one side (indicated by a shorter distance between the ipsilateral hip and shoulder)
Impact Movements	**Jump**: typically stays in place; one foot to one foot, two feet to two feet **Leap**: typically traveling; one foot to the other foot **Fall**: a drop that moves from standing to the floor
Partnering Movements	**Lift**: Dancer A's entire body weight is moved by Dancer B so that Dancer A's feet/hands are off the ground or not bearing weight **Catch**: Dancer A is in motion towards Dancer B, who lifts them off the ground by catching their momentum, so that Dancer A's feet or hands are off the ground or not weight-bearing **Lean**: Dancer A maintains some weight-bearing in their feet/hands, while Dancer B accepts some of this weight.

In ballet and most modern dance classes, all students performed the same movements except for some "on your own" stretch time at the end of barre and minor sex variations in some ballet classes. Most instructors began repetitions on the right side, and all instructors required identical repetition on both the right and left sides. Therefore, both iterations were included, even if not shown in the video. In these instances, the first side was counted twice to account for a second side, assuming identical movements. In each performance piece, one dancer was observed, typically a principal or "main character" dancer. For ballet performances, one male principal and one female corps de ballet dancer was observed in five ballets, as previous researchers have identified the rates of back injuries to be highest in these roles.[102] Non-proscenium performance pieces had more equality amongst participating dancers, and thus the first dancer to perform was observed whose movements were clearly visible.

Two reviewers, myself (Erica D. Henn – EDH) and my research assistant, Samantha Lanza (SL), analysed all videos and collected spinal, impact, and partnering data. The video recording angles and close-ups caused some movements to be ambiguous. In these cases, the reviewers did their best to make reasonable assumptions of the movement using context clues and did not include movements that were unclear. All ballet class, modern dance, and hip-hop data were recorded by a single reviewer (EDH), with discrepancies or judgement calls mediated by a second reviewer (SL). The reviewers consulted one another for judgement calls approximately once per each video. Due to their substantial length, the two reviewers divided ballet performance data collection between them. The second reviewer (SL) was trained on movement definitions and assessed three of the ten ballet videos (4% of total videos screened) and mediated discrepancies across all categories.

5.2.3.2 Test-Retest Reliability

Although a previously published method for data collection was utilized, a reliability check was included to validate differences between reviewers and between reviewing sessions. The movement definitions were tested on 24 different dance videos. A primary reviewer (EDH) completed a test-retest procedure: three videos were screened twice, two weeks apart, in the eight possible movement categories (ballet class, ballet performance: male principal, ballet performance: female corps de ballet, modern dance class, modern dance performance, hip-hop breaking, hip-hop battle, hip-hop cypher). Approximate total movements ranged from 25 to 518 and time spent dancing ranged from 0.5 minutes to 99.5 minutes. The movement counts that differed ranged from 0/62 movements rated as different to 58/420 total movements rated as different. Percent difference was calculated for pieces with more than 50 total movements.

For dance pieces with 50 movements or less, differing counts were used to avoid inflated percent difference. A percent difference of 8% was typical for studies with more than 50 movements, and typically two movements different for studies with 50 movements or less. Two hip-hop breaking pieces had more movements different than the other dance genres (16/44 and 18/64 movements different), likely due to the speed and density of the movements in this dance style. For the secondary reviewer (SL), inter-reliability was tested for a male principal ballet dancer's performance that was 70.5 minutes in length. Both reviewers assessed this dance piece, and then met to discuss any differences that occurred. The number of differences was small; there were zero spinal differences, eight impact differences, and one partnering difference, making for nine total differences within 109 movements.

5.2.4 Data Analyses

A summary of outcome measures in the current study included: length of dance video, time dancing, rest time, WTR ratio, the number and length of dancing work intervals, counts of spinal (flexion, extension, lateral flexion, rotation), impact (jumps, leaps, and falls), and partnering (lifts, catches, and leans) movements, and movement dynamics (slow, medium, fast). All units of time were reported in minutes. All statistics were calculated using Jamovi[144] Version 1.6 (the Jamovi project, Sydney, Australia). Normality was determined using Shapiro-Wilk tests. Movement data were reported as totals, percentages, frequencies, ranges, means with standard deviations (SD), and medians with interquartile range (IQR) where appropriate. Significant differences were calculated using Mann-Whitney U tests for non-normal data. The WTR ratio was calculated by subtracting the time dancing from the entire length of the piece to obtain the time resting. The time dancing was then divided by the time resting to obtain the WTR ratio. The statistical program Jamovi performed a WTR ratio calculation for every dance piece, and then obtained the median with IQR (rather than performing one WTR ratio calculation on the median work and median rest reported). The WTR ratios were also expressed as a ratio of X:Y, where X represents work (time dancing), and Y represents rest (time resting/not dancing). One modern dance piece[166] had no rest time, and therefore it was not possible to calculate a WTR ratio for this dance piece.

5.2.5 Validity considerations

As mentioned previously, the use of videos created by dancers and dance teachers themselves in this study increased ecological validity, but may have decreased internal validity, as controlling for variables, such as dancer skill level, were reduced. Additional validity considerations include the subjective nature of this type of video analysis; data collection was completed by two different researchers, adding to the subjective complexity. However, inter- and intra-reliability measures were taken in an effort to increase confidence in repeatability. Additional steps were taken to eliminate search algorithm bias and increase internal validity. The URLs of the included videos were included as an appendix to facilitate repeatability and transparency, even as the internet and search engine algorithms change over time.

5.3 Results

A detailed account of all movement counts for each video analysed can be found in

Table 5.3. Video length ranged from three minutes and 12 seconds to two hours, 27 minutes, and 55 seconds (38.4±38.3, range: 138). Time dancing ranged from 30 seconds to 99 minutes and 30 seconds (18.1±21.4, range: 99). Out of the 20 combined ballet and modern dance class videos, 14 videos were uploaded March 2020 or later (during the time the COVID-19 pandemic hit the United States). Only one modern dance performance video and one hip-hop cypher video were uploaded March 2020 or later. Hip-hop cyphers were the shortest videos, while ballet performances were the longest. Ballet classes and modern dance classes were nearly the same length of time, but ballet dancers spent more time dancing during class than the modern dancers did (although these results were not statistically significant: $p=0.14$; Mann-Whitney U).

Movements are reported as Means±SD. Table 5.4 shows the average number of each movement category (e.g., spinal movements) and the average number of movements per minute for each of the seven dance environments. Table 5.5 shows the average number of each movement category separated by the individual movement subcategories (e.g., spinal extension). Table 5.6 shows the average number of movements per minute of dancing, separated by the individual movement subcategories.

Table 5.3: Spinal, impact, and partnering dance movement counts for each individual video included in a YouTube video analysis study on ballet, modern, and hip-hop dance classes and performances.

Dance environment	**URL**	**EXT**	**FLX**	**ROT**	**LF**	**Total S**	**Jump**	**Leap**	**Fall**	**Total I**	**Lift**	**Catch**	**Lean**	**Total P**
ballet dance class	https://www.youtube.com/watch?v=ZSIfgTOowYk	54	14	4	42	114	0	0	0	0	0	0	0	0
	https://www.youtube.com/watch?v=FySuVhmb-OY	92	6	6	36	140	108	6	0	114	0	0	0	0
	https://www.youtube.com/watch?v=kMwPoN7gw0E	67	10	4	44	125	88	3	0	91	0	0	0	0
	https://www.youtube.com/watch?v=e_veY_EdHys	12	2	0	6	20	0	0	0	0	0	0	0	0
	https://www.youtube.com/watch?v=FrISNpG0bZk	58	16	0	8	82	0	0	0	0	0	0	0	0
	https://www.youtube.com/watch?v=iuapa4DB6AE	74	10	4	32	120	40	0	0	40	0	0	0	0
	https://www.youtube.com/watch?v=RErBAfGZ7zc	44	16	10	24	94	0	0	0	0	0	0	0	0
	https://www.youtube.com/watch?v=KGN9O0NFyM0	60	18	10	55	143	100	0	0	100	0	0	0	0
	https://www.youtube.com/watch?v=hjBTf58Wto4	60	19	0	22	101	26	0	0	26	0	0	0	0
	https://www.youtube.com/watch?v=z45vQHbi9nc	84	12	18	44	158	36	2	0	38	0	0	0	0
ballet dance performance - male principal	https://www.youtube.com/watch?v=9rJoB7y6Ncs	57	4	40	7	108	70	49	0	119	23	7	50	80
	https://www.youtube.com/watch?v=g6eA4PjWhws	32	0	2	0	34	42	32	0	74	15	0	20	35
	https://www.youtube.com/watch?v=-hM0B70F1YM	194	52	41	52	339	176	48	7	231	57	43	33	133
	https://www.youtube.com/watch?v=kFZ8v5FfDd8	34	0	0	0	34	20	14	0	34	20	6	8	34
	https://www.youtube.com/watch?v=AmT4v4rDwHc	18	1	2	12	33	30	5	0	35	21	0	0	21
ballet dance performance - female corps de ballet	https://www.youtube.com/watch?v=9rJoB7y6Ncs	198	54	15	89	356	129	7	2	138	6	0	0	6
	https://www.youtube.com/watch?v=g6eA4PjWhws	58	0	7	1	66	82	16	0	98	14	0	0	14
	https://www.youtube.com/watch?v=-hM0B70F1YM	30	5	9	0	44	60	0	0	60	2	0	5	7
	https://www.youtube.com/watch?v=kFZ8v5FfDd8	123	4	3	18	148	90	14	0	104	9	0	3	12
	https://www.youtube.com/watch?v=AmT4v4rDwHc	21	11	10	13	55	44	1	0	45	2	0	1	3
modern dance class	https://www.youtube.com/watch?v=RRnD8o-KCJE	52	46	127	77	302	28	0	3	31	0	0	0	0
	https://www.youtube.com/watch?v=k7xDuQvMyVQ	60	146	45	106	357	35	18	0	53	0	0	0	0
	https://www.youtube.com/watch?v=gG68LBBzgFQ	11	97	54	69	231	0	0	0	0	0	0	0	0
	https://www.youtube.com/watch?v=42nmC31pV7g	26	62	59	74	221	32	0	0	32	0	0	0	0
	https://www.youtube.com/watch?v=-VK2hNMfetE	26	83	32	68	209	45	4	0	49	0	0	0	0
	https://www.youtube.com/watch?v=d_R47wSn3OI	35	202	104	104	445	20	8	0	28	0	0	0	0
	https://www.youtube.com/watch?v=tI1ZsA9_iZo	18	70	58	56	202	101	0	0	101	0	0	0	0
	https://www.youtube.com/watch?v=nbN6aVQQEhk	34	29	2	78	143	0	0	0	0	0	0	0	0
	https://www.youtube.com/watch?v=mFovPTvJPLY	68	113	103	71	355	32	28	2	62	0	0	0	0
	https://www.youtube.com/watch?v=5bG2AB9jCS4	40	38	12	35	125	14	0	0	14	0	0	0	0
modern dance performance	https://www.youtube.com/watch?v=veZdwbBqYNQ	7	35	14	26	82	0	0	1	1	0	0	1	1
	https://www.youtube.com/watch?v=N1ihBx32lpY	33	104	38	34	209	10	2	2	14	1	0	0	1
	https://www.youtube.com/watch?v=37fHJAocm24	8	31	60	37	136	0	0	0	0	0	0	0	0

	https://www.youtube.com/watch?v=OG4U_BJIzpI	96	53	25	51	225	69	6	1	76	37	11	7	55
	https://www.youtube.com/watch?v=RrPJ4kt3a64	180	173	30	110	493	16	0	0	16	1	0	2	3
	https://www.youtube.com/watch?v=-AEZg0NEQRk	42	110	56	84	292	11	2	1	14	10	0	9	19
	https://www.youtube.com/watch?v=JhJii7RkZD4	45	87	3	17	152	37	1	1	39	48	6	5	59
	https://www.youtube.com/watch?v=qSIddQNyYVE	64	119	36	106	325	26	0	3	29	17	9	28	54
	https://www.youtube.com/watch?v=0CGIltoq3Ms	32	21	7	43	103	0	0	0	0	0	0	7	7
	https://www.youtube.com/watch?v=VxP37djqmUg	17	31	17	20	85	4	0	4	8	1	0	0	1
hip-hop breaking	https://www.youtube.com/watch?v=-kT0HJhm5ck	7	20	11	14	52	5	0	3	8	2	0	0	2
	https://www.youtube.com/watch?v=QgGUrDV_8Kk	5	8	11	8	32	4	0	1	5	0	0	0	0
	https://www.youtube.com/watch?v=NFzJyJXWkeU	3	22	30	10	65	3	3	5	11	0	0	0	0
	https://www.youtube.com/watch?v=9tG-xwv0kw0	0	19	13	11	43	7	0	1	8	0	1	0	1
	https://www.youtube.com/watch?v=T1hydrnjWek	3	5	3	3	14	1	0	0	1	0	0	0	0
	https://www.youtube.com/watch?v=V5L6x_p2z7w	4	7	11	3	25	3	0	0	3	0	0	0	0
	https://www.youtube.com/watch?v=GmoCdid5P2E	4	14	28	6	52	8	1	1	10	0	0	0	0
	https://www.youtube.com/watch?v=Wce1hwpNx-A	1	18	37	10	66	15	0	7	22	0	0	0	0
	https://www.youtube.com/watch?v=8RB6675aq98	3	12	32	5	52	2	0	1	3	0	0	0	0
	https://www.youtube.com/watch?v=m0Ec8CTpiLU	5	19	18	7	49	9	0	3	12	0	0	1	1
hip-hop battles	https://www.youtube.com/watch?v=Weob1_d1TAY	8	0	7	4	19	4	0	0	4	0	0	0	0
	https://www.youtube.com/watch?v=0rOzeDr6d6g	5	12	9	18	44	0	0	0	0	0	0	0	0
	https://www.youtube.com/watch?v=IPXIqueuQNE	2	31	20	19	72	34	0	1	35	0	0	0	0
	https://www.youtube.com/watch?v=WGFS6FuZmzU	15	10	12	10	47	1	0	2	3	0	0	0	0
	https://www.youtube.com/watch?v=5jGFlNXYqIs	13	21	14	4	52	11	0	2	13	0	0	0	0
	https://www.youtube.com/watch?v=ljC5TxDqa88	9	13	7	2	31	5	0	0	5	0	0	0	0
	https://www.youtube.com/watch?v=MIqL8J6W5qw	8	14	12	8	42	7	0	0	7	0	0	0	0
	https://www.youtube.com/watch?v=GnKAGDYar2w	50	57	18	17	142	22	0	7	29	0	0	0	0
	https://www.youtube.com/watch?v=aTjzcPFLEYY	5	21	36	18	80	2	0	0	2	0	0	0	0
	https://www.youtube.com/watch?v=QmxiqtsKtcQ	6	15	25	9	55	11	0	1	12	0	0	0	0
hip-hop cyphers	https://www.youtube.com/watch?v=0YXxG0ZnUfs	0	3	2	1	6	11	0	0	11	0	0	0	0
	https://www.youtube.com/watch?v=Vz6HfBm4Dqw	0	0	2	1	3	0	0	0	0	0	0	0	0
	https://www.youtube.com/watch?v=M9Dhrxb-0Sw	1	4	5	4	14	0	0	0	0	0	0	0	0
	https://www.youtube.com/watch?v=GbEiGM9wpqc	4	10	12	3	29	18	0	1	19	0	0	0	0
	https://www.youtube.com/watch?v=b63ZqAL0MfI	2	0	3	2	7	0	0	0	0	0	0	0	0
	https://www.youtube.com/watch?v=2ue6MDrth84	1	4	9	3	17	5	1	0	6	0	0	0	0
	https://www.youtube.com/watch?v=_GKy5rea8wc	10	6	3	9	28	0	0	0	0	0	0	0	0
	https://www.youtube.com/watch?v=vqACeiawarg	2	15	41	10	68	35	0	0	35	0	0	0	0
	https://www.youtube.com/watch?v=zUyhR-Qnobw	0	3	0	2	5	1	0	0	1	0	0	0	0
	https://www.youtube.com/watch?v=xyIcS68qulA	1	4	3	1	9	9	0	1	10	0	0	0	0

Abbreviations are defined as follows: EXT: spinal extension movements; FLX: spinal flexion movements; ROT: spinal rotation movements; LF: spinal lateral flexion movements; Total S: the total count of spinal movements (the combination of EXT, FLX, ROT, and LF movement counts); Total I: the total count of impact movements (the combination of jump, leap, and fall movements); Total P: the total count of partnering movements (the combination of lift, catch, and lean movements).

Table 5.4: Average counts and movements per minute of dancing across classes and performances of three dance genres

Dance Genre	Activity	Average Length of Dance (mins)	Average Time Dancing (mins)	Average spinal movement counts in one environment	Average impact movement counts in one environment	Average partnering movement counts in one environment	Average spinal movements per minute dancing	Average impact movements per minute dancing	Average partnering movements per minute dancing
Ballet	Class	56.3 ± 15.0	39.6 ± 24.0	110 ± 39.2	41 ± 45.1	0	4 ± 1.3	1 ± 1.4	0
	Performance	96.3 ± 44.4	46.8 ± 35.7	122 ± 125	**94 ± 60.1**	**35 ± 41.4**	3 ± 1.5	3 ± 1.0	**1 ± 1.0**
Modern	Class	57.1 ± 31.5	23.6 ± 10.7	**259 ± 103**	37 ± 30.8	0	12 ± 2.7	2 ± 1.4	0
	Performance	37.1 ± 15.9	22.3 ± 7.54	210 ± 130	20 ± 23.5	20 ± 25.5	10 ± 6.1	1 ± 0.8	1 ± 0.9
Hip-Hop	Breaking	7.5 ± 4.3	1.35 ± 0.7	45 ± 16.8	8 ± 6.07	0.4 ± 0.7	**36 ± 10.3**	6 ± 2.1	0.3 ± 0.5
	Battle	8.3 ± 6.1	2.30 ± 0.9	58 ± 34.3	11 ± 11.9	0	28 ± 23.8	5 ± 5.8	0
	Cypher	5.8 ± 3.1	0.950 ± 0.9	19 ± 19.6	8 ± 11.4	0	21 ± 15.7	**10 ± 12.9**	0

Note: Bold indicates highest values for that category of movement.

Table 5.5: Average movement count data from a video analysis of classes and performances of three dance genres

Dance Genre	Activity	Spinal Extension	Spinal Flexion	Spinal Rotation	Spinal Lateral Flexion	Jumps	Leaps	Falls	Lifts	Catches	Leans
Ballet	Class	61±22.2	12±5.4	6±5.7	31±16.1	408±43.6	1±2.0	0	0	0	0
	Performance	**77±69.8**	13±21.3	13±15.2	19±29.1	**74±48.0**	**19±18.2**	1±2.2	**17±16.0**	**6±13.4**	**12±17.2**
Modern	Class	37±18.3	**89±53.6**	**60±40.8**	**74±20.7**	31±28.8	6±9.7	1±1.1	0	0	0
	Performance	52±52.2	76±50.1	29±19.3	53±34.7	17±21.9	1±1.9	1±1.3	125±17.5	3±4.4	6±8.5
Hip-Hop	Breaking	4±2.0	14±6.1	19±11.4	8±3.6	6±4.2	0.4±0.9	**2±2.3**	0.2±0.6	0.1±0.3	0.1±0.3
	Battle	12±13.9	19±15.5	16±9.1	11±6.6	10±10.7	0	1±2.2	0	0	0
	Cypher	2±3.0	5±4.6	8±12.1	4±3.3	8±11.3	0.1±0.3	0.2±0.4	0	0	0

Note: Bold indicates highest values for that category of movement.

Table 5.6: Average number of dance movements per minute from a video analysis of classes and performances of three dance genres

Dance Genre	Activity	Spinal Extensions per Min	Spinal Flexion per Min	Spinal Rotation per Min	Spinal Lateral Flexion per Min	Jumps per Min	Leaps per Min	Falls per Min	Lifts per Min	Catches per Min	Leans per Min
Ballet	Class	2±0.7	0.4±0.2	0. 2±0.2	1±0.5	1±1.3	0.0±0.1	0	0	0	0
	Performance	2±1.0	0.3±0.3	0.3±0.3	0.5±0.5	2±0.9	**0.5±0.4**	0.0±0.1	**0. 7±0.8**	**0.1±0.223**	**0.3±0.3**
Modern	Class	2±0.8	4±1.4	3±1.5	4±1.5	1±1.4	0.2±0.3	0.02±0.01	0	0	0
	Performance	2±2.6	3±2.3	1±0.9	2±1.4	0.7±0.8	0.0±0.1	0.1±0.1	0.4±0.7	0.1±0.2	0.2±0.3
Hip-Hop	Breaking	3±2.5	**12±3.9**	**15±7.9**	**6±2.6**	4±1.8	0.3±0.6	**1. ±1.1**	0.1±0.4	0.1±0.3	0.1±0.2
	Battle	**7±9.6**	9±10.4	7±2.5	5±3.7	4±4.6	0	0.7±1.4	0	0	0
	Cypher	3±3.3	6±5.7	8±7.6	4±2.3	**10±12.2**	0.2±0.6	0.4±0.8	0	0	0

Note: Bold indicates highest values for that category of movement.

5.3.1 Spinal Movements

Modern dance class and performance had the highest spinal movements per dance piece, with ballet having half as many and hip-hop having a quarter (Table 5.4). When spinal movements were separated into subcategories (Table 5.5), modern class and performance had the highest number of spinal flexion movements (89±53.6 and 76±50.1, respectively), spinal rotation movements (60±40.8 and 29±19.3), and spinal lateral flexion movements (74±20.7 and 53±34.7). However, ballet class and performance had the highest number of spinal extension movements (61±22.2 and 77±69.8, respectively), likely due to the frequency of arabesque and cambré derrière movements. Hip-hop battles had the most frequent spinal extensions per minute (7±9.6) and modern dance class had the lowest (2±0.8). Breaking had the highest number of spinal flexion movements per minute (12±3.9), spinal rotation movements per minute (15±7.9), and spinal lateral flexion movements per minute (6±2.6).

5.3.2 Impact Movements

Ballet performances also had the highest number of impact movements (94±60.1), having many more jumps and leaps than any other dance environment studied. Hip-hop breaking had the highest number of falling movements (2±2.3), followed by hip-hop battles (1±2.2) and modern dance performances (1±1.3), although the total number of falling movements was low overall. Hip-hop dance cyphers had the most frequent jumps per minute (10±12.2). Ballet performance has the most frequent leaps per minute (0.5±0.4). Breaking had the highest number of falls per minute (1±1.1).

5.3.3 Partnering Movements

Only three dance environments had consistent partnering movements throughout their videos: ballet performances had the highest (35±41.4), followed by modern dance performances (20±25.5), and then breaking (0.4±0.7). Lifts were the most common form of partnering. The male principal and female corps de ballet roles were observed in five full length ballets, comprising the ten ballet performance data points. There were statistically significant differences in total partnering movements between the two roles (p=0.01; Mann-Whitney U) and lifts (p=0.01), as well as non-significant differences in catches (p=0.07), and leans (p=0.09). Ballet performance had the most frequent lifts per minute (0.7±0.8), catches per minute (0.1±0.2), and leans per minute (0.3±0.3).

5.3.4 Quantifying Genre Demands and Differences

For the genres in aggregate, ballet and modern dance had WTR ratios of approximately 1:1, meaning for every minute of dancing there was one minute of rest (Table 5.7). Hip-hop dance had WTR ratios of approximately 1:3.4, meaning there was more rest time than time dancing. There was a statistically significant difference between ballet and hip-hop median WTR ratios (p<.001; Mann-Whitney U) and modern dance and hip-hop median WTR ratios (p<.001; Mann-Whitney U). There was not a statistically significant difference between ballet and modern dance WTR ratios (p=.71; Mann-Whitney U).

Table 5.7: Work-to-rest ratios for ballet, modern, and hip-hop dance environments: ballet and modern class and performance, and hip-hop breaking, cyphers, and battles

		Median WTR decimal [IQR]	**Median WTR Ratio**
Ballet	Aggregate	0.996 [1.26]	1 to 1.0
	Class	1.61 [1.08]	1.6 to 1 **†**
	Performance	0.900 [1.19]	1 to 1.1
Modern	Aggregate	1.04 [1.11]	1.0 to 1
	Class	0.933 [1.20]	1 to 1.1
	Performance	1.27 [1.05]	1.3 to 1 **†**
Hip-hop	Aggregate	0.29 [0.357]	1 to 3.4
	Breaking	0.258 [0.357]	1 to 3.9
	Cyphers	0.143 [0.181]	1 to 7.0
	Battles	0.583 [0.616]	1 to 1.7

Those environments whose work-to-rest ratio represent more work than rest are highlighted by **†**.

WTR ratios were 1:4.5 for breaking, 1:5.1 for cyphers, and 1:2.6 for battles. Hip-hop dancers spent less time dancing overall, with statistically significantly shorter times dancing than ballet (p<0.001; Mann-Whitney U) or modern dance (p=0.001; Mann-Whitney U). The “question and answer” format in hip-hop breaking, battle, and cypher environments utilized short intervals of dancing. Hip-hop dancers had shorter total rest times than modern (p<0.001; Mann-Whitney U) or ballet dancers (p<0.001; Mann-Whitney U), especially in battle formats. During 1v1 battles, dancers only had the duration of their opponent’s dancing to rest, typically 30 seconds. Cypher formats or team battles, as seen in some breaking videos, allowed for more individual rest time since there were multiple people who took turns dancing.

Contrastingly, ballet and modern dancers had longer periods of dancing, but often had more time to rest in between. In ballet performance pieces, the male principal mean WTR ratio was 0.7±0.6 minutes with a median of 0.4 and female corps de ballet mean WTR ratio was 2.5±2.8 minutes with a median of 0.9, although the difference in medians was not statistically significant (p=.31; Mann-Whitney U). The median number of dance intervals and the median length of the intervals are reported in Table 5.8. Both ballet and modern dance classes had more intervals (H(1)=8.5, p=0.004 and H(1)=5.3, p=0.02, respectively) and shorter intervals (H(1)=3.9, p=0.05 and H(1)=3.9, p=0.05, respectively) as compared to ballet and modern dance performance.

Table 5.8: Median values (interquartile range) for work and rest results from video analysis of 40 ballet and modern classes and performances (10 videos each)

Outcome Measure	Genre	Class	Performance	Kruskal-Wallis Test Statistic and P value	
Time Dancing (min)	Ballet	30.3 (7.1)	31.8 (56.1)	H(1)=0.1	0.7
	Modern	23.0 (16.3)	23.3 (7.4)	H(1)=0.01	0.9
Rest time (min)	Ballet	21.0 (23.6)	39.8 (42.6)	H(1)=2.3	0.1
	Modern	34.8 (18.9)	14.0 (17.5)	H(1)=4.6	0.03*
Work/Rest ratio	Ballet	1.6 (1.1) 1.6:1	0.900 (1.2) 1:1.1	H(1)=1.0	0.3
	Modern	0.9 (1.2) 1:1.1	1.3 (1.1) 1.3:1	H(1)=1.5	0.2
Number of intervals	Ballet	16.5 (9.0)	5.5 (2.0)	H(1)=8.5	0.004*
	Modern	11.0 (9.8)	4.0 (2.3)	H(1)=5.3	0.02*
Interval Length (min)	Ballet	1.5 (0.4)	1.9 (0.9)	H(1)=3.9	0.05*
	Modern	1.3 (0.5)	4.5 (2.4)	H(1)=3.9	0.05*

** Indicates a significant difference, α=0.05*

5.4 Discussion

Spinal extension movements ranged from just under two per minute for modern dance classes to as high as almost seven per minute for hip-hop battles (2±0.8 and 7±9.6, respectively). For those afflicted with low back pain, frequently executing spinal extensions at minimum every 30 seconds is not inconsequential. The results of the current study show that the movement counts, and thus the demands of each genre and dance environment, are not the same. And while the differences between ballet, modern, and hip-hop dance repertoire may seem self-evident in their stylistic differences, these perceived differences were able to be quantified using movement counts.

5.4.1 Spinal Movements

The current study was the first to examine the number of spinal movements in different dance genres. Thus, direct comparison with other prior movement counts was not possible. Additionally, no published studies were found on the relationship between spinal movement counts and LBP or injury. Because there is little research on movement frequencies in dance, the link between movements and injury can only be theorized at this time. Specifically, it can be hypothesized that an increased number of spinal extension movements would likely increase a dancer's risk of a LBP complaint, based on the following (Figure 5.1). The lifetime prevalence of LBP in dancers reported in literature reviews suggests dancers are likely to experience this condition.[12,93] Dancers have reported spinal extension movements as increasing their LBP,[94] and they can develop negative back pain beliefs around extension movements even if the dancers have not experienced LBP themselves.[32]

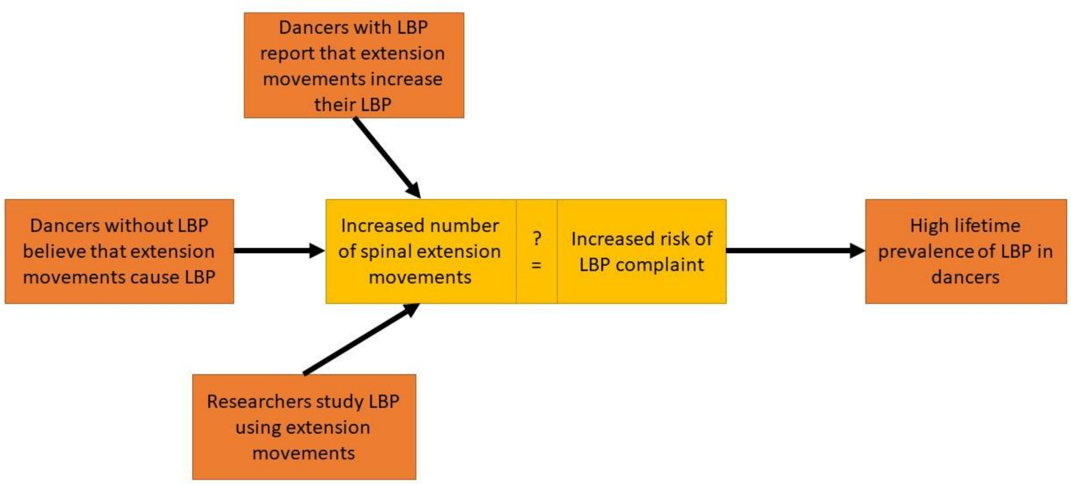


Figure 5.1: Rationale to support the hypothesis that increasing number of spinal extension movements would likely increase a dancer's risk of a low back pain (LBP) complaint

The repeated microtrauma and compression that occurs during extension movements[167-169] are likely contributors to LBP in dancers,[170] and thus increasing the number of these movements that dancers are exposed to would probably increase their risk of LBP. More research is needed to definitively conclude this theory. If this hypothesis is accepted, then the current study findings would suggest that genres like ballet performance and breaking may be at a higher risk of LBP due to their high total number and frequent spinal extension movements, respectively. However, duration and speed of the movements may affect number of movements as a risk factor for LBP. For example, hip-hop battle dancers danced for shorter durations before resting than ballet performers. The shorter duration may allow the dancers more recovery time and result in less fatigue.

There is no published literature examining the effects of these factors on LBP in hip-hop dancers. Still, the reports of injury rates of LBP and low back injuries in hip-hop and ballet dancers from the literature review of this thesis suggest hip hop dancers are at increased risk for both, at least in comparison to modern dancers. The frequency and speed at which the extension movements are performed may also play a role as they do in flexion movements,[171,172] but extension movements are understudied to date. While the relationship between frequency of movements and LBP or injury can only be speculated at this time, these findings suggest that dancers are performing movements that may increase their LBP often (~2-7 extension movements per minute of dancing), and that this frequency varies depending on dance genre and dance environment.

5.4.2 Impact Movements

Researchers have previously quantified impact movements for ballet and modern dance genres. A study that examined movement counts in contemporary dance performance had more than double the average jumps per minute (1.7±2.2)[157] than the current study (0.7±0.8). Twitchett et al.[156] found that male principals averaged four jumps per minute and female corps de ballet averaged six jumps per minute during classical ballet performances. The current study found mean±SD for both sexes to be 2±1.1 and 2±1.0 jumps per minute for male principal and female corps, respectively. However, the current study separated leaps and jumps, with male principals averaging 1±0.3 leaps per minute and female corps de ballet averaging 0.2±0.2 leaps per minute. In support of the current study's findings, researchers who completed a literature review examining activity demands and physiological responses in professional ballet dancers found that males and females jumped at similar rates.[173]

5.4.3 Partnering Movements

A comparison of ballet performance partnering data revealed that the lifts per minute, catches per minute, and leans per minute in the current study were lower than the results from other similar studies.[156,157] The discrepancy among the current findings and prior observations could be due to differing movement definitions, the dance repertoire analysed, or the subjective nature of this type of analysis. One study[157] that analysed contemporary dance performance had less partnering movements per minute on average, but used slightly different partnering movement definitions (lifts: 0.1±0.2, assisted lifts: 0.02±0.1, and supports: 0.1±0.2) when compared to the current study. Published literature on hip-hop movement counts was unable to be located. Lastly, it can be surmised that the partnering movements during ballet performances are infrequent but still present, with the current study calculating that total partnering movements approximate occur once per minute (1±1.0).

Both ballet and modern dance genres had partnering in performance environments and none in class environments. The lack of partnering in classes could have occurred for two reasons: class is not where dancers are trained in partnering movements or YouTube videos do not represent a traditional in-person dance class where partnering would be inherent. If dancers are not learning partnering skills in class, it is assumed that either partnering-specific classes or rehearsal time would be used to fill this gap. However, logistically it may be a challenge for some studios or schools to hold partnering classes. Limited published literature (academic or otherwise) exists describing the number or type of institutions that offer partnering-specific dance classes or contact improvisation/weight-sharing classes. If dancers do not train partnering skills in class, then theoretically, they can use rehearsal to train these movements. However, we were unable to identify video analysis of movement counts in rehearsals, and data on how much rehearsal time is spent training partnering skills would be required to make a definitive conclusion. Further research into partnering exposure is needed to determine where dancers are learning and practicing their partnering skills, and if the amount of partnering practice time is sufficient.

5.4.4 Quantifying Genre Demands and Differences

5.4.4.1 Work-to-Rest Ratios

In the current study, the median percentage dancing was lower in male principals (29.1%) than female corps de ballet (47.5%), respectively. However, the performances themselves may account for this difference, as each ballet performance has its own story, roles, and choreography. In a recent literature review[173] comparing activity demands and physiological responses across professional ballet studies, WTR ratios ranged from 1:1.6 and 1:3.4 during specific performance variations, higher than the current study's findings of 1:1 for ballet performances. WTR ratios in the current study were lower than the performance ratios identified previously. Wyon et al.[157] used a similar methodology to the current study, and found a lower percentage dancing for ballet dancers (~62%) than contemporary dancers (~69%) during performance. The trend of ballet dancers having a lower percentage dancing than modern dancers is supported by the current study's findings for percentage dancing during ballet (47.4%) and modern dance (57.2%) performances.

Furthermore, in the current study, ballet class had more work than rest when compared to ballet performance. Previous studies have shown that the time dancing is at a higher intensity during ballet performance[156] with more time spent in the aerobic training heart rate zone, an intensity that is not matched in class.[128] WTR ratios do not account for effort or intensity, but do provide a measure of recovery time in comparison to work time. Therefore, WTR ratios may serve as a general guideline, but should not be the only metric used to measure demand, as WTR ratios do not consider the variability of effort during the work phases.

The current study's results are also in agreement with previous researchers' suggestions that ballet and modern dance are intermittent exercise.[174] Ballet and modern dance class have structured rest periods, especially for novice dancers. During these periods, the instructor takes time to correct the dancers' technique.[159] In the current study, classes for both genres had more intervals and shorter intervals compared to performance. Because difficulty was not controlled for in the current study, the WTR ratio may have less rest during class for expert dancers. Future studies may consider stratifying work and rest based on dance proficiency to account for the increased rest during class corrections or novice dancers.

Modern dance does not have the same standardized movement vocabulary as seen in ballet. Therefore, a modern dance instructor may require more time to explain dance combinations than a ballet instructor would need. More explanation in between class combinations may result in more instructional time when the dancer is still learning the movement or skill but is physically at rest. However, Batson[175] suggests a link between repetition without rest and overuse injuries in dancers and Batson recommends that any interval of rest can be beneficial in learning complex motor sequences.

Modern dance classes had more rest than performance (WTR ratio close to 1:1), similar to prior work.[174] The current study's findings are in support of preceding suggestions that dance classes do not elicit cardiovascular adaption.[174] Conversely, dance performances may elicit a training response,[176,177] possibly due to the dancers working at increased intensities and working for longer times before rest. If the main goal of a dance class is to prepare a dancer through skill development[159,174,178] and motor learning, rather than acclimating to the fitness demands, more rest may be beneficial and supplemental training may be required for physical adaptation.[128,161,174] However, if the goal of the dance class is to prepare dancers through fitness development without additional supplemental training, then existing research, including Study 2 of this thesis, suggests that the current structures of the dance class do not meet this goal.[128,161]

Previous researchers examining the demands of breakers[179] and pre-choreographed street dance[180] have found breaking and street dance to tax the dancer's cardiovascular system and metabolism. The high number of movements within 30 second intervals of hip-hop breaking and battles found in the current study seem to support the demanding nature of hip-hop dance. However, in the study with Brazilian dancers,[180] the dancers performed the same movements for a sustained amount of time, which may be more representative of (Los Angeles) L.A. style hip-hop, where the dancers are more choreographed and not as improvisational. Researchers in another study found new style hip-hop females to have lower volume of oxygen demands, similar to theatrical dance styles.[179] In the current study, hip-hop cyphers had less spinal movements and those movements were performed less frequently than the other two genres, and may be representative of new style hip-hop.

5.4.4.2 Sex Role Differences

Ballet often has fixed choreography within its classical repertoire and the movements will differ based on the sex of the role and the rank of the dancer. A typical ballet class will have less rank differences, but often some sex differences, such as having male dancers perform a tour jump instead of a developpé.[181] The current study reported differences in movement demands between the different ballet sex or ranks. However, the data show that the variations were not always consistent in direction. For example, the male principal dancer in the *Swan Lake*[182] ballet completed 57 spinal extension movements, whilst a female corps dancer completed 198 spinal extension movements. Yet this ratio is nearly reversed in the ballet *Romeo & Juliet,*[183] where the male principal performed 194 spinal extension movements and the female corps performed 30 spinal extension movements. Repertoire has a marked influence on the movements and workload of the dancer. A previous study examined the work and rest periods for professional ballet dancers by sex and rank, and found that sex alone did not have significance, but rank and sex by rank did, with females spending more time at a vigorous activity level than male counterparts.[184]

In contrast, modern dance rejects the hierarchical rank system of ballet and sex-neutral dance roles are a hallmark of this genre. In many classical modern dance techniques, movements attempt to be sex neutral. However, roles separated by sex do occur in some performances, especially as a form of social commentary. In the current study, there are at least two examples of modern dance performances that had clear sex roles: Alvin Ailey's *Revelations*[185] and MN Dance Company's *S/HE*.[186] Lastly, hip-hop dance can include both males and females, although clear roles were not identified in the observations of the current study. The majority of breaking dance videos analysed in this study had male dancers or male groups, with the exception of an all-female Red Bull BC One[187] competition. Similarly, the cypher groups and hip-hop battles analysed in this study were male dominated but did have females present and participating.

5.5 Conclusions

Movement demands differed by dance genre, which agreed with previous studies that measured demand using other methods. Aggregate work-to-rest ratios were 1:1 for ballet and modern dance, compared to 1:3.4 for hip-hop dance. Ballet dance class and modern dance performances had increased work-to-rest ratios when compared to their performance and class counterparts, with modern dance class having significantly increased rest compared to performance. Both ballet and modern dance classes had more intervals and shorter intervals than performance. Ballet and modern dance educators can consider increasing the number of movements in a row without rest during classes to prepare for the longer and less frequent intervals seen during performance. Ballet dancers are likely to experience more impact movements (jumps, leaps, or falls) during performance. There were also differences in the movement counts between male principal and female corps de ballet dancers, suggesting that movement demands differ based on rank or role within performance.

The current study found that there are clear differences in movement counts between ballet, modern, and hip-hop dance. Overall, modern dance class had the most total spinal movements, and ballet performance had the most total impact and partnering movements. Dancers can expect to be exposed to movements that may increase their LBP in the seven dance environments studied here. Spinal extension movements were frequent across all three dance genres, ranging from ~2-7 spinal extension movements per minute, with the highest rate seen during hip-hop battles. The average number of total spinal extension movements within one performance setting ranged from 4±2.0 (breaking) to 77±69.8 (ballet performance) movements, with average number of total spinal movements ranging from 19±19.6 (hip-hop cypher) to an astounding 259±103 (modern dance class) movements. Because ballet, modern, and hip-hop dancers seem to be exposed to high numbers of spinal extension movements, the third and final study investigated what biomechanical aspects of performing these types of movements may contribute to LBP link reported by dancers in Study 1.

6 Using motion capture to examine the effect of speed on spinal extension dance movements (Study 3)

Henn wrote the procedure, with Smith (TS) supervising. Henn recorded participant data using the motion capture equipment for the two pilot participants and one case study participant (ballet). Wyon recorded participant data for the case study participant (modern, hip-hop). Smith assisted with training on equipment, creating the model, filtering the motion capture data. Behraznia (MB) and Till (JT) assisted with pilot study data collection. Abadiotakis (AA) wrote the copy/paste macro, with Abadiotakis and Henn testing its efficacy. Henn processed the data, with Smith overseeing. Henn wrote this thesis chapter, and feedback on the drafts were given by Ambegaonkar, Smith, and Wyon.

6.1 Introduction

Study 2 (Chapter 5) benchmarked how frequently dancers are exposed to spinal extension movements that could increase their LBP and identified the dance environments that present the most risk. The next logical step was to assess what, in relation to the spinal extension movements identified in Study 1 (Chapter 4), may increase LBP, within the context of frequent movements and at-risk environments identified in Study 2. Therefore, Study 3 used motion capture technology to examine spinal extension movements from ballet, modern dance, and hip-hop performance repertoires.

The two previous studies in this thesis have identified 1) the types of movements that dancers complain increase their LBP and 2) the frequency with which ballet, modern, and hip-hop dancers are exposed to these movements. When dance research has traditionally examined low back pain, it is either in the context of capturing injury data for a certain population or in a comparison study between LBP and non-pain groups. However, since dancers in Study 2 have reported that spinal extension movements can increase LBP, a new approach to LBP dance research may be helpful, where the movement itself is examined outside of the context of injury capture or comparing pain and non-pain groups. Two such factors could be the asymmetry of an extension movement (discussed in Chapter 1, section 1.3 of this thesis) and speed of the movement, discussed at length here.

6.1.1 Speed research in dance

To date, the speed at which movements like the arabesque have been performed has not been published previously. As the tempo of the music increases, and thus the speed of the movement increases, the time from the beginning to the end of the movement decreases. Using the arabesque movement as an example, it would be logical to assume that to achieve the same height of the leg within a shorter time, the gesture leg would be required to move faster; an increased angular velocity to accommodate for increased speed of the music and movement. An increase in angular velocity would therefore suggest an increase in angular acceleration of the segment (α) and the overall joint moment (τ):

$$\tau = I\,\alpha$$

where τ is torque, a measure of force; I = moment of inertia; and α = angular acceleration.

This assumption was the basis for the research question of this study: does an increase in the speed of movement performance cause an increase in angular velocity and angular acceleration and, by association, the overall joint moment acting on the low back. Researchers[188] have suggested that increased forces acting on the lumbar spine may account for the increased rate of spondylolysis seen in athletes, especially adolescent athletes[188] and gymnasts,[189,190] as compared to the general population. A high rate of spondylolysis has been extensively documented in another aesthetic athlete population, gymnasts, who experience significant forces in extreme hyperextension positions.[189] Repetitive loading of the spine, particularly at maximum ranges of motion,[191,192] is a concern for pain or injury.[167] Therefore, identifying if increased speed of a movement increases angular displacement, angular velocity, and/or angular acceleration of the spine could provide an important direction for new injury prevention strategies for LBP, a problem which is prevalent for the general population,[1,3,193] athletes,[194,195] and dancers.[119]

Traditional sports research has examined speed in the context of running loads,[196] throwing speeds such as in pitching[197] or bowling,[198] lacrosse injuries,[199] and training.[200] Alternatively - based on the dance form - dancers may perform the same movement across multiple tempos throughout their career to meet the aesthetic demands of choreography. Dance researchers have not extensively examined speed, with only three studies to our knowledge in non-recreational dancers examining the effects of movement speed,[70,201,202] and none specifically examining back extension movements. Establishing preliminary research on speed as a risk factor for LBP during spinal extension can focus the direction of future studies and possibly provide initial recommendations to protect dancers against risks of LBP.

Therefore, in this final study, we examined a dancer trained in ballet, modern dance, and hip-hop as the dancer performed specific movements that moved the spine into extension at three different speeds (two speeds for hip-hop). The movements were piqué first arabesque for ballet, attitude with body roll for modern dance, and a dolphin dive for hip-hop (subgenre breaking). The objective of this research study was to identify any differences in angular displacement, angular velocity, or angular acceleration of the spine as the tempo of the music, and thus the speed of the movement, increases. A secondary objective was to identify any asymmetrical movement patterns between right and left trials of each speed.

6.2 Method

6.2.1 Study Design

The study design was a case study (n=1) where the participant completed 4-5 successful trials of three dance movements: a ballet arabesque, a modern dance-style attitude with body roll, and a hip-hop dolphin dive. Data collection ranged from 2-2.5 hours, with data recorded in two sessions using the same participant between January and February 2023. Due to scheduling conflicts, Henn (EDH) collected data for the ballet movement, and Wyon (MW) collected data for the modern dance and hip-hop movements but used similar data collection techniques.

6.2.2 Movement descriptions

Three representative movements were selected for this study, one from each dance genre: a ballet piqué first arabesque, a modern dance style attitude with body roll, and a hip-hop dolphin dive.

6.2.2.1 The Arabesque Movement

As explained in Chapter 4 (Study 1), the dance movement called ‘arabesque’ is one of the movements dancers specifically named as increasing their LBP. During arabesque, the spine will move into extension, sometimes extreme or end-range spinal extension. An arabesque position refers to standing on one leg, called the working leg, and lifting the other leg, called the gesture leg, in the sagittal plane behind the dancer. Piqué first arabesque (as shown in Figure 6.1) is an arabesque body position where the ipsilateral arm of the working leg reaches forward in a straight line sagitally, with the fingertips level with the eyeline of the dancer. The contralateral arm of the working leg reaches slightly behind the dancer, creating the illusion of a diagonal line from the fingertip of one arm to the other, and therefore causing the torso to open, or rotate, towards the gesture leg. The torso should maintain an erect posture during the movement. The gesture leg is aesthetically desired to be as high as possible. As the height of the leg increases, the hip of the gesture leg will rotate open, and the spine will move into extension to accommodate. Arabesques can be slow and sustained to quick, light, and in rapid succession.

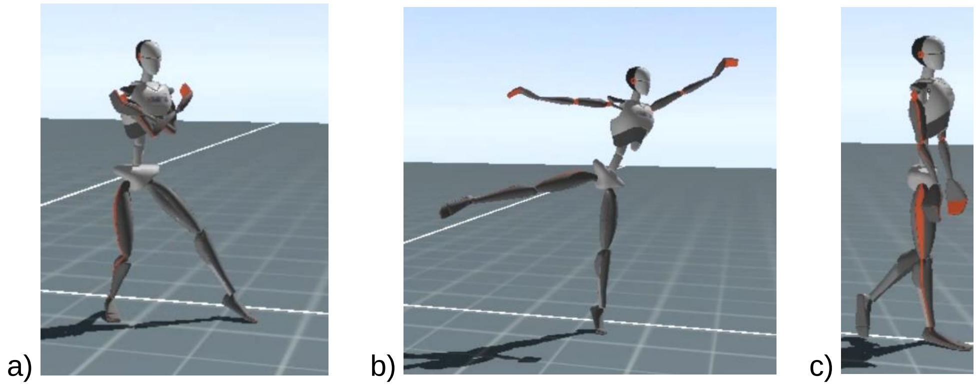


Figure 6.1: The XSENS MVN Link avatar in the MVN Analyze program demonstrates the ballet dance movement, piqué first arabesque
a) the movement begins with the working leg stepping forward onto the ball of the foot (piqué); b) the height of the movement is reached; c) the movement ends when the gesture leg contacts the ground.

The piqué first arabesque is a dance position that all ballet dancers of all levels and most modern dancers will be familiar with, if not proficient at, from an early age. Numerous arabesque variations exist, typically categorized by how one enters, or begins, the movement. The working leg can be flat (whole foot stays in contact with the floor the entire time), piqué (stepping onto the ball of the foot), relevé (lifting onto the ball of the foot or toes if using a pointe shoe), or sauté (one-legged jump). The position of the arms also changes how the arabesque is named. Discussion of the different methods of arabesque naming (e.g., Cecchetti, Vaganova) is beyond the scope of this thesis.

6.2.2.2 The Attitude Movement

As will be detailed later, modern dance-specific movements have not been commonly studied from a biomechanical perspective. The attitude movement is performed in both ballet and modern dance environments. However, the addition of the body roll is a modern dance movement choice that is rarely seen in classical ballet, where an upright torso is considered a key aesthetic.

An attitude position (Figure 6.2) is essentially an arabesque with a bent knee, where the knee lifts laterally while the leg is still posterior to keep the gesture hip open. The modern dance version of the attitude used in this study involves the dancer stepping forward on the working (non-gesture) leg with a flat foot (no piqué), and then the head dives downwards over the working leg. Next, the head and gesture foot both lift upwards nearly simultaneously, with the gesture leg in a back (posterior) attitude shape. At the height of the movement, the gesture foot moves into passé (gesture toe in contact with the working leg's knee), the pelvis shifts anteriorly, and the head initiates a body roll (sequentially moving each spinal segment from head to pelvis into extension and then flexion). The movement ends with the gesture leg returning to the floor in a forward step down.

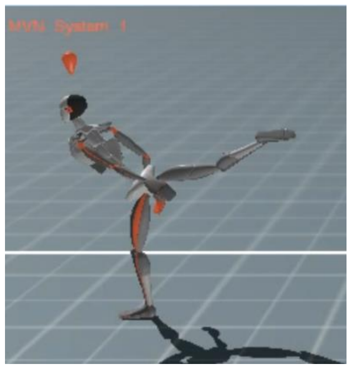
a)  b)  c)  d) 

Figure 6.2: The XSENS MVN Link avatar in the MVN Analyze program demonstrates the modern dance movement, attitude with body roll
a) the initial step forward with the upper body diving downwards; b) the upwards motion of the head and gesture (attitude) leg; c) a forward shift of the pelvis while the gesture leg lowers towards the standing leg's knee; d) the movement ends when the gesture foot contacts the ground.

6.2.2.3 The Dolphin Dive

The dolphin dive movement is a hip-hop spinal extension movement typically seen in breaking. However, biomechanical research on this movement has not been published previously. The dolphin dive movement (Figure 6.3) consists of the dancer first leaping forward onto their hands. Then, using the push from their feet, they lift their feet overhead with all their weight in their hands, but their head still looks forward; this moves the spine into extension. Lastly, they slowly lower their body towards the ground sequentially from pelvis to toes. It should be noted that unlike ballet and modern dance, codified formal instruction was not part of the formation of hip-hop dance, which originated from a street dance tradition.[162] Therefore, to set rigid parameters of speed timing seemed inauthentic to the dance form. Instead, the participant was asked to complete the dolphin movement at two speeds of their own choosing, one slower and one faster, as breakers chose their own tempo during performances. In performance conditions, breakers typically choose a speed based on their own preferences, proficiencies with a movement, and their interpretation of the music.

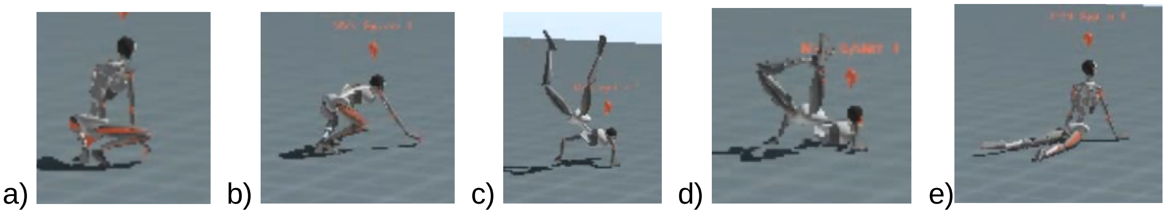


Figure 6.3 The XSENS MVN Link avatar in the MVN Analyze program demonstrates the hip-hop dance movement, the dolphin dive
a) the crouched starting position; b) the movement begins with a leap forward onto the hands; c) the legs lift; d) the chest lowers; e) the movement ends when the feet contact the ground.

6.2.3 The need for multi-segment spine models

Researchers in non-dance populations have found that the upper and lower regions of the lumbar spine can show differing amounts of movement[203,204] that cannot always be identified with a one segment lumbar model,[205] necessitating two segments for the lumbar spine. A four-segment model of the spine (two lumbar, two thoracic) is assumed to be the most accurate model of the spine. Within the biomechanical community, there does not seem to be consensus on which multi-segment model is the most accurate.[206] Additionally, non-dance populations that have chronic LBP have been shown to have altered thoracic kinematics,[207] suggesting that the thoracic spine may display altered movement patterns when compared to the lumbar spine.

In reference to dancers, to our knowledge, the attitude with body roll and dolphin dive have not been studied from a biomechanical viewpoint previously. During the arabesque movement, more motion has been shown to occur in the thoracic spine as compared to the lumbar spine, with the upper and lower thoracic regions showing differing amounts of movement within a multisegmented model of the spine.[62] More than one arabesque study[60,61,67] has reported lumbar spine angles, however, studies that utilised a one-segment model or a model that does not separate the lumbar from the thoracic spine may not be detailed enough to capture the complexity of spinal extension movements. One-segment studies on the arabesque measured the angle between C1 vertebrae and the gesture leg, with the apex at the lumbar spine or pelvis, to obtain a back extension angle. This diminishes the contribution of individual portions of the spine to the movement and assumes that the entire spine is always in extension. Therefore, a model of the spine that examines the individual contributions of the thoracic and lumbar spine in detail was chosen for Study 3: a multi-segment model with two thoracic and two lumbar segments.

6.2.4 Trial conditions

The participant performed dynamic trials of varying speeds (Figure 6.4). The speed trials were performed on both the left and right sides at three different speeds, resulting in a total of six speed trials, with groupings of at least three successful trials each. The order of the speed trials was randomized, as was which side - left or right - that the participant would complete first for each trial.

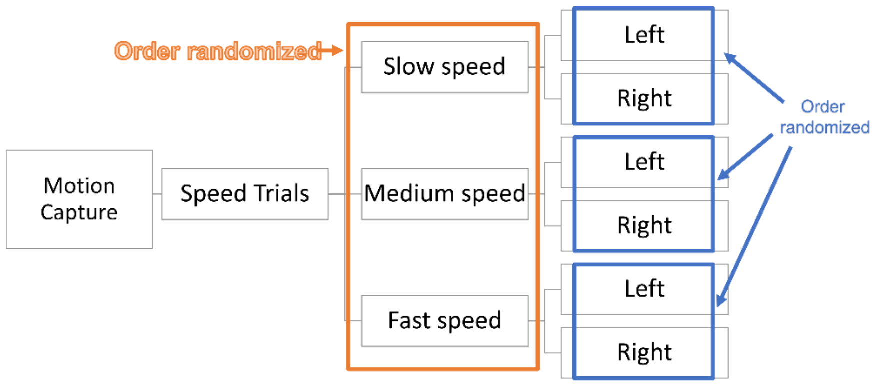


Figure 6.4: A visual representation of data collection for the motion capture study

To mirror performance conditions more closely, music was used to keep tempo for the participant. During the recording of Study 2 ballet performance data, where the arabesque movement occurred frequently, three tempos were identified. Tempos were quantified using an online counting website[208] and reported in beats per minute (BPM): slow (approximately 60 BPM), medium (approximately 100 BPM), and fast (approximately 160 BPM). After identifying the common tempos within ballet performance, matching music files were selected and purchased:

- Slow: Sleeping Beauty theme[209] at 61 average BPM
- Medium: Dance of the Swans[210] at 103 average BPM
- Fast: The Coda from Black Swan pas de deux in Act III[211] at 158 average BPM

As data collection progressed, the researcher aided the participant in counting the music (in eights, as is traditional for formal instruction across a range of dance disciplines) to ensure that the participant was following the tempo of the music, and therefore the speed of the trial, exactly. The same section of music for each speed was used for all trials to standardize for any musician-oriented tempo alterations. Trials were repeated until at least three successful trials were obtained.

A trial was removed as a ‘failed’ trial if the participant did not perform the movement successfully (e.g., heel drop of the standing leg, fell out of the attitude, did not achieve balance in the peak of the arabesque position) or did not follow the tempo (e.g., suspending the arabesque movement beyond the given timing, leaving the arabesque position too soon). The participant was given rest time between trials within the speed trial sequences; the amount of rest attempted to mirror the median 1:1 work-to-rest ratio identified in Study 2 that dancers can expect in aggregate for ballet and modern dance environments, and 1:3 for hip-hop dance environments in aggregate (Table 5.7).

In the speed trials, the participant was given freedom in determining how they started prior to the beginning of the movements, with their selections as follows: In ballet: B+ position: crossed at the knees, with one leg behind the other with the top of the foot/toes in contact with the ground, in modern dance: 5^{th} position (one heel in contact with the toes of the other foot, with both toes pointing laterally at 45° or greater), and in hip-hop: a crouched position with hands and feet in contact with the floor. They were also given freedom in how they ended the movement, as data analysis was only performed on the movement itself. For the arabesque trials, to mirror arabesques in performance settings (as identified in Study 2), the participant was instructed to step across with the gesture leg when exiting the arabesque movement.

6.2.5 Pilot Studies

A pilot study was initiated with a non-dancer prior to official data collection. The non-dancer participant was asked to walk several steps from left to right across the laboratory. When they were in the middle of the space, they would lift their downstage leg (the leg closest to the researcher) with a small arch backwards, and then continue walking. Ten total trials were recorded. The goal of this non-dance preliminary study was to compare motion capture data and logistical processes between two data collection methods when collected simultaneously. The pilot study data collection used 1) an XSENS MVN suit with 2) two marker systems overlaid (i.e., taped) on top: a CAST full-body marker system[212] and a thoracic and lumbar spine four-segment model marker system as described in Hagins et al.[62] and Swain et al.[51] (referred to as the Hagins/Swain model hereafter).

After the initial non-dance pilot, a second, dance-specific pilot was employed. The dance-specific pilot participant was a recently retired, 30-year-old female dancer (5 years since they had been performing frequently) who had over 20 years' experience with the arabesque movement. An identical data collection procedure was applied to this pilot participant as is described in section 6.2.9 of this thesis chapter, with the addition of the two QTM marker systems overlaid on top of the XSENS suit. Some logistical challenges arose when balancing both data collection systems. As the dancer became warm and perspired throughout the movement trials, the QTM markers began to slide and even detach from the lycra of the XSENS MVN suit. The 1:1 work-to-rest ratio that was selected to mimic performance conditions was unable to be maintained, as multiple markers needed to be re-taped after every trial, providing extra rest to the participant. Therefore, logistical challenges in combination with sufficient data reported from the XSENS suit alone led to the selection of using the XSENS suit for future participants. The data from the pilot studies were used to construct two biomechanical models within Visual3D software: one based on the XSENS data, and another based on the QTM data. The pilot work and data processing showed outputs from the XSENS data alone seemed sufficient to answer the research question, as the suit provided a four-segment model of the spine, aligning with spine research best practices (as explained in section 6.2.3 of this thesis).

6.2.6 Participant

Ethical approval was obtained from The University of Wolverhampton (ethics approval code: 03/22/EH/UOW, Appendix 4.2). A risk assessment was also submitted. A participant of convenience was recruited that was skilled in all three dance genres. The participant completed an informed consent prior to data collection. This informed the participant of the nature of the study, their ability to withdraw at any time, and to confirm they were 18 years of age or older.

The participant also completed a questionnaire to obtain demographic information, dance background, relevant dance injury history, movement preferences, or any general body discomfort. Additionally, the questionnaire had multiple sections that examined LBP occurrence, treatment, impact, and perceived aggravating factors. The questionnaire was a modified version of the questionnaire used by Swain et al.[51] in their LBP multi-segment model study in 2019. This questionnaire was comprised of several pieces from other well-established questionnaires (the Orebro Pain Questionnaire,[213] the Harkness Dance Discomfort Rating Scale, the Tampa Scale for Kinesiophobia[214]), but has not been validated as a whole, which is an accepted limitation of using the questionnaire. The wellness questionnaire portion was omitted as it did not describe any of the outcome measures related to the primary objective of this study.

The following alterations and additions were included in the questionnaire to aid in laboratory logistical preparation, to make the questionnaire more applicable to a broader dance population, or to make the questionnaire more dance-specific:

- Two questions (questions 1 and 2) to gauge which XSENS suit size would be most appropriate: “What is your typical men’s t-shirt size?” and “What is your approximate height in centimetres?”
- For question 6, which inquired about the professional level of the dancer, two additional choices were added: “Recreational dancer” and “Retired dancer”.
- For question 12, which inquired how many years the dancer had danced professionally, additional wording was added to the question for clarity: “If you have never danced professionally, you can put zero years.”
- Question 39 was added to address dance-specific asymmetrical preference: “When performing single leg movements during dance, which leg do you prefer to have as your STANDING leg?”

6.2.7 Determining motion capture systems

To select to most appropriate data collection method, a motion capture system (Qualisys Track Manager (QTM) 2022.1 [Build 7420] software and 14 infrared [Oqus 6]) sampling at 100Hz with 16mm and 12.5mm markers was compared to the XSENS MVN Link motion capture suit (referred to as ‘the suit’ or ‘the XSENS suit’ hereafter) and a combination of both. The XSENS MVN Link motion capture suit uses 17 wired sensors[215] to report angles in three planes of motion for five spinal angles, creating a multi-segment spinal model. The relevant spinal segments are T8, T12, L3, L5. The angles are located between the following vertebrae: T8-T9 angle, T12-L1 angle, L3-L4 angle, and the L5-S1 angle. It should be noted that according to the manufacturer’s manual, “Spine segments [are] not measured directly in MVN, they are interpolated between the MT’s [motion trackers] of the Pelvis, Sternum and Head using a model of the spine. Joint origins are the rotation points in the vertebrae.”[215] The validity of multiple IMUs at different speeds has been evaluated in running.[216-218] Some IMUs were more accurate in tracking movement at higher speeds than others. The XSENS MVN Link motion capture suit has been shown to have excellent validity in the sagittal plane during multiple speeds of running.[219] There have been no validity studies on the XSENS suit for the dance movements used in this study.

6.2.8 Outcome Measures

Sagittal plane movement (flexion and extension) were the focus of this study. The XSENS suit model uses two different coordinate systems for segments and angles. Segment measures, such as segment position, angular velocity, and angular acceleration, use a coordinate system where the X axis points anteriorly, the Z axis points up, and the Y axis points left. Flexion and extension motions would therefore occur about the Y axis. Joint angles use a coordinate system where the X axis points anteriorly, the Y axis points up, and the Z axis points to the left. Flexion and extension motions would occur about the Z axis. Although the terms spinal flexion and spinal extension are used for familiarity when describing the overall trunk movements in the sagittal plane, positive angular velocity values for spinal segments (vertebrae) were defined as the superior aspect of a segment rotating anteriorly with respect to the inferior aspect, while negative angular velocity values were defined as the superior aspect of a segment rotating posteriorly with respect to the inferior aspect. These are in accordance with the handling of coordinate systems by the MVN Analyze computer program.[215] The outcome measures collected in this study are as follows, as categorized by units of measure.

- Joint angle measures
    - **Mean peak joint angles** in degrees between L5S1, L4L3, L1T12, T8T9; obtained by MVN Analyses' use of Euler angle extractions (Z-X-Y) about the Z axis. Positive values represent flexion; negative values represent extension.
    - **Range of motion (ROM) of the joint angles** in degrees at L5S1, L4L3, L1T12, T8T9; this was calculated by taking the absolute value of the positive and negative degrees of motion and adding them together.
    - **Asymmetry magnitude and percentage of joint angles** at L5S1, L4L3, L1T12, T8T9; this was calculated using a modified BAI-1 formula (as explained in section 1.3 of this thesis) by subtracting the mean of left-sided trials ROM from the mean right-sided trials ROM (to obtain magnitude), and then dividing that value by the total ROM from both left and right trials, multiplied by 100 to obtain a percentage. Positive percentages imply larger ROM during the right-sided trials; negative percentages imply larger ROM during the left-sided trials.
- Velocity measures
    - **Mean peak angular velocity** in radians per second (rads/s) of segments T8, T12, L3, L5, Right Foot, and Left Foot, as reported by the MVN Analyze software.

    - **Asymmetry magnitude and percentage of mean angular velocity** of segments T8, T12, L3, L5, Right Foot, and Left Foot, calculated in the same way as the joint angles.
- Acceleration measures
    - **Mean peak angular acceleration** in radians per second per second (rads/s/s) of segments T8, T12, L3, L5, Right Foot, and Left Foot, as reported by the MVN Analyze software.
    - **Asymmetry magnitude and percentage of mean angular acceleration** of segments T8, T12, L3, L5, Right Foot, and Left Foot, calculated in the same way as the joint angles.

6.2.9 Procedure and Data Collection

Data were collected using the XSENS MVN Link motion capture suit and the accompanying MVN Analyze Pro software[220] [version 2021.0.1, build 6752, rev 110421] sampling at 240 Hz. The suit uses an integration of gyroscopes and accelerometers with the manufacturer's biomechanical models to produce an avatar of the movements, which is transmitted to a computer in real time. An XSENS suit matching the participant's size (small, medium, or large) was prepared; more information on how an XSENS suit is prepared for data collection can be found in the manufacturer's instruction manual.[215]

The participant verbally confirmed no exclusions, and then put on the previously prepared XSENS suit. Privacy was provided before, during, and after putting on the suit. Anthropometric values, including height and body mass, were measured by the researcher. MVN Analyze prompts the researcher to provide the following information: body height, foot size, elbow span, wrist span, arm span, hip height, knee height, ankle height, hip width, shoulder width, shoulder height, and extra sole height (if wearing shoes that add an appreciable thickness off the ground). Then, the researcher followed manufacturer guidelines[215] for activating, connecting, and calibrating the suit. If a sensor fell off or the MVN Analyse avatar displayed an incorrect model during data collection, a recalibration was performed until the issue was resolved.

The participant was then given as much time to warm up in preparation for the movements as they required, with the researcher checking in with them in intervals of five minutes after an initial 10-minute warm-up period. The participant was shown the space they would be dancing in with a walkthrough of the movement. The participant completed multiple practice trials until they felt comfortable in the space. Then, the dynamic trials followed, as visually depicted in Figure

6.4 in section 6.2.4. A data collection sheet was employed to keep track of the randomisations and to note any failed trials.

6.2.10 Data Processing and Analyses

Motion analysis data was recorded in the MVN Analyse software.[220] The trials were individually exported as Excel (.xlsx) files. Preliminary analysis of outcome measures was conducted in Microsoft Excel using the .xlsx files. A Kalman filter is automatically applied by the MVN Analyze software during data collection, and no additional filters were applied to the raw data. Raw data was prepared by “cropping” the data files within Excel by identifying the beginning and end of the desired movement using the right and left foot segments’ orientation within the space. The definitions to classify the start and end of movements are detailed below. It should be noted that the ballet arabesque and modern dance attitude movements are ‘sided’, meaning the left and right movements mirrored one another and the movements are considered asymmetrical. Because the dolphin dive is performed as a symmetrical movement, data from both feet were examined in the Z direction and found to be similar. Therefore, only the right foot was used to determine the start and end of the dolphin dive movement for consistency across trials.

- <u>Arabesque movement</u>: the foot of the gesture leg lifts, as indicated by moving in the positive Z direction (vertical off the ground); the foot of the gesture leg steps across and down, as indicated by decreasing in the Z direction (Figure 6.5).
- <u>Attitude movement</u>: the foot of the working leg steps forward, as indicated by moving in the positive Z direction (vertical off the ground); the foot of the gesture leg steps forward and down, as indicated by decreasing in the Z direction (Figure 6.6).
- <u>Dolphin dive</u>: the right foot lifts, as indicated by an increase in the positive Z direction; the right foot lands on the ground, as indicated by a decrease in the Z direction (Figure 6.7).

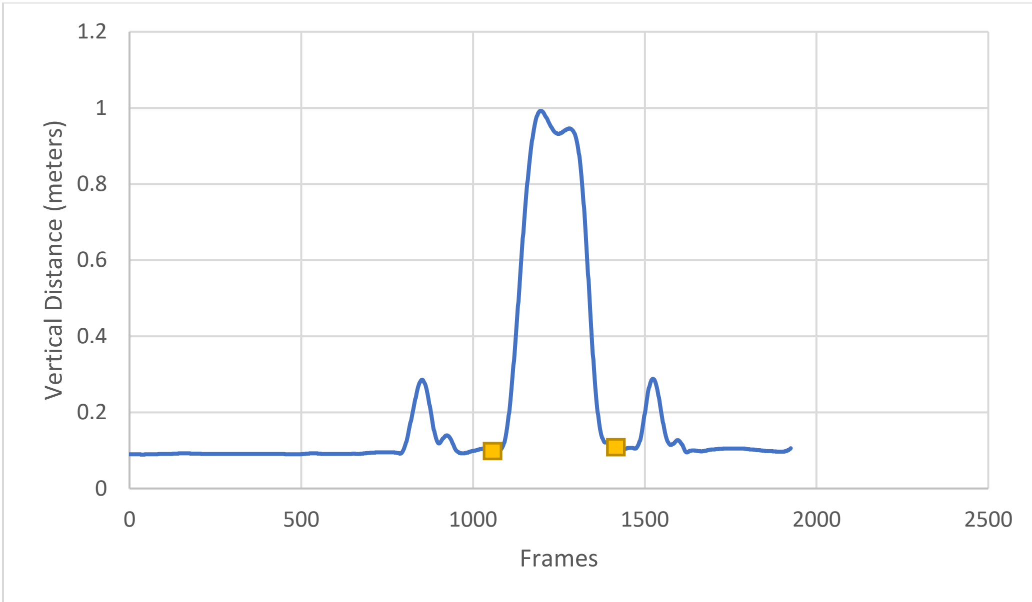


Figure 6.5: The vertical distance of the ballet participant's left foot performing the arabesque movement at medium speed with a left gesture leg
Yellow squares indicate the approximate cropping locations.

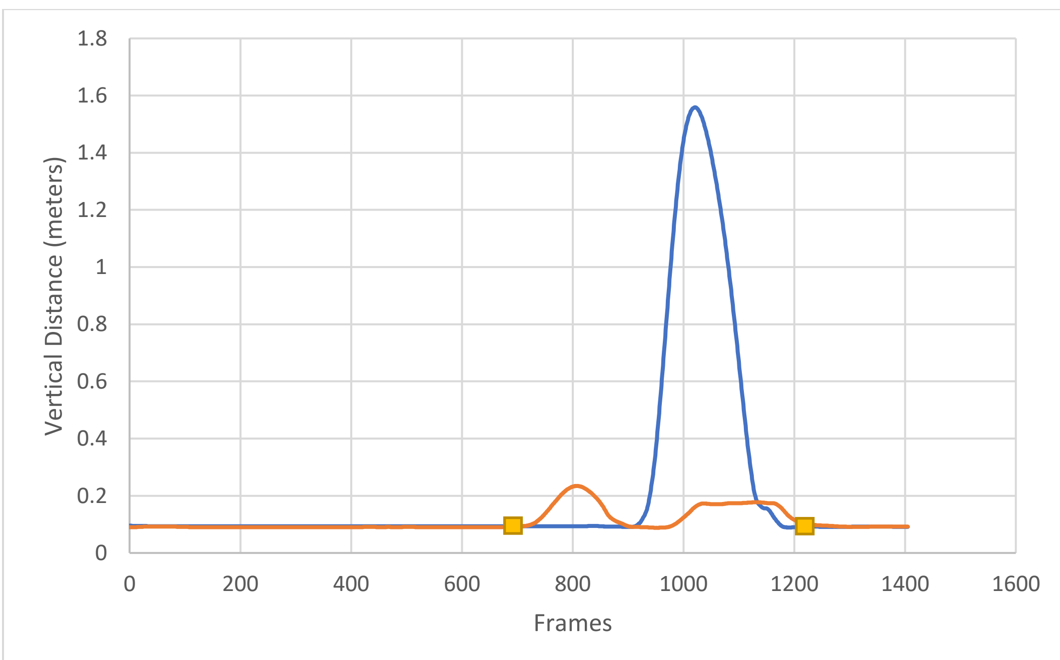


Figure 6.6: The vertical distance of the modern dance participant's left and right feet performing the attitude movement at medium speed with a right gesture leg
Blue represents the gesture leg, orange represents the working (standing) leg, and yellow squares indicate the approximate cropping locations.

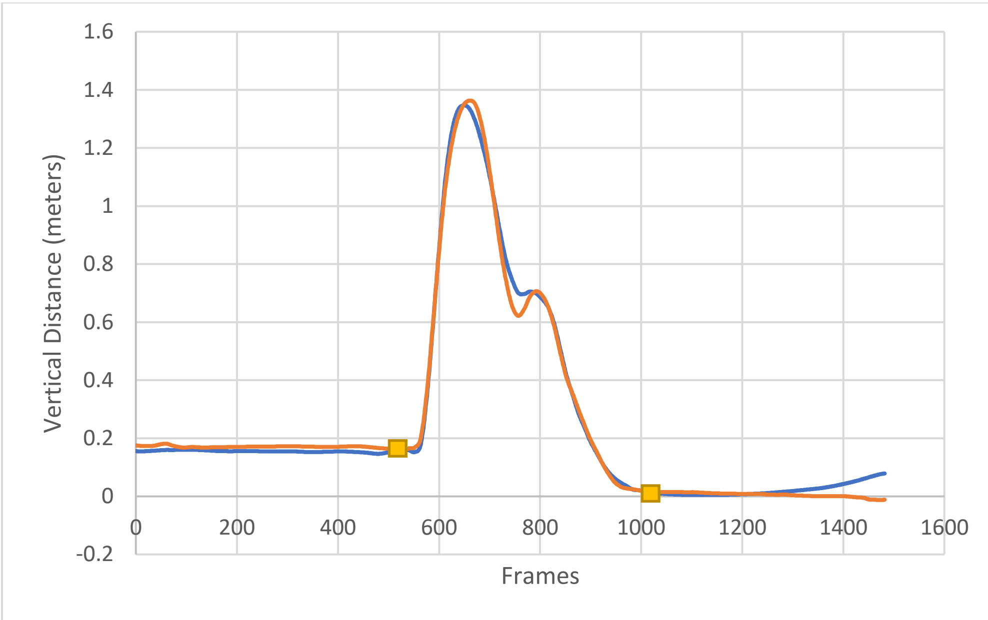


Figure 6.7: The vertical distance of the hip-hop participant's left and right feet performing the dolphin dive movement at a self-selected slow speed

Yellow squares indicate the approximate cropping locations.

The lowest value prior to the rise and following the end of the movement was determined as the cut-off. However, some trials did not have a clear cut-off, as occasionally there was an infinitesimally small, continuous increase or decrease in Z values, possibly because the participant was anticipating the movement or relaxing after completing the movement. This prevented clear identification of cut-off values based on the foot segments alone. In these cases, the Toe Z segment of the same foot/feet was/were examined to assist in determining a clear cut-off value for cropping.

After cropping the files, the movement was time normalised by use of two Excel macros written by my second research assistant, Alexander Abadiotakis (AA), and by Dr. Tina Smith (TS), respectively. The first macro was tested by EDH and AA, and it performed simple copy and paste functions to extract the already cropped data from the original data collection file and move it into the data processing Excel file. The second macro (TS) performed calculations to time-normalise data to 101 frames: values 0 to 100 (Figure 6.8).

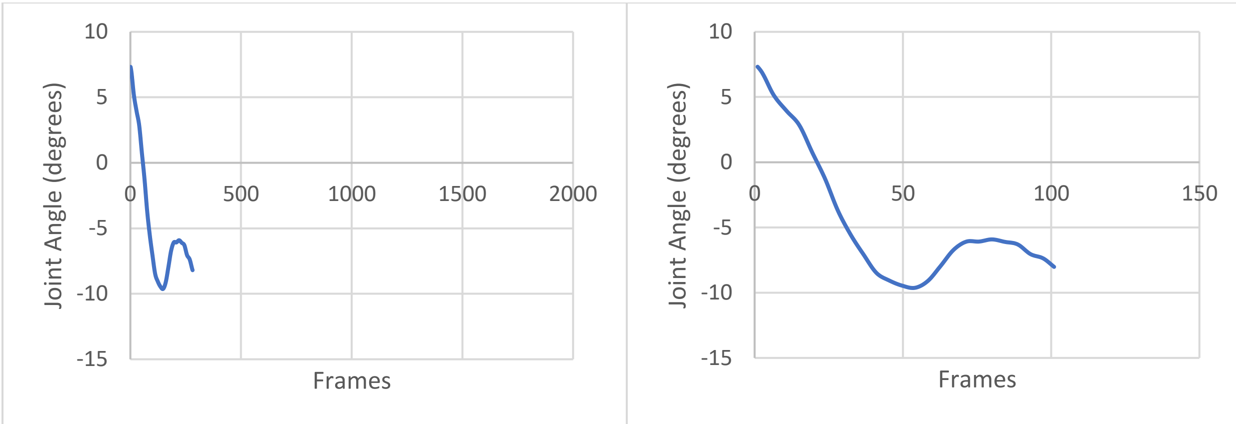


Figure 6.8a & b: Hip-hop participant's flexion and extension angles (about the Z-axis in the joint angle coordinate system), measured in degrees, of the L1T12 joint while performing a dolphin dive movement
a) cropped data prior to time normalising. b) data after it has been time normalised from 0 to 100 frames.

The cropping and time-normalising process was repeated for three spine variables and two gesture leg variables: **spine joint angles** (T8T9, T12L1, L3L4, L5S1), **spine angular acceleration** (T8, T12, L3, L5), **spine angular velocity** (T8, T12, L3, L5), **foot angular acceleration** (Right foot, Left foot), **foot angular velocity** (Right foot, Left foot). Data processing encompassed both the left and the right gesture leg trials for ballet and modern dance, and the symmetrical dolphin dive trials; three different speeds for ballet and modern dance, and two speeds for the dolphin dive. Values for all trials were reported as ensemble averages and 95% confidence intervals.

Graphical representations of ensemble averaged data, asymmetry magnitude, and asymmetry percentages for angular displacement, angular velocity, and angular acceleration measures were calculated using Excel formulas. Asymmetry magnitude was calculated by subtracting left values from right values (positive = right side greater, negative = left side greater). Asymmetry percentages were calculated using a modified BAI-1 formula (positive = right side greater, negative = left side greater). An asymmetry cut-off of 10% was used as this has been used as an acceptable asymmetry percentage in sport,[38,39] and no asymmetry cut-off values have been proposed for the ballet arabesque, modern dance attitude with body roll, or hip-hop dolphin dive movements.

6.2.11 Validity considerations

A specific choice regarding tempo was made to mirror performance conditions more closely in this study, and thus increase ecological validity: the use of music to create a consistent tempo.

As mentioned in the Introduction (section 1.4), I have been critical of other studies that did not report or consider this aspect of ecological validity, as timing and tempo are central aspects of dance performance. However, the use of a rigid timing structure may present a challenge, albeit a familiar challenge, to dancers to execute the movement within the prescribed time, possibly affecting internal validity.

Multiple decisions were made during the study design process concerning hip-hop dancers that increase ecological validity but may threaten internal validity. While internal validity suggests that the tempos, and even the exact music track, should be standardized across all three dance genres, this reduces ecological validity significantly. Additionally, as mentioned previously in section 6.2.2.3, hip-hop dance does not follow fast, medium, and slow tempos as strictly as codified ballet and modern dance. Because hip-hop dance is typically performed in a non-proscenium setting, set to the music of a live DJ, without a fully pre-choreographed routine, it is more ecologically valid to allow the dancer to determine the pace of the movement, where the researchers asked for 'fast' and 'slow' self-selected speeds for purposes of comparison. Challenges to validity include the use of a laboratory setting for data collection, reducing ecological validity, and the scheduling issue that required data collection to be performed by two different researchers at two different time points.

6.3 Results

6.3.1 Demographics

The participant (age: 28 years old, height: 186.4cm, body mass: 76.4kg) had danced for 16 years, 10 of which were at the professional level, although they were retired (dancing zero hours per week) at the time of data collection. Their primary dance style studied was Chinese classical dance, but their training background included proficiency in ballet, modern, and hip-hop dance. They were confident in performing the movements required for this study. Although the participant described himself as not having had any injuries, past or present, that would limit his participation in physical activity, he did report LBP within the last 12 months, the most recent episodes being within the two months preceding the study. He cited "Standing" and "Long dance hours / high workloads" as activities that would cause him to experience LBP. He had never sought professional help for his LBP nor used medication to manage it. When assessing discomfort of certain joints within the body, the participant had occasional discomfort in the foot-ankle, knee, hip, low back, and frequent discomfort of the shoulder-arm, with severity ranging from moderate to significant. He was healthy and pain free at the start of data collection and had no concerns about what was required to participate in the study. His preferred standing leg for dance movements was his left leg, and his preferred side for non-dance movements, such as throwing or kicking a ball, was his right side.

6.3.2 Graphical representations

All time-normalised data were analysed as line graphs. Joint angles were reported as a combined value (total mean across both left and right trials), as well as left and right separately when assessing asymmetry. Hip-hop movement values did not have left- or right-sided trials and only “combined” values were reported. Because angular velocity and angular acceleration had different graphical shapes for left and right trials, angular velocity and angular acceleration variables were reported as right and left trials, and not as a combined value (except for hip-hop data, which did not have left and right trials). Graphical representations in their entirety can be viewed in Appendix 6.1. It should be noted that when viewing ballet arabesque data that right- and left-sided trials of this movement changed facings, which causes the MVN Analyze program to “flip” graphical representations of data of the gesture foot for right-sided trials. In these trials, negative values represented flexion for right-sided trials, positive values represented flexion for left-sided trials, as noted in the captions.

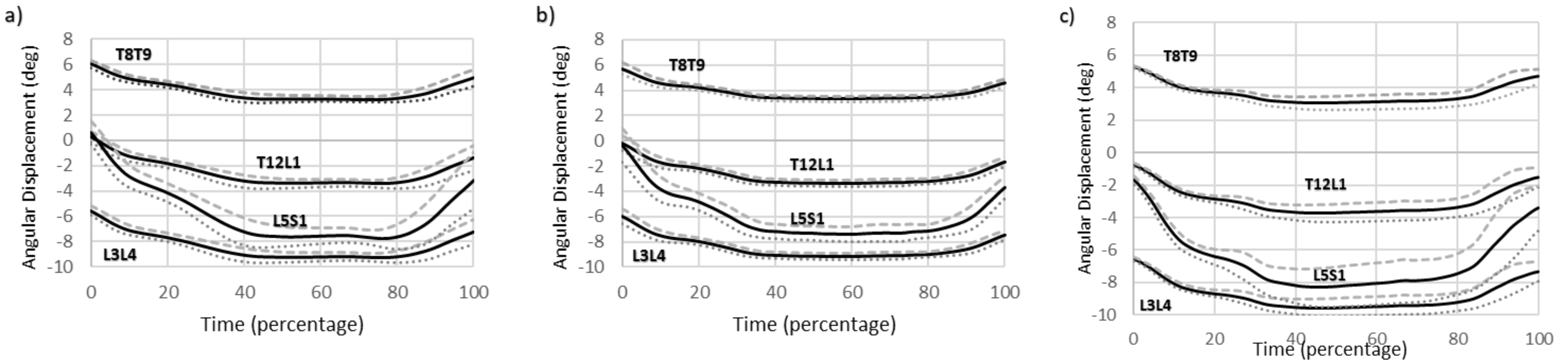


Figure 6.9a-c: Ballet arabesque sagittal motion of four spine joint angles (in degrees) total mean (right- and left-sided trials combined) and 95% confidence intervals at three speeds: a) fast, b) medium, and c) slow

Positive values represent flexion of the spine, negative values represent extension of the spine.

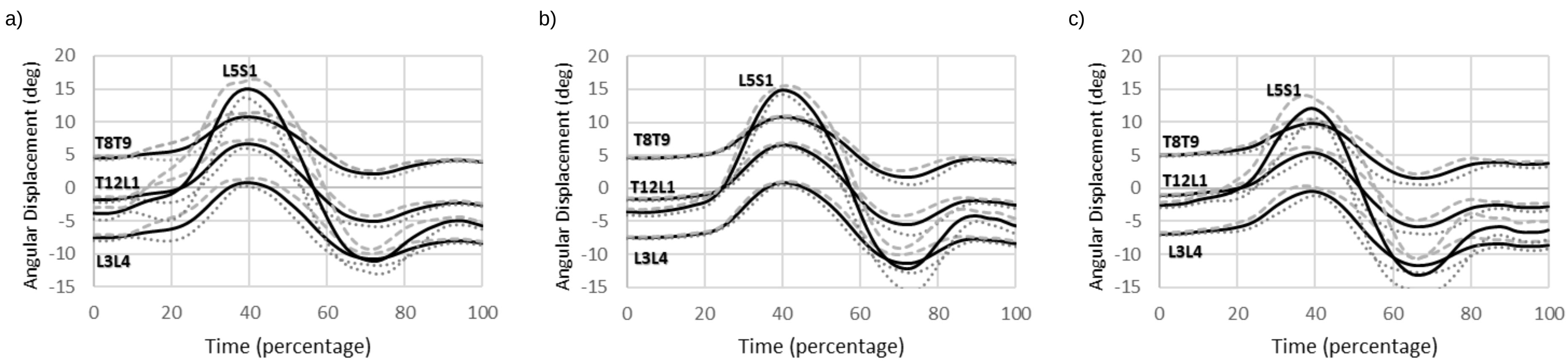


Figure 6.10a-c: Modern dance attitude with body roll sagittal motion of four spine joint angles (in degrees) total mean (right- and left-sided trials combined) and 95% confidence intervals at three speeds: a) fast, b) medium, and c) slow

Positive values represent flexion of the spine, negative values represent extension of the spine.

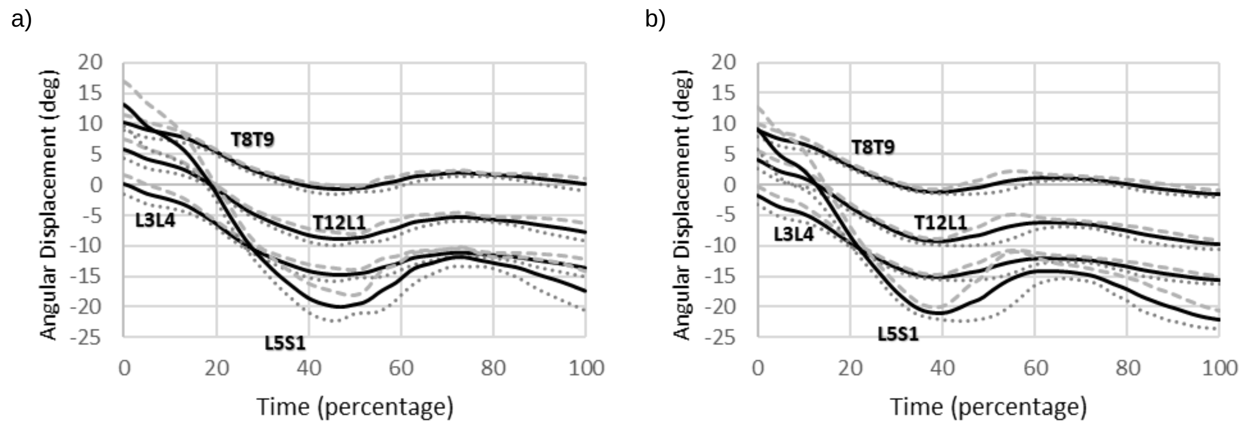


Figure 6.11a-b: Hip-hop dolphin dive sagittal motion of four spine joint angles (in degrees) mean and 95% confidence intervals of left-sided trials at two speeds: a) fast and b) slow
Positive values represent flexion of the spine, negative values represent extension of the spine.

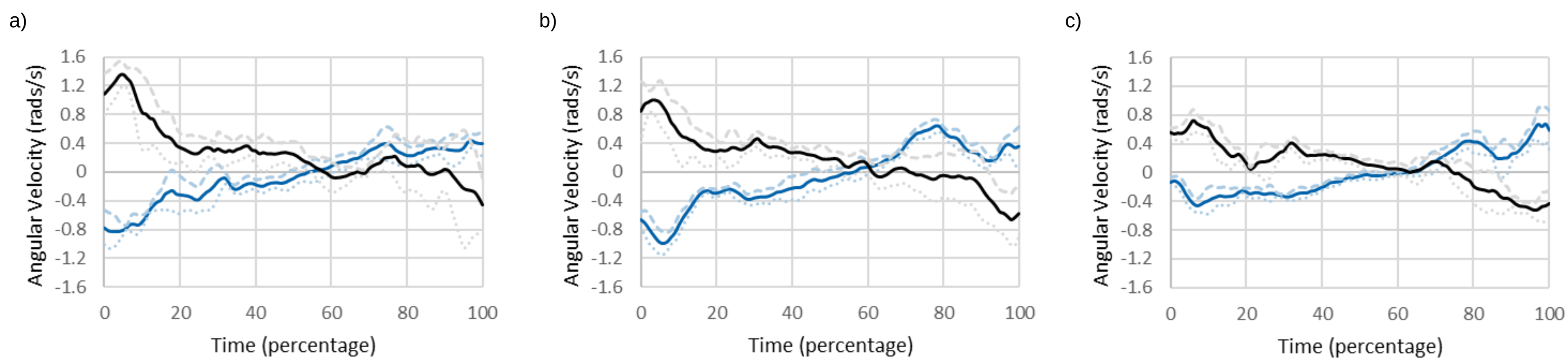


Figure 6.12a-c: Ballet arabesque sagittal plane mean angular velocity of the spine and 95% confidence intervals for spinal segment L5 for right- and left-sided trials at three speeds: a) fast, b) medium, and c) slow
The blue line represents right-sided trial data (negative values represent flexion), the black line represents left-sided trial data (positive values represent flexion).

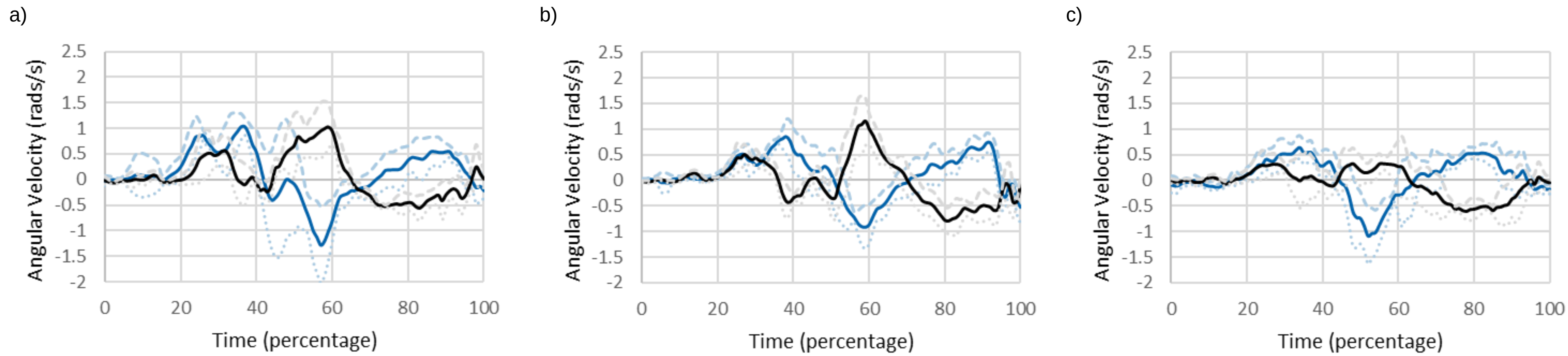


Figure 6.13a-c: Modern dance attitude with body roll sagittal plane mean angular velocity and 95% confidence intervals of the spine for spinal segment L5 for right- and left-sided trials at three speeds: a) fast, b) medium, and c) slow

The blue line represents right-sided trial data, the black line represents left-sided trial data. Positive values represent flexion of the spine, negative values represent extension of the spine.

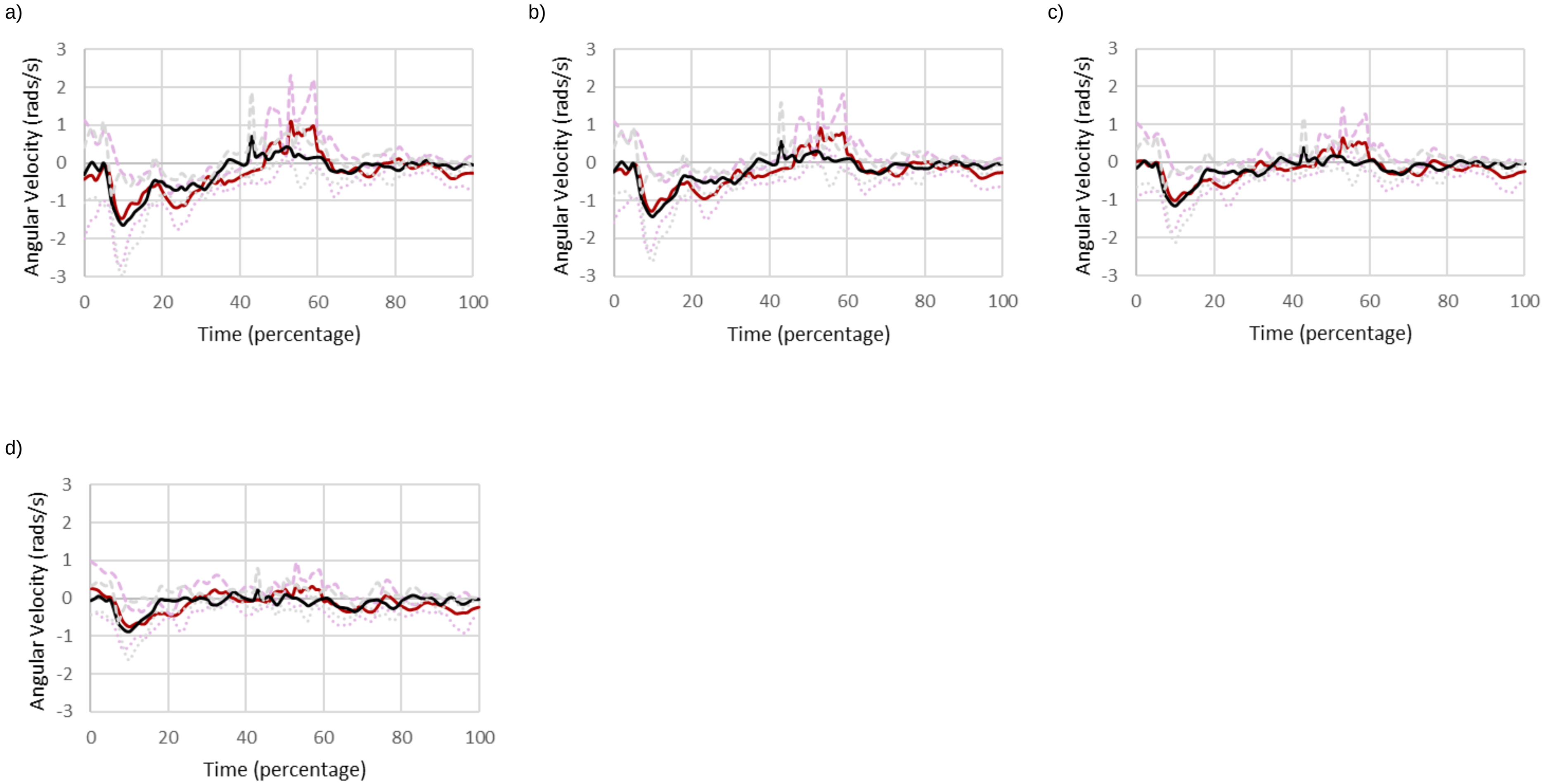


Figure 6.14a-d: Hip-hop dolphin dive sagittal plane mean angular velocity of the spine and 95% confidence intervals at fast and slow speeds for four spinal segments: a) T8, b) T12, c) L3, and d) L5

The red line represents fast trial data, the black line represents slow trial data. Positive values represent flexion of the spine, negative values represent extension of the spine.

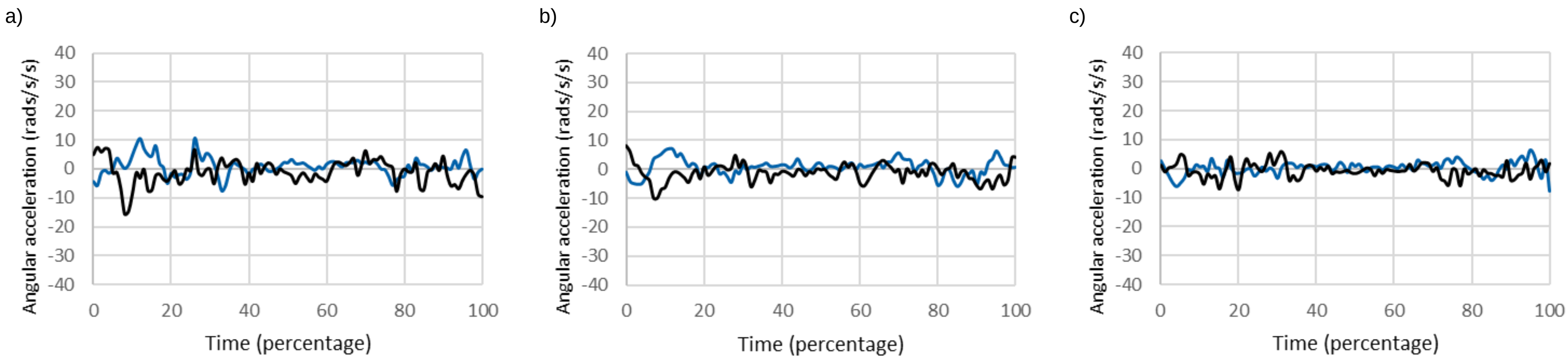


Figure 6.15a-c: Ballet arabesque sagittal plane mean angular acceleration of the spine for spinal segment L5 for right- and left-sided trials at three speeds: a) fast, b) medium, and c) slow

Confidence intervals omitted for clarity. The blue line represents right-sided trial data (negative values represent flexion), the black line represents left-sided trial data (positive values represent flexion).

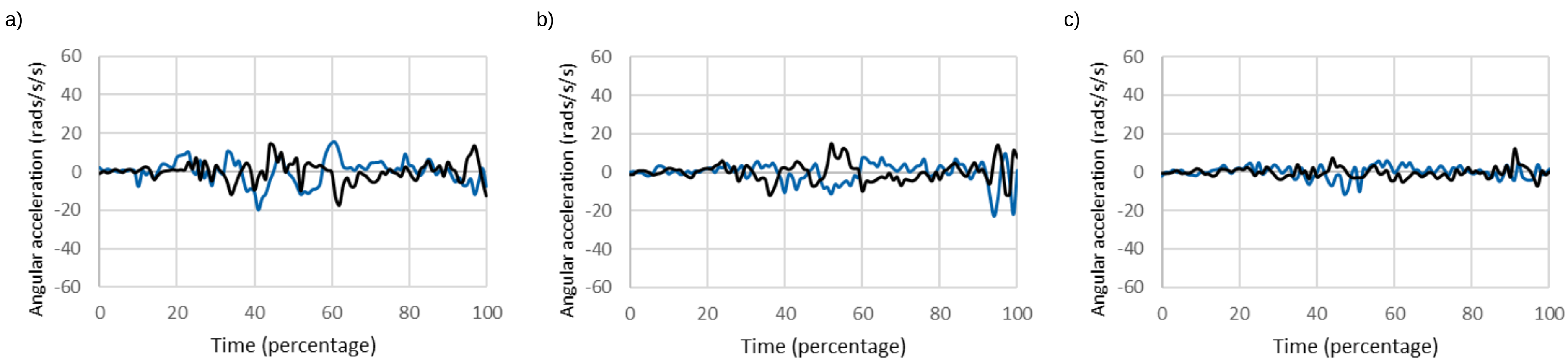


Figure 6.16a-c: Modern dance attitude with body roll sagittal plane mean angular acceleration of the spine for spinal segment L5 for right- and left-sided trials at three speeds: a) fast, b) medium, and c) slow

Confidence intervals omitted for clarity. The blue line represents right-sided trial data, the black line represents left-sided trial data. Positive values represent flexion of the spine, negative values represent extension of the spine.

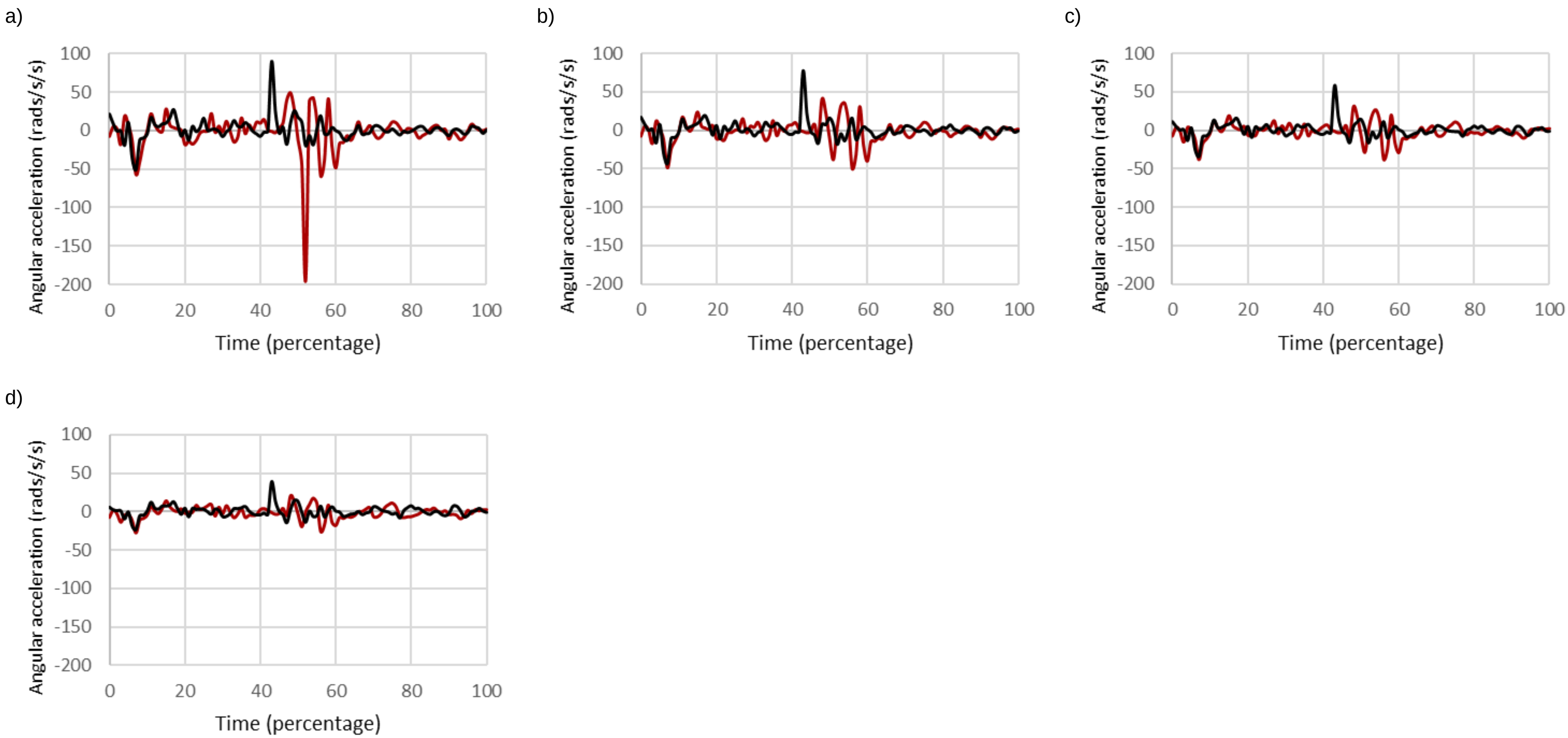


Figure 6.17a-d: Hip-hop dolphin dive sagittal plane mean angular acceleration of the spine at fast and slow speeds for four spinal segments: a) T8, b) T12, c) L3, and d) L5 Confidence intervals omitted for clarity. The red line represents fast trial data, the black line represents slow trial data. Positive values represent flexion of the spine, negative values represent extension of the spine.

6.3.3 Speed

For ballet, modern dance, and hip-hop movements, as trial speed increased, the range of motion in degrees for all spine angles (T8T9, T12L1, L3L4, and L5S1) increased in magnitude (Table 6.1). However, the medium speed for the modern dance movement was an exception to this trend, showing an increase larger than either the fast or slow modern dance movement trials. The spine angles confidence intervals also widened with speed, except for modern dance medium speeds, which displayed narrower confidence intervals for spine angles than the fast or slow modern dance trials. The most flexed angles for spine joints occurred at approximately 40% of the modern dance movement and the most extended angles occurred at approximately 70% of the movement. The confidence intervals tend to be the narrowest at 40% and 70% of the modern dance medium speed when compared to the fast or slow speeds at the same time percentage (Figure 6.10, Appendix 6.1).

Table 6.1: The mean range of motion angles, in degrees, of four spinal joints during fast, medium, and slow trials of ballet, modern dance, and hip-hop movements (arabesque, attitude, and dolphin dive, respectively)

Spine	Ballet			Modern			Hip-hop	
Angles	Fast	Med	Slow	Fast	Med	Slow	Fast	Slow
T8T9	2.78	2.38	2.22	8.75	**9.12***	8.46	11.04	10.44
T12L1	3.71	3.18	2.97	11.65	**12.15***	11.27	14.72	13.92
L3L4	3.71	3.18	2.97	11.65	**12.15***	11.27	14.72	13.92
L5S1	8.37	7.01	6.60	26.06	**27.10***	25.22	33.16	31.30

*Range of motion increased as speed increased for all speeds and genres, except for the modern dance medium speed trials, denoted by * in the table.*

Visually, the graphical representations of the data suggest that mean angular velocity of the spine angles, their corresponding confidence interval, and mean angular acceleration of the spine increased for all dance genres as the speed of the trial increased. This trend is exemplified by the peaks and troughs being more exaggerated in trials at higher speeds. Fast trials of modern dance spine angular velocity had wider confidence intervals when visually compared to medium or slow speeds, as seen in the peaks and troughs within 20-60% of the movement.

Graphical representations suggest that foot angular velocity and foot angular acceleration increased as speed of the trial increased; however, some large, singular spikes in angular acceleration movements, particularly in hip-hop trials (example seen in Figure 6.18), prevent definitive conclusions. It is possible that impact of body parts with the floor may have contributed to the large spikes seen in angular acceleration data.

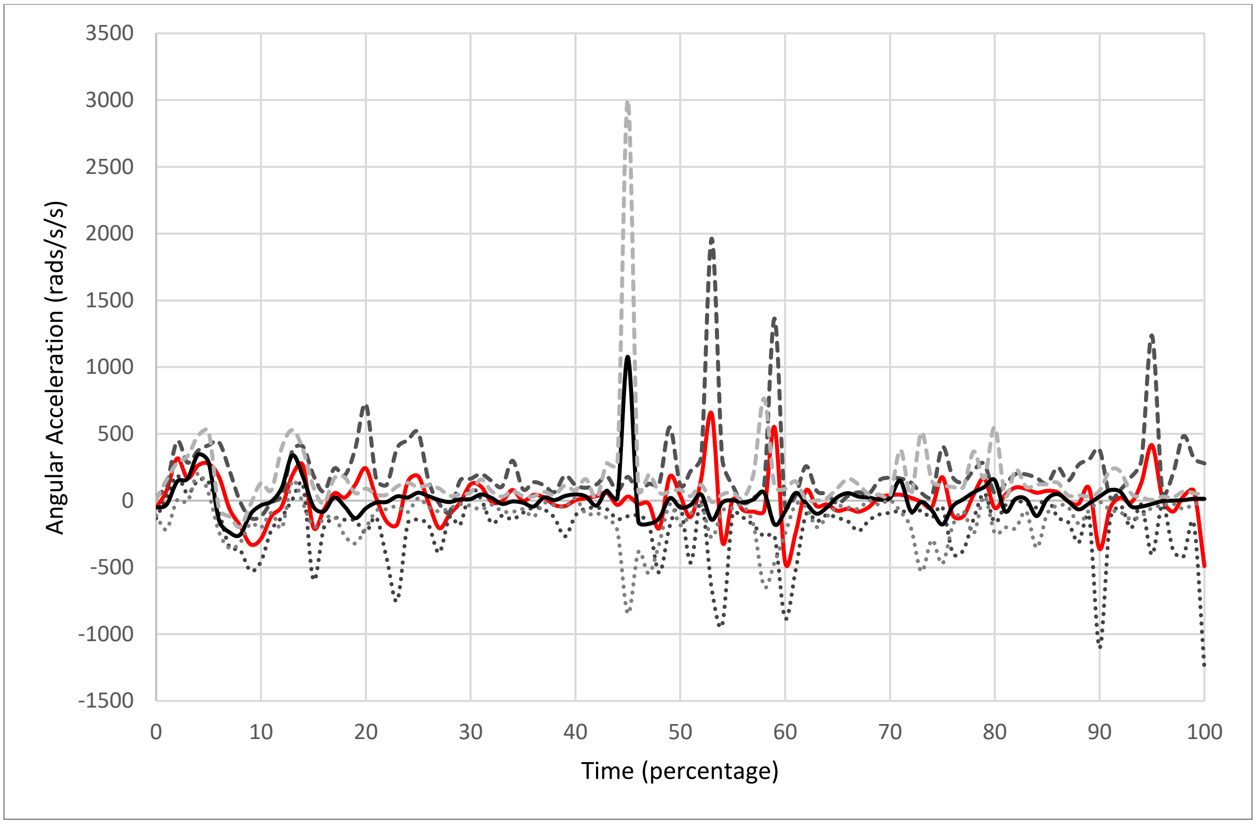


Figure 6.18: Angular acceleration mean and 95% confidence intervals of the left foot in the Y (upwards) direction for fast (red line) and slow (black line) trials of the hip-hop dolphin dive movement
Positive values represent flexion of the spine, negative values represent extension of the spine.

6.3.4 Spine segment comparison

A comparison of the four spine segments to one another yielded similar movement patterns, but differences in magnitude for ballet (Figure 6.9, Appendix 6.1), modern dance (Figure 6.10, Appendix 6.1), and hip-hop movements (Figure 6.11).

For all three dance genres, regardless of speed:

- T8T9 stayed nearly entirely in flexion (positive (+) values) throughout all movements, with a decrease in flexion during the height of the extension movement; it was the most flexed of all segments.
- T12L1 typically began slightly flexed (+) and would usually experience both flexion and extension (negative (-) values) at some point throughout the movements.

- L3L4 was extended (-) throughout the movements, with an increase in this extension at the height of the extension; it was the most extended of all segments.
- L5S1 had the greatest range of motion for all spine segments and moved through both flexion (+) and extension (-) during all modern dance and hip-hop movements.
- For ballet movements specifically, T12L1 and L5S1 had minimal flexion, and stayed extended through nearly the entirety of the movements.

Spine segment angular velocity for ballet (Figure 6.12, Appendix 6.1), modern dance (Figure 6.13, Appendix 6.1), and hip-hop (Figure 6.14) and angular acceleration for ballet (Figure 6.15, Appendix 6.1), modern dance (Figure 6.16, Appendix 6.1), and hip-hop (Figure 6.17) did not show any clear trends when comparing the spine segments to one another. A possible pattern of decreasing angular velocity and decreasing angular acceleration from T8 to T12 to L3 can be seen, but repeated trials would be needed to confirm as there exist exceptions to this trend.

6.3.5 Foot segment comparison

Foot angular velocity (Appendix 6.1) increased as the speed of the trial increased for ballet and modern dance movements. However, in the dolphin dive, larger peaks can be seen at 5% and 60% of the movement in the slow speed as compared to the fast speed. Mean angular acceleration of the gesture foot generally increased as speed increased. The exceptions were 5% of the time percentage in slow ballet trials, 50% of the time percentage in medium modern dance trials, and 45% of the time percentage (Figure 6.18) for hip-hop movements.

6.3.6 Asymmetry magnitudes and percentages

As mentioned previously, left and right trials were analysed separately for ballet and modern dance movements and reported as asymmetry magnitude (Table 6.2) and asymmetry percentages (Table 6.3).

Table 6.2: Asymmetry magnitudes between right (positive) and left (negative) for mean of ballet and modern dance movements across three speeds

(-) = L		Mean					
		Ballet			**Modern**		
		Fast Max	Med Max	Slow Max	Fast Max	Med Max	Slow Max
Spine Angles	T8T9	0.50	1.08	1.13	-1.83	-2.44	-1.28
	T12L1	0.60	1.40	1.51	-2.39	-3.22	-1.66
	L3L4	0.60	1.40	1.51	-2.40	-3.22	-1.66
	L5S1	1.03	2.91	3.29	-5.44	-7.18	-3.72

Spine Angular Velocity	T8 Y	0.42	0.52	0.28	0.99	0.45	0.76
	T12 Y	-0.15	0.05	-0.29	1.15	0.53	0.83
	L3 Y	-0.55	-0.09	-0.44	1.16	0.37	0.81
	L5 Y	-0.56	-0.03	-0.12	0.71	-0.17	0.81
Spine Angular Accel	T8 Y	-4.49	10.23	6.28	4.48	5.08	4.51
	T12 Y	-0.42	7.89	5.27	4.58	0.63	0.85
	L3 Y	-3.13	2.10	-0.22	10.18	2.53	0.30
	L5 Y	-5.13	-4.83	1.07	3.48	5.30	-1.73
Angular Velocity	Foot Y	-4.29	3.52	0.26	9.86	4.82	2.73
Angular Acceleration	Foot Y	-98.49	23.61	755.25	464.30	222.80	201.73

Asymmetry magnitude values were calculated by subtracting the mean of left-sided ranges from the mean of right-sided ranges. Negative values indicate greater magnitudes for left-sided trials, (-) = L, while positive values indicate greater magnitudes for right-sided trials.

Table 6.3: Asymmetry percentages between right (positive) and left (negative) for mean of ballet and modern dance movements across three speeds

shading > 10%			Ballet			Modern		
			Fast Max	Med Max	Slow Max	Fast Max	Med Max	Slow Max
Spine	Angles	T8T9	9%	22%	25%	-10%	-13%	-7%
		T12L1	8%	22%	25%	-10%	-13%	-7%
		L3L4	8%	22%	25%	-10%	-13%	-7%
		L5S1	6%	21%	24%	-10%	-13%	-7%
Spine	Angular Velocity	T8 Y	16%	28%	14%	23%	13%	25%
		T12 Y	-8%	3%	-19%	30%	17%	31%
		L3 Y	-26%	-4%	-27%	34%	13%	32%
		L5 Y	-18%	-1%	-5%	18%	-5%	30%
Spine	Angular Acceleration	T8 Y	-8%	24%	13%	6%	8%	9%
		T12 Y	-1%	21%	15%	7%	1%	2%
		L3 Y	-8%	6%	-1%	17%	5%	1%
		L5 Y	-13%	-15%	4%	5%	9%	-5%
Foot	Angular Velocity	Foot Y	-11%	11%	1%	29%	15%	17%
Foot	Angular Acceleration	Foot Y	-6%	2%	60%	26%	15%	31%

Asymmetry percentages were calculated by subtracting the mean of left-sided ranges from the mean of right-sided ranges, dividing by the total of both ranges (sum of left-sided and right-sided ranges), multiplied by 100 to obtain a percentage. Shaded cells represent asymmetry percentages that exceed 10%, which is the benchmark used in this study to quantify notable asymmetry.

In spine angular velocity ballet trials, the left-sided trials had wider confidence intervals than right-sided trials, especially at fast speeds. When comparing left and right angular velocities of the gesture leg, ballet trials showed an additional peak on the right side that was not seen in the left in all three speeds (example seen in Figure 6.19).

a) b)

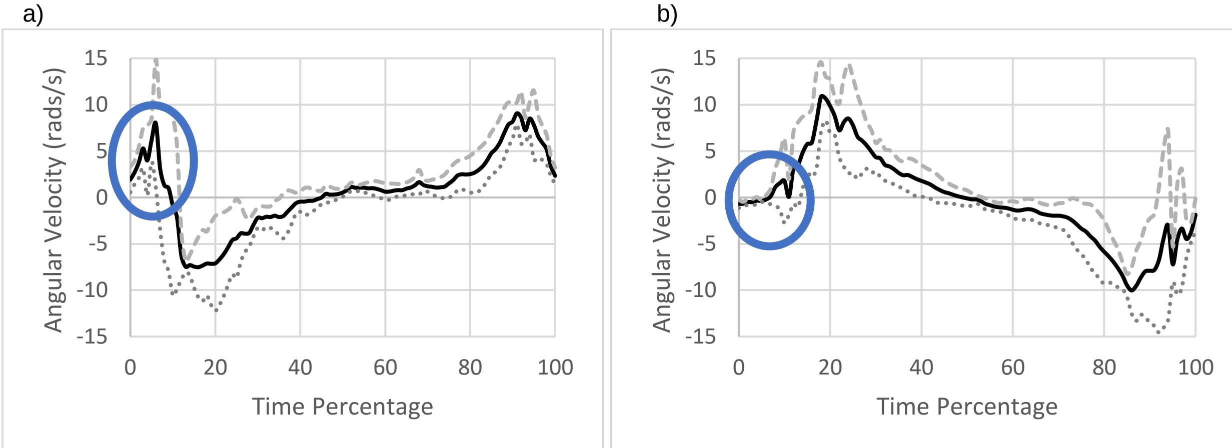


Figure 6.19a-b: Mean angular velocity (in rads/s) and 95% confidence intervals of the ballet arabesque gesture foot during right- (a) and left-sided (b) trials at a fast speed.
(a) represents Left Foot Y data (right-sided trials, negative values represent the superior aspect of the segment rotating anteriorly) and (b) represents Right Foot Y data (left-sided trials, positive values represent the superior aspect of the segment rotating anteriorly),

Angular acceleration differed between the left- and right-sided trial graphs when comparing ballet right and left trials at the fastest speed. Minimal acceleration occurred between 40% and 80% of the time-normalised movements on right-sided trials. However, more acceleration occurred on the left-sided trials during the same points in time (Figure 6.20). Ballet fast left trials had larger angular acceleration of the spine and foot segments from 40-80% of the time percentage. Foot angular velocity and foot angular acceleration were similar across ballet trials in magnitude when comparing right and left.

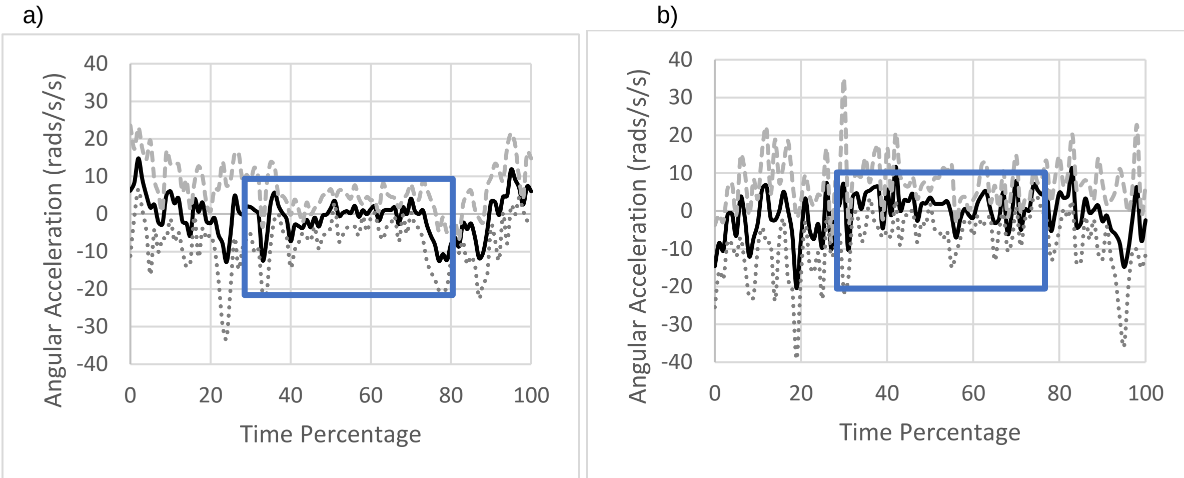


Figure 6.20a-b: Mean angular acceleration and 95% confidence interval of T8 in the Y direction on the right and left sides during a fast speed ballet arabesque movement
(a) represents right-sided trial data (negative values represent flexion) and (b) represents left-sided trial data (positive values represent flexion). The boxes around the 40-80% time-normalised values illustrate how more acceleration occurs in the left-sided trials (b) than the right-sided trials (a) during a point in the movements where the gesture leg is typically held still.

For modern dance movements, left sided trials had larger ranges of motion in all four spine angles studied for all speeds, with an asymmetry percentage of -7% for slow trials, -13% for medium trials, and -10% for fast trials (negative values indicate that the difference between mean maximum and minimum values of the left-sided trials was larger than those of the right-sided trials) (Table 6.3). For spine angular velocity, the difference between the highest and lowest values of right-sided trials was larger than those of left-sided trials for modern dance movements, apart from three medium speed values: L3 Y Right (less than the slow speed), L3 Y Left and L5 Y (more than the fast speed).

Modern dance movements had greater angular acceleration during right-sided trials of both spine and foot segments than left-sided trials, other than L5 Y at the slowest speed (Table 6.2). However, the graphs of mean angular acceleration show a larger mean and wider confidence interval at the beginning of the movement for this spine segment at the slow speed for the left-sided trials that is not present in the right-sided trials. The mean and widths of the confidence intervals for both angular velocity and angular acceleration were greater in modern dance right-sided trials than their left-sided counterparts.

6.4 Discussion

The initial objective of this case study was to determine if the speed of a movement would increase angular displacement, angular velocity, and/or angular acceleration of the spine segments during extension movements from a ballet, modern dance, and hip-hop movement vocabulary, and therefore present a risk of increasing LBP. Although only a preliminary study, the data do seem to support this claim. Across all three dance genres, angular velocity and angular acceleration overall increased both in magnitude and confidence interval widths for both spine and foot variables with increased trial speed (i.e., faster speeds resulted in higher angular velocities and angular accelerations). This finding suggests that an increase in angular acceleration would produce an increase in the torque on the spine. Magnitude of joint angles and the corresponding confidence interval did seem to increase as the speed of the trial increased (i.e., each joint flexed/extended a larger number of degrees as the movements increased in speed). However, this trend was not consistent across all dance genres, as modern dance did not have a consistent increase of ROM within the medium speed for the joint angles, nor for confidence interval width increase within the medium and slow speeds.

6.4.1 Spine angles and spine segments

As previously stated, each of the four spine angles studied (T8T9, T12L1, L3L4, and L5S1) increased in magnitude as the speed of the trials increased except for the modern dance medium speed. Although the fast speed magnitudes during modern dance trials were larger than the slow speed magnitudes, the medium speed displayed larger magnitudes than either the fast or the slow speeds. The width of the modern dance confidence intervals of the spine angles was also narrowest during the medium speed (±1 at 40%), in comparison to the fast and slow speeds (±1-2 at 40%) (Figure 6.10).

Given the uniqueness of the modern dance medium speed trials stated in the preceding paragraph, it is possible that the medium speed of the modern dance movement was more comfortable or more challenging for this participant than the other speeds. It is not clear from the current data what an increase in spine angles implies for the dancer (e.g., more comfort, so they can extend their ROM, or more challenge, where ROM is a compensation strategy?), only that the angles generally increased as the speeds increased. For instance, perhaps the slow speed is the most challenging because it requires a suspended movement quality; therefore, the participant may consciously or unconsciously have changed how they perform this movement to account for this challenge. Future studies may wish to include a subjective component to this type of research, as the amount of effort or the compensation strategies the dancer knowingly employs to complete the movement may uncover new information on these anomalies.

When comparing the four spine segments (T8, T12, L3, L5) to one another, the angles of the spine seem to increase for joints that were more inferior for all speeds and dance genres, implying that more motion occurs in the lumbar spine than the thoracic, and that joints lower in the spine provide more of the extending motion during arabesques, attitudes, and dolphin dives. At the time of this research, no literature has been published on spine angles of a multi-segment nature for the attitude movement or the dolphin dive movement.

Recent marker motion capture research by Hagins et al.[62] on dancers during a ballet arabesque posited that during extension movements, most extension (range of motion) occurs in the thoracic spine, as opposed to the lumbar spine. They defined four angles of interest between five segments: UT-LT (T6), LT-UL (L1), UL-LL (L3), LL-P (L5). They reported joint range of motion in the sagittal plane: LT-UL had the most segmental motion at 15 degrees, UT-LT had 9 degrees, UL-LL had 4 degrees, and, lastly, LL-P had about 1 degree of segmental motion. Ballet arabesque data from the current study showed the range of motion from across the three speeds to have largest values within the lumbar spine, as opposed to the thoracic: T8T9: 2.22 to 2.78 degrees, T12L1: 2.97 to 3.71 degrees, L3L4: 2.97 to 3.71 degrees, L5S1: 6.60 to 8.37 degrees. Comparing the ballet arabesque data from the current study to the Hagins results shows the range of motion in the current study to be smaller for the thoracic spine, similar for the upper lumbar area at the fastest speed, and much larger for the lower lumbar area.

It should be noted that the current study's values are from one male participant, while the Hagins et al. study had 59 dancers (females: 47, males: 12), and this may contribute to the differences seen here. The ballet arabesque position studied also differed; in the current study, first arabesque was used, while Hagins et al. used a square-shoulder second arabesque. Both are correct forms of arabesque; however, the first arabesque typically requires a rotation of the upper trunk and shoulders towards the gesture leg as part of the aesthetic of the movement. The Hagins study's second arabesque did not show this upper body rotation, and therefore, it may be more accurate for future studies to consider the different "types" of arabesques (e.g., first, second, third; Cecchetti, Russian) as individual movements that may require different spine motions or strategies to complete.

Wilson et al.[65] studied the ballet movement rond de jambe en l'air, which is a circular leg movement that passes through a stationary arabesque position, with the right leg used as the gesture leg in all trials. They used a four-segment model of the spine, but the lumbar spine was one segment (T12 to between the two PSISs), and the thoracic spine was three segments (C7 to T3, T3 to T7, and T7 to T12). They reported a "trunk" angle of 10 degrees extension during the arabesque phase of this movement, which it seems they defined as the thoracic spine, with an origin at T12 and end point at C7. This is comparable to the 9 degrees of the UT-LT segment in the Hagins et al. study but is significantly more than the 2-3 degrees seen in the current study. These similarities are likely because both the Wilson et al. study and the Hagins et al. study utilised square torsos, as opposed to the rotation of the torso towards the gesture leg seen in the arabesque used in the current study.

6.4.2 Spine angular velocity

The angular velocity of the spine segments mostly decreased for sequentially inferior segments, with a few exceptions and the entirety of L5, which had a larger range than the superior L3 segment in the ballet and modern dance movements. The mean angular velocity did decrease in more sequentially inferior segments for hip-hop dance; T8 had the largest range of mean angular velocity and L5 had the least during the dolphin dive. There was also a clear increase in angular velocity with the speed of dolphin dive movement. This trend is less clear in ballet and modern dance; the slow speed always had less angular velocity mean than the fast speed, but the medium speed had five instances where the medium speed values did not fall between the other two speeds. These anomalies occurred across all spine segments and in both left and right ballet and modern dance trials. It is possible with a larger sample size that these anomalies may not be as apparent. As mentioned in the Introduction section of this chapter, not much research has been published on the multisegmented motion of the spine during dance tasks, therefore comparison is difficult. To date, no research on the angular velocity or linear velocity of multiple spinal segments during the arabesque, attitude, or dolphin dive movements has been published.

6.4.3 Spine angular acceleration

In the current study, angular acceleration in the sagittal plane increased as the speed of modern and hip-hop dance movements increased, implying that faster movements had greater angular accelerations. In ballet movements, only L3 left- and right-sided trials and L5 left-sided trials followed this trend; spine angular acceleration in the remaining segments did not show any clear trends for ballet movements. However, if the medium speed is ignored, then increased angular acceleration with increased speed is conserved, apart from slow right-sided trials for the T8 segment, which had 0.11 rads/s/s more range than the fast speed.

Small sample size and different performance strategies may have influenced these anomalies. However, the amount of spinal movement when comparing the ballet, modern dance, and hip-hop movements may also play a role. Due to the ballet arabesque having the most upright spine, with the least amount of torso movement when compared to the modern dance attitude and hip-hop dolphin dive movements, it is plausible that a great amount of angular acceleration is not required, or at least, does not greatly differ when increasing movement speeds. Additional manipulation of an off-centred pelvis is required to achieve the aesthetic desires of the modern dance and hip-hop movements studied here; in contrast, a ballet arabesque is typically performed with the aesthetic desire of *reducing* momentum as much as possible. Perhaps there exists a span of angular accelerations for the piqué arabesque at any speed, and speed does not necessarily influence angular acceleration within a certain span. The spine segment angular acceleration for the ballet arabesque ranged from -20.41 rads/s/s (T8; left-sided trial, fast speed) to 16.15 rads/s/s (T8; right-sided trial, slow speed). Future studies can consider quantifying the speeds of other dance genres or specific repertoire when completing motion capture studies on the ballet arabesque. Then, angular acceleration values can be compared to those provided in the current study to address if angular acceleration values exist outside of the angular acceleration presented here.

6.4.4 Foot angular velocity and angular acceleration

Angular or linear velocity measures have been reported in some studies for the ballet arabesque, typically in degrees per second (deg/s) or metres per second (m/s), respectively. In the current study, ballet arabesque mean angular velocities (expressed here as absolute values) for the gesture leg foot ranged between 5.41 rads/s (left-sided trial, slow speed) and 10.85 rads/s (left-sided trial, fast speed). Feipel et al. reported maximal velocity of the gesture leg during arabesque, which they called the velocity of plateau installation in flexion/extension, to be 19±13 deg/s. The speed of the trial and specifications regarding which kind of arabesque was used were not reported, although there are context clues that suggest they did not use a developpé-style arabesque. The mean maximal velocity of the arabesque gesture leg in the current study (where positive was “up” and negative was “down”) was +10.85 rads/s for left-sided trials (fast speed), and +9.44 rads/s for right-sided trials (medium speed), which is significantly faster than the Feipel et al. study values (10 rads/s is approximately 573 deg/s).

Bronner[67] quantified the timing of joints during the ballet arabesque movement for dancers of three different experience levels. While they did measure mean peak velocity of the gesture knee, these values were not reported, as only the timing (in seconds) of hitting the peak velocity was reported. The current study reports mean angular velocity of the gesture foot to be approximately -10 to 11 rads/s for the fast speed, -7 to 9 rads/s for the medium speed, and -7 to 7 rads/s for the slow speed. Bronner and Ojofeitimi[66] also published a study on the battement derrière, which can be thought of as a stationary arabesque where the gesture leg is “kicking backwards” posteriorly. They reported linear velocity of the toe in the sagittal plane to be approximately 4.2 m/s during the ascent and approximately 2 m/s during the descent. Because the current study measured angular velocity of the gesture leg, direct comparisons cannot be made.

In 2022, Kawano et al.[64] used a two-segment model of the spine to examine piqué arabesque en pointe. They tracked the displacement of a 36-marker system and performed first- and second- order derivatives to obtain their velocity and acceleration values. However, this study was primarily concerned with using biomechanical factors as determinants for identifying "good" arabesques, and therefore, the reported outcome measures did not match those examined in the current study. For their high scoring (most desirable arabesque) group, they did report lumbar spine rotation angle (28.41±3.65 degrees), maximum linear velocity of the thorax (1.63±223.71 m/s), and maximum angular velocity of the gesture leg hip, which was the right hip for all trials (174.26±46.15 deg/s, which is approximately 3.04 rads/s).

To date, no one has reported angular acceleration of the gesture leg during arabesque, attitude, or dolphin dive movements. Han et al.[87] did report angular velocity measures for limb parameters (e.g., ankle, wrist) during the windmill, a popular hip-hop movement. While direct comparison with the current study is not possible, this study demonstrates that hip-hop dancers are exposed to high angular velocities during their movements.

6.4.5 Asymmetry

Asymmetry percentages were reported for ballet arabesque and modern dance attitude movements. Ballet spine angles had positive asymmetry magnitudes in the sagittal plane for all right-sided trials (Table 6.2) and had the highest asymmetry percentages at slow speeds, followed by medium speeds; the fast speeds had less than 10% asymmetry for all spine angles (Table 6.3). Wang et al.[221] presented a conference proceeding in 2008 on the grand battement, and although it is not clear which directions were examined due to the translation. Possible directions include anteriorly (devant), laterally (a la seconde), or posteriorly (derrière), with posterior being the direction of grand battement that most closely mimics the arabesque used in the current study. Overall, the researchers found no differences in hip and trunk flexibility measures between the preferred and nonpreferred sides.

However, skilled dancers have been shown to utilise compensations in the pelvis and the torso during grand battement devant, but the compensations were not made especially visible, to maintain the aesthetics of the movement.[222] Impaired motor control may also lead to compensatory strategies in the spine and lower limbs in dancers,[223] although the study did not specify which genres of dance were included. The asymmetries seen in the current study may be explained by a similar alteration of movement strategy or a compensation that favours additional motion on the right side, and even more motion as speed decreases.

During the peak of the arabesque, the gesture leg is suspended in the air; this suspension occurs between 40% and 80% of the time percentage of the movement. There should be minimal changes in acceleration because the leg is aesthetically desired to be held still at the peak of the movement. However, as shown in Figure 6.20 and Appendix 6.1, larger acceleration oscillations occurred in the spine and gesture leg between 40% and 80% of the movement during left-sided arabesque trials than during their right-sided counterparts. This may imply more movement or less stability of the gesture leg when it is in the air during left-sided trials, foreshadowing a muscle imbalance/weakness or a compensation strategy. Dance research on lateral bias suggests that a right-sided bias is common, with university dance majors having the expectation of dance classes beginning with right-sided movements[42], and up to 26% more repetitions of movements on the right rather than the left during ballet classes.[45] Asymmetries were found to be common in collegiate dancers during the Functional Movement Screen™, with more than 44% of the dancers presenting with one or more asymmetries.[224] The same study reported that 43% had dysfunctional movement patterns when performing non-dance tasks.[224] Ballet dancers have been shown to have asymmetrical trunk musculature.[109] All of these factors: lateral bias, functional asymmetry, additional right-sided repetitions when learning, and dysfunctional movement patterns, may contribute to the asymmetry seen in the current study.

In the ballet trials of the current study, mean angular velocity and mean angular acceleration for both the spine and the foot of the gesture leg did have some high asymmetry percentages sporadically, but there was no discernible pattern, possibly due to the low number of participants in the study. It could also be that mean range of motion does not provide a clear measure of asymmetry for these variables within a small case study. Ballet movements may be more symmetric than modern dance movements, as modern dance movements had larger mean and asymmetry magnitudes. However, subtle asymmetries in the ballet movements may be present, as they had larger asymmetry percentages than their modern dance counterparts. Yet the magnitude of ballet movements was small overall, thus the asymmetry percentages may be inflated for these movements. More research is needed to determine asymmetries using a multi-segment spine model during arabesque.

During right-sided ballet trials (left foot as the gesture leg) of all speeds in the current study, the angular velocity trajectories displayed an additional increase (in the positive direction) at the beginning of the movement that is not seen in left-sided trials (right foot as the gesture leg) (Figure 6.20). Because the increase is seen consistently in all speeds and all trials on one side but not the other, it is unlikely to be an equipment error, such as a loose sensor, as sensors were checked every few trials. This same increase was mirrored in the toe angular velocity data, but not in the lower leg angular velocity data, and the positional data of the foot and toe showed no anomalies. Two explanations for this occurrence may be the utilisation of a stronger "push off" from the foot or a "hitch" in the gesture leg as it leaves the ground.

First, if previous asymmetry research into lateral bias applies to the current study, then arabesques where the right leg is the supporting or standing leg (in this case, right-sided trials) may include an additional strategy at the left foot or ankle to perform the movement, as the right sided movements are more practiced than the left in class.[43] Dancers may include greater involvement of the ankle during ballet jumps as opposed to countermovement jumps,[225] so pushing off of the foot through the ankle may represent a more advanced skill of additional ankle/foot involvement. However, the vertical positional data (Z-direction) of the gesture leg's foot segment showed the same height, ranging from approximately 0.8m to 1m, reached for both the right and left-sided trials, suggesting that this "push off" may not improve a central aesthetic desire of the arabesque movement.

Second, a lack of smoothness in movement execution can be quantified as jerk, the second derivative of velocity. The initial increase in mean angular velocity seen in the graphical representations of right-sided trials (Figure 6.19) corresponds to large peaks and troughs seen in the graphical representation of the mean angular acceleration of right-sided trials (Appendix 6.1). Jerk cost functions have been used to measure the smoothness of developpé arabesque previously, where more skilled dancers applied a minimum jerk model of skill acquisition[226] (i.e., expert ballet dancers had less jerk and more smoothness than beginners). Female ballet dancers with LBP have also shown less lumbar movement smoothness than those without LBP during non-dance flexion and extension tasks.[227] In the current study, the increase in initial angular velocity and the larger angular acceleration values may indicate jerk. More jerk and less smoothness present during right-sided trials may suggest less skill or an alternative movement strategy that was not present in left-sided trials. Repeated trials with the addition of a detailed foot model may provide more definitive conclusions on this asymmetrical movement pattern.

For modern dance trials, the asymmetry percentages were consistent across spinal joints (e.g., the asymmetry percentage was - 7% for all spine angles during slow trial speeds), and relatively low (-7 to -13%) (Table 6.3). Spine angular velocity asymmetry percentages were larger for right-sided trials and notable in size (+13 to +34%), except for L5 during the medium speed trials, which did not present with marked asymmetry (-5%) (Table 6.3). Spine angular acceleration had only one asymmetric segment, L3, during the fast trial speed (+17%); the rest of the segments were symmetric through all speeds, meaning less than 10% difference in asymmetry percentage. Modern dance right-sided trials had greater angular velocity and angular acceleration, with spine angular acceleration having some anomalies to this pattern. However, the spine angles had greater mean ranges of motion on the left-sided trials. It is possible that increased angular acceleration and angular velocity can compensate for decreased range of motion in spine angles, or vice versa. A previous study by Yoon and Lee[48] on Korean university dance major students reported that torsion of the right pelvis half was most common in modern dancers when standing at rest. Although their findings were not significant ($p>0.88$), physical asymmetry does provide a possible explanation for the imbalances seen in the current study.

The role of the pelvis in the attitude movement may also be supported by research on rond de jambe en l'air,[65] where expert ballet dancers employed a strategy of pelvic movement not seen in novice dancers. More pelvic movement may suggest a more effective movement strategy, and more shift in the pelvis would undoubtedly be reflected in the adjacent spinal segments. Arabesque research also suggests that hip flexibility may contribute more than the lumbar spine to the arabesque movement,[59] again implicating the importance of the pelvis and hip during extension movements like the arabesque. Chowning et al.[49] examined leap-landings of saut de chat leaps in contemporary (modern) dancers and found that dancers may use different landing strategies for dominant limbs as compared to non-dominant. It is possible that a similar asymmetry in movement strategies is seen in the data from the current study. However, it is unclear if ballet findings could be applied to a modern dance movement in this context.

6.5 Conclusion

The current case study presented here demonstrated some interesting trends that require further study within a larger sample to confirm. Trends of increased angles of the spine, increased angular velocity, and increased angular acceleration as the speed of the movements increased were observed. The trend of increasement suggests that forces at the spine will also increase during extension movements, making the arabesque, the attitude with body roll, and the dolphin dive risks for exacerbating LBP in dancers who perform them at faster speeds. The trends shown here may be particularly relevant for the level of the L5 and S1 vertebrae, where the largest range of motion occurred. It is possible that L5, being adjacent to S1/the pelvis, displayed the most movement because increasing movement in the pelvis is an adaptive strategy employed by experienced dancers to complete complex movements.[65,222] More research is required to confirm if the trends shown here would apply to a larger population or additional trials.

The participant in this case study showed subtle but marked asymmetries in performing the three movements. The asymmetries seen in the current study may have been part of a movement strategy to adapt to the challenges presented or to elongate within the dancer's comfortability. The medium speed may have been a more comfortable speed for the modern dance movement, as confidence intervals were the narrowest during this speed. Future research can consider reporting both sides of a movement to aid in asymmetry research even if the focus of the study is not to compare right and left sides. Researchers may also consider adding dance-specific sidedness questions to their pre-study questionnaires or including subjective measures where the participants can note any differences that they perceive in their performance of a movement. Giving dancers the opportunity to note if they are consciously using a certain movement strategy or to incorporate participant input on how the movement "feels" (too fast, too slow) can allow for further exploration about the nature of asymmetry in dance.

7 Summary discussion

7.1 Introduction

The summary discussion presented here will synthesise the major results from the studies within this thesis. Then, the summary discussion will offer applied applications for the research findings, as well as providing recommendations for future studies in the field of LBP in dance.

The initial goal of this thesis research was to determine prevalence and ideally risk factors for LBP across ballet, modern, and hip-hop dance populations. However, a systematic review of the literature revealed that a dearth of publications and the heterogeneity of methodology used in the existing studies prevented comparison, and, in terms of prevalence, often contradicted one another. The lack of agreement on LBP prevalence led to the first study, Study 1, aiming to establish prevalence of LBP through an online survey, although limited survey reach prevented conclusive quantification. Additional goals of the survey were to ask the dancers who had LBP in what ways it may have impacted their lives, the severity of their LBP, and how they managed their LBP. Within the survey, dancers with LBP identified spinal movements, especially extension movements like the arabesque, as increasing their LBP.

To test if frequency of exposure to spinal extension movements may play a role in LBP, the aim of Study 2 was to quantify how often dancers are exposed to spinal movements within various dance environments. Therefore, Study 2 used videos on YouTube.com to count spinal, impact, and partnering movements in seven dance environments: ballet class and performance, modern dance class and performance, and hip-hop breaking, cypher, and battle environments. The high frequency and high rate of spinal extension movements across the dance environments led to the final study, Study 3, in which three spinal extension movements were examined in a case study using motion capture technologies: the ballet arabesque, the modern dance attitude with body roll, and the hip-hop dolphin dive. Two novel approaches were applied to studying the spinal extension movements: an examination of speed and asymmetry. The main aim of Study 3 was to determine if angular displacement, angular velocity, and/or angular acceleration of the thoracic or lumbar spine would increase as speed of the movement increased, and therefore increase the risk of LBP by increasing the associated joint moment. A secondary goal was to assess if there were any noticeable asymmetries present that could present a risk of asymmetrical forces.

7.2 Summary of the main findings

The main findings are summarised here. The literature review was the first of its kind to directly compare LBP research in ballet, modern, and hip-hop dancers while assessing the quality of the research; the review revealed that not enough research of high quality exists. The heterogeneity of research techniques prevented comparison across studies. Too little research on LBP in modern and hip-hop dancers has been published. From what has been published, ballet, modern, and hip-hop dancers may be at risk for LBP or LBI, but to what extent cannot be concluded until more evidence has been reported.

Study 1 used an online survey to assess prevalence of LBP in ballet, modern, and hip-hop dancers. The survey queried dancers for their perspectives on the impact of their LBP and management strategies of their LBP, with a secondary goal of comparing differences across dancers from different primary dance genres. While a lower-than-desired response rate prevented a confident establishment of prevalence, the novel impact and management data obtained in the survey were the first reports to focus on the LBP experiences of dancer in their own words. The Study 1 results supported claims that dancers do not always seek care for LBP, as well as providing important benchmark measures for pain intensity (2-4 out of a 0-10 scale). Dancers may not seek care until their LBP becomes debilitating and dancers may seek out care from multiple professionals when they do. The survey also established which spinal extension movements dancers noted increase their LBP. There were no notable differences between the dance genres. The findings from Study 1 suggest that dancers may be at risk of LBP regardless of their primary dance genre, with a low-moderate pain intensity, and that dancers may not seek care until pain increases.

Study 2 established important benchmark counts of spinal (flexion, extension, lateral flexion, and rotation), impact (jumps, leaps, and falls), and partnering (lifts, catches, and leans) movements in seven performance environments: ballet class and performance, modern dance class and performance, and hip-hop breaking, cypher, and battle environments. This is the first study to report movement counts in class environments, and for hip-hop dance genres. Work interval, length, and work-to-rest ratios were also calculated. Study 2 confirmed that movement demands do differ across ballet, modern dance, and hip-hop dance genres. The work-to-rest ratios were not the same for ballet and modern dance classes and performances, and ballet and modern dance had work-to-rest ratios of 1:1 in aggregate, as compared to the 1:3 of hip-hop dance. To summarise, notable differences emerged in the demands of class environments versus performance environment and demands amongst the three dance genres. Movement counts also differed between the three dance genres, but all dancers will likely be exposed to either a high number or high frequency of spinal extension movements. Ballet performances saw the highest number of spinal extension movements (77±69.8 movements), while hip-hop battles had the greatest rate of spinal extension movements (approximately 7 movements per minute). The innovative findings from Study 2 also suggest that dancers will be frequently exposed to the specific movements identified in Study 1 as increasing their LBP, such as the arabesque.

Lastly, Study 3 presented a motion capture case study of three spinal extension movements, one from each dance genre studied in this thesis: the ballet arabesque, the modern dance attitude with body roll, and the hip-hop dolphin dive. This study was the first motion capture study to report on the attitude with body roll and dolphin dive movements. A general trend of increased joint angles, increased angular velocity, and increased angular acceleration were seen in all four spine joints/segments, two thoracic and two lumbar, as the speed of movement performance increased. This trend suggests that the joint moments may increase as speed increases, which would make speed a risk factor for compression and thus pain within the spine.[167,170] There may exist preferred speeds for movement performance, as the confidence intervals of the mean spine angles in the modern dance movement were narrowest during the medium speed. Asymmetrical movement patterns were present in the ballet and modern dance movements (hip-hop movement asymmetries were not reported due to the symmetrical nature of the dolphin dive movement). The asymmetries seen here may foreshadow either movement compensation strategies or comfortability with certain speeds/movements on one side more than the other. The case study presented here has shown that speed and asymmetrical movement patterns exist that may be associated with increased risk of LBP, but further investigation is required to confirm if there is a concrete risk of LBP.

7.3 Limitations

As with all studies, the recognition of limitations is crucial to situate results appropriately. The initial pilot study within Study 1 was small, and the participants were more experienced and older than the final survey population results; a tool with confirmed validity within the target population would allow future studies to be more robust. Data within the Study 1 survey were collected over two month-long time points. Dancers could complete the survey anytime within the month that the round was open. While this sampling technique was purposefully chosen to increase the completion numbers of the participants, the findings are limited to a part of the year (i.e., when students go back to school after summer break).

Participants were actively recruited from university-level dance programs; therefore, the dataset in Study 1 was skewed towards younger adults whose dominant dance style was modern dance. And as mentioned previously, participation bias may also be a limitation to this study, i.e., participants were more likely to take part if they had LBP than those who did not have any LBP. Therefore, prevalence data here should be interpreted with caution. Additionally, the response rate is unknown other than 22 of the 150 contacted universities confirmed they would share this study with their networks. Finally, while multiple steps were taken to limit recall bias in Study 1, there was a possibility of recall bias in questions that assessed lifetime history of a condition or previous action.

In Study 2, the use of YouTube dance videos provided data on the dancers' real-life experiences and, therefore, increased ecological validity. However, the subjective nature of video recording led to some limitations for this study. The videos were not recorded with the goal of aiding movement count video analysis. Thus, the camera angles or cuts forced the reviewer to make assumptions based on what movements may have transpired outside of the camera's view. Additionally, hip-hop dance videos were densely populated with multiple, quick movements and required videos to be slowed to 0.25x-0.5x speed for viewing. The "costumes" were not form fitting and camera angles were more challenging with the dancers changing their facing to address all members of audiences who sat in the round. Future research examining movements counts in hip-hop dance may benefit from a reviewer who has achieved expertise in the movement vocabulary to overcome the inherent video recording challenges, and hip-hop data for Study 2 should be interpreted with caution due to these limitations.

Study 2 also assumed that dance classes and performances posted to YouTube were representative of their in-person counterparts. Level of difficulty of the classes was not controlled for. With the COVID-19 global pandemic, in-person activities like dance classes moved online. Class leaders did not specify if they had altered their typical class structure due to online format, although some did give modifications for dancers who may not have as much movement space, with some leaders referencing the pandemic as the impetus for recording a class video. Additionally, modern dance is a broad categorisation that encompasses a wide range of movement styles within it (exemplified when comparing the different modern dance works of Pilobolus,[228] versus those of the Kansas City Contemporary Dance,[229] versus those of the Alvin Ailey group[185]). The lack of subdivision within this study's modern dance category may have affected the movement count medians for this dance genre, while also being representative of the eclectic nature of the "modern dance" genre. Future researchers should consider sorting their modern dance videos into subgroups, such as by subgenre (e.g., classical, post-modern) to improve practical recommendations.

A limitation of Study 3 was that the pre-screening questionnaire changes had not been independently validated. The changes made to the questionnaire were small, added to better suit a dance-specific population, but it is possible that these alterations in phrasing or the inclusion of additional questions may have had an unintended effect or produced inaccurate data by influencing the participant in unknown and unanticipated ways. Additionally, as mentioned previously, asymmetry "best practices" have not been established for the dance movements within the current study; results based on asymmetry magnitude and a modified BAI-1 formula may be proven by future research to be incorrect measures of asymmetry. Another limitation was that the investigation was a case study. However, by utilising the same dancer for all movements, some confounding variables could be reduced when comparing across dance genres due to a single individual having performed all three movements.

Lastly, the third study relies heavily on the biomechanical model of the XSENS suit and the MVN Analyze program. Although this motion capture suit allowed for collection of whole body and multi-segment spine segment data simultaneously, the manufacturer has provided limited information on data processing. Future studies may consider creating their own model of the spine "from scratch", so that details on data outputs can be more transparent and validated. While direct validity testing of the suit in relation to the model of the spine seems to be lacking in published literature, the validity of the sensors individually placed on the spine[230-238] and the XSENS MVN suit built-in model as a whole[239] have been studied previously.

7.4 Strengths of the present research and contribution to literature

The strengths of the research presented in this thesis are summarised here. Important contributions to research on LBP have been offered through these studies. While there have been multiple literature reviews on LBP in dance since this thesis was undertaken, a focus on ballet, modern, and hip-hop dance in LBP review simultaneously, with inclusion of risk of bias and study quality, adds important visibility and robustness for the three dance genres studied here.

The practical relevance is a strength of Studies 1, 2, and 3, which will be discussed at length in section 7.5 of this thesis. Study 1 provides a measure of the dancer's experience with LBP, while also placing that experience at the centre of the reported results. The dancer-centric approach taken in Study 1 is as important scientifically as it is philosophically for researchers trying to understand LBP in a dance context. Pain intensity parameters, LBP management, and care-seeking behaviours have significant means to direct future research and to inform applied recommendations.

While movement count studies have been performed previously on ballet and contemporary performance,[156,157] Study 2 was the first study to establish movement count data for class environments. To date, Study 2 provides the first movement count video analysis study on any hip-hop dance environment. An additional strength of Study 2 would be not just the inclusion of hip-hop dance in the study, but to tailor the study to fit what is authentic to hip-hop dance. Rather than separating hip-hop dance into class and performance as with ballet and modern dance, environments that are more authentic to hip-hop were used: breaking, cypher, and battle environments. The three hip-hop environments were combined into a 'non-proscenium performance' environment, because most hip-hop performances do not occur within a traditional proscenium stage setting. Thoughtful consideration of hip-hop dance's inclusion within research can make practical recommendations more relevant and accurate for the target population.

Study 3 lays the foundation for future research, as no movement analysis studies on the attitude and dolphin dive movements have been published previously. Additionally, no multi-segment spine studies have been published on the first arabesque, attitude, or dolphin dive movements. Testing multiple models and motion capture recording equipment options allowed for a repeatable solution that was practical while still capturing data from within a multi-segment spine model framework.

Two central underpinnings of the current studies have been to include populations that may have less research published previously, such as modern dancers but especially hip-hop dancers, and to include the dancers' perspectives/voices in the research. While the research presented here does take important steps towards those goals, I challenge myself and future researchers to continue to strive for inclusivity and visibility for a variety of dancer populations, and to keep the dancer experience central to the research.

7.5 Applied implications and recommendations for future research

Due to the numerous practical applications of the research presented in this thesis, this section has been divided into three 'Practical Applications' headings: one for each of the three studies. Study 2 presents strengthening suggestions for each individual dance genre, ballet, modern dance, and hip-hop, as well as suggestions for all dancers; the suggestions correspond to four subheadings within the Study 2 practical application section.

7.5.1 Practical Applications from Study 1

The current findings suggest that dancers of any dance genre are likely to experience LBP, as dance genre did not significantly impact LBP prevalence in Study 1. Health care professionals should expect LBP complaints when working with dancer populations and may consider preventative LBP measures for all dancers. In the Study 1 survey, most dancers reported that their LBP increased through spinal extension movements; dance educators and artistic directors who support dancers with high volume repertoire should implement specific LBP preventions or interventions for dancers who participate in creative works that contain these movements repetitively. Dancer support staff should be aware that their dancers may have LBP but may not seek care until pain increases or function decreases. It may be prudent to discuss local or widely accessible LBP resources with dancers to hopefully increase care-seeking. Fostering an environment of communication around LBP can encourage dancers to proactively address their LBP before it becomes debilitating.

7.5.2 Practical Applications from Study 2

Dancers with LBP can expect a high number of spinal movements in ballet, modern, and hip-hop dance. According to the results of the Study 2, dancers can expect to be exposed to a high number of total spinal movements in both ballet and modern dance classes and performances. Dancers may also expect a high frequency of spinal movements per minute of dancing within modern dance class and performance, hip-hop breaking, cypher, and battle environments. Dancers with LBP should recognise their frequent exposure to LBP-associated spinal movements may cause an increase in their LBP. Dancers should discuss preparation, movement technique, and recovery from pain with a qualified professional to prevent negative impact to activities of daily living or dancing.[94] If dancers are exposed to movements that exacerbate low back pain as often as these findings suggest, a targeted supplemental training program may be helpful to reduce pain or injury. For example, dancers with LBP display altered lumbopelvic motor control as compared to dancers without LBP.[223] Adding exercises to improve this control may be beneficial to all dancers who may be exposed to movements that are associated with LBP.

Additionally, dancers with or without LBP who may be mixing genres or alternating between dance genres should expect that the movement demands of each will be different and each may present different risks for LBP. Dance educators and support staff can help dancers avoid injury by thinking through the demands of the repertoire and helping dancers structure their classes or extracurricular activities to strengthen the necessary muscles. Dancers returning from an injury may also consider the movements demands of their repertoire and how this may impact their return-to-work plan. With these overarching themes, the following recommendations are offered for specific dance genres.

7.5.2.1 Strengthening Recommendations for Ballet Dancers

I have observed that during performance, ballet dancers are exposed to a high number of spinal extension movements, jumps, leaps, and partnering movements (lifts, catches, and leans) in comparison to the other dance genres and to ballet classes. Spinal extension movements occurred most often in the form of arabesques, where one leg lifts behind the dancer, but the chest is aesthetically required to remain upright. Therefore, I recommend that ballet dancers strengthen their back extensor muscles (such as multifidus muscle, which has been shown to have a smaller cross-sectional area in professional ballet dancers with LBP than those without[240]) and their antagonists, the core musculature (such as the transversus abdominus, which has been shown to have reduced slide during 'drawing in' for professional ballet dancers with LBP[109]). To manage the high number of leaps and jumps, ballet dancers would benefit from strengthening their lower extremity muscles[241,242] while also avoiding overuse injuries,[241] particularly of the ankle which has increased involvement in ballet jumps as compared to countermovement jumps.[225] Lastly, because lifts, catches, and leans were relatively frequent (once per minute) during ballet performance, ballet dancers should ensure that they are obtaining adequate partnering instruction and practice in a safe environment to prepare themselves for partnering movements.

7.5.2.2 Strengthening Recommendations for Modern Dancers

The current study found the highest number of spinal flexion, spinal rotation, and spinal lateral flexion movements during modern dance classes. In modern dance performance videos, it was also observed that the clear delineations of movement planes that exist during classes were blurred, with dancers often employing two, sometimes even three, spinal movements at one time (e.g., flexion, rotation, and lateral flexion simultaneously). The emphasis on movement of the spine would seem to require maintenance of spinal flexibility and mobility. Modern dancers would likely benefit from a warm-up routine that includes a particular focus on the spine to prepare for the high number of spinal movements they will experience. Strengthening the muscles involved in spinal motion, such as the core musculature and back muscles may be helpful. Having dancers strengthen their internal and external oblique muscles specifically will assist them with spinal rotation and lateral flexion movements.

7.5.2.3 Strengthening Recommendations for Hip-hop Dancers

Because hip-hop breaking, cyphers, and battles are social dance forms that do not have a formal class structure in most cases, individual hip-hop dancers should find what works for them in terms of routine and dance preparation. While there were a few movements that were common within the hip-hop category, each dancer had their own individual repertoire and style of execution, meaning overarching recommendations may not work for this dance style. However, I observed that most hip-hop dancers performed for approximately 30 seconds, often at a quick pace or high intensity. Some high-intensity interval training (HIIT) may be beneficial to mimic the 30 seconds dancing, 30 seconds rest format.

The current study identified that breakers were exposed to the highest number of falling movements, as well as high numbers of spinal flexion and rotation movements per minute of dancing. Therefore, I recommend that breakers find safe environments to practice these falling movements, and caution breakers from attempting new falling movements for the first time during performance. Breakers may also benefit from strengthening their internal and external obliques to prevent fatigue of these muscles during toprock and downrock movements, as well as some power moves and freezes.

In the cypher and group battle formats, I noted that dancers were likely to have more time to recover as they waited for the other dancers in the group or on their team to take a turn dancing. The dancers observed in the cypher format had a high frequency of jump movements, meaning fatigue could be an issue for dancers that include many jumping movements in their repertoire. Plyometric movements, especially those involving jumping, may be beneficial to increase power and stamina for dancers who jump often. In the battle format, a high number of spinal extension movements per minute were identified. Strengthening the back extensor muscles and their antagonistic abdominal muscles, with a focus on muscular endurance, may help hip-hop dancers with repertoires that include frequent spinal extension to avoid fatigue.

7.5.2.4 Strengthening Recommendation for All Dancers

Based on these findings, I recommend that all dancers strengthen their back and core muscles due to the frequency of spinal movements in all dance environments included in this study. I also suggest that ballet dancers strengthen their lower extremity muscles due to high volume and frequency of impact movements, as well as obtaining sufficient partnering movement practice as partnering movements could be as frequent as one per minute in ballet performance environments. For modern dancers and breakers, I recommend strengthening the internal and external obliques due to the frequency of spinal rotation and spinal lateral flexion movements.

For hip-hop dancers who participate in cypher and battle formats, I recommend increasing muscular endurance to avoid fatigue.

7.5.3 Practical Applications from Study 3

Although more research is needed to confirm the trends from the motion capture case study from Study 3, the data does suggest tendencies that have a practical relevance to the dance populations studied. There may be an increased risk of LBP as the speed of the movement increases. Ballet, modern, and hip-hop dancers may wish to develop a preparation plan for repertoire that contains spinal extension movements at a fast speed. Specific strengthening recommendations for each genre have been presented in the previous section. Dancers may find certain movement speeds to be more comfortable or more challenging depending on the movement being executed. Therefore, dancers may wish to assess which tempos present them with the most challenge so that they can practice incrementally increasing or decreasing comfortable tempos to prepare for the speeds they find most challenging.

The asymmetrical movement execution seen in Study 3 suggests either anatomical imbalances or movement strategy differences between right and left sides; future research to determine the context surrounding the asymmetries is required. Dancer support staff may consider screening dancers to identify body asymmetries. Dancers and support staff with access to motion capture technology can use it to assess asymmetries in movement patterns. For dancers and support staff without access to motion capture technology, an innovative strategy may be to instead review recorded videos of the dancer performing common or repeated movements on both left and right sides to identify differences in movement patterns or possible compensations. However, subjective interpretation of movement may be a limitation of this methodology. Dancer support staff should be aware that asymmetries may be more subtle in the ballet arabesque as compared to the modern dance attitude with body roll. Modern dance movements specifically may demonstrate an increased angular velocity and angular acceleration of the spine and gesture leg for right-sided than left-sided modern dance movements. Lastly, dancer support staff may wish to examine the spine and torso more closely during certain speeds of movement, as Study 3 noted that higher asymmetry percentages for mean spine joint angles (T8T9, T12L1, L3L4, and L5S1) were identified as speed decreased for ballet arabesques, and during the medium speed for the modern dance attitude.

Concluding remarks

The body of work presented in this thesis has examined LBP in ballet, modern, and hip-hop dancers and provided practical recommendations for these dance populations. A review of previous research indicated that more research on modern and hip-hop dance populations was required. Thus, a survey queried dancers about the prevalence, impact, and care-seeking strategies associated with their LBP. Dancers reported that their LBP was mild to moderate, and that it negatively impacted many aspects of their daily life and dancing. The survey also indicated that spinal extension movements like the arabesque increased the dancers' LBP, but it was unknown how often dancers are exposed to these movements.

To quantify exposure, a video analysis study was undertaken to count spinal, impact, and partnering movements in seven dance environments: ballet class and performance, modern dance class and performance, and hip-hop breaking, cyphers, and battles. The total counts and rates of spinal extension movements were high, with the average number of spinal extension movements and movements per minute being highest in ballet performance environments (77±69.8 movements) and hip-hop cypher environments, respectively (7±9.6 movements per minute). Dancers can expect to experience spinal extension movements 2-7 times per minute across ballet, modern, and hip-hop dance genres.

The high exposure to spinal extension movements across all three dance genres studied and the acknowledgement by dancers that spinal extension movements were a concern for their LBP culminated in the final study: a case study on spinal extension movements. The three dance movements examined in this motion capture case study were the ballet arabesque, the modern dance attitude with body roll, and the hip-hop dolphin dive. The focus of the study was using a new approach of examining movement speed and asymmetry for the three movements from the lens of LBP risk. The data obtained in the study suggest that spine joint angles, angular velocity, and angular acceleration increase as the speed of the movement increases for all three dance genres. The modern dance medium speed movement had some exceptions to this trend and provides a starting point for future research.

Overall, ballet, modern, and hip-hop dancers were found to be exposed often to movements and tempos that could exacerbate their LBP, and that LBP negatively impacts the lives and dancing of afflicted individuals. This thesis contributes to the existing literature by addressing an anecdotally pervasive ailment, LBP, and providing numerous practical recommendations, tailored to ballet dancers, but also to the less-studied modern and hip-hop dance populations.

The experience of the dancer with LBP was intentionally integrated throughout the body of research. The inquiries provided here lay the foundation for future studies, and demonstrate novel approaches (movement counts, speed, asymmetry) to the problem of examining LBP in dancers.

References

1. Hoy D, Bain C, Williams G, et al. A systematic review of the global prevalence of low back pain. *Arthritis & Rheumatism.* 2012;64(6):2028-2037.
2. World Health Organization. *World Report on Ageing and Health.* 2015.
3. Hoy D, March L, Brooks P, et al. The global burden of low back pain: estimates from the Global Burden of Disease 2010 study. *Ann Rheum Dis.* 2014;73(6):968-974.
4. McMeeken J, Tully E, Stillman B, Nattrass C, Bygott I, Story I. The experiences of back pain in young Australians. *Man Ther.* 2001;6(4):213-200.
5. Caine D, Goodwin B, Caine C, Bergeron G. Epidemiological review of injury in pre-professional ballet dancers. *JDMS.* 2015;19(4):140-148.
6. Jacobs C, Hincapie C, Cassidy J. Musculoskeletal injuries and pain in dancers: a systematic review update. *JDMS.* 2012;19(4):74-84.
7. Smith P, Gerrie B, Varner K, McCulloch P, Lintner D, Harris J. Incidence and prevalence of musculoskeletal injury in ballet: a systematic review. *Ortho J Sports Med.* 2015;3(7):eCollection: 2325967115592621.
8. Hincapie C, Morton E, Cassidy J. Musculoskeletal injuries and pain in dancers: a systematic review. *Arch Phys Med Rehabil.* 2008;89(9):1819-1829.
9. Wanke E, Arendt M, Mill H, Groneberg D. Occupational accidents in professional dance with focus on gender differences. *J Occup Med Toxicol.* 2013;8(35):1-7.
10. Smith T, Davies L, de Medici A, Hakim A, Haddad F, Macgregor A. Prevalence and profile of musculoskeletal injuries in ballet dancers: A systematic review and meta-analysis. *Phys Ther Sport.* 2016;19:50-56.
11. Smith TO, de Medici A, Oduoza U, et al. National survey to evaluate musculoskeletal health in retired professional ballet dancers in the United Kingdom. *Physical Therapy in Sport.* 2017;23:82-85.
12. Swain C, Bradshaw E, Ekegren C, Whyte D. The epidemiology of low back pain and injury in dance: a systematic review. *J Orthop Sports Phys Ther.* 2019;49(4):239-252.
13. Grčić V, Miletic A, Miletic D. Pain prevalence among female street dancers. *Acta Kinesiol.* 2017;11(1):28-33.
14. Cho CH, Song KS, Min BW, Lee SM, Chang HW, Eum DS. Musculoskeletal injuries in break-dancers. *Injury.* 2009;40(11):1207-1211.
15. Ojofeitimi S, Bronner S, Woo H. Injury incidence in hip hop dance. *Scand J Med Sci Sports.* 2012;22(3):347-355.
16. Dionne C, Dunn K, Croft P, et al. A consensus approach toward the standardization of back pain definitions for use in prevalence studies. *Spine.* 2008;20(5):95-103.
17. Stanton T, Latimer J, Maher C, Hancock M. A modified Delphi approach to standardize low back pain recurrence terminology. *Eur Spine J.* 2011;20(5):744-752.
18. von Korff M. Studying the natural history of back pain. *Spine.* 1994;19(18Suppl):2041S-2046S.
19. Pengel L, Herbert R, Maher C, Refshauge K. Acute low back pain: systematic review of its prognosis. *BMJ.* 2003;327:1-5.
20. Stanton T, Henschke N, Maher C, Refshauge K, Latimer J, McAuley J. After an episode of acute low back pain, recurrence is unpredictable and not as common as previously thought. *Spine.* 2008;33(26):2923-2928.
21. Hurwitz EL, Randhawa K, Yu H, Cote P, Haldeman S. The Global Spine Care Initiative: a summary of the global burden. *European Spine Journal.* 2018;27:796-801.
22. Dagenais S, Caro J, Haldeman S. A systematic review of low back pain cost of illness studies in the United States and internationally. *Spine J.* 2008;8(1):8-20.

23. Froud R, Patterson S, Eldridge S, et al. A systematic review and meta-synthesis of the impact of low back pain on people's lives. *BMC Musculoskeletal Disorders.* 2014;15(50):1-14.
24. Schofield DJ, Shrestha RN, Percival R, Callander EJ, Kelly SJ, Passey ME. Early retirement and the financial assets of individuals. *European Spine Journal.* 2011;20:731-736.
25. Bunzli S, Watkins R, Smith A, Schutze R, O'Sullivan P. Lives on hold: a qualitative synthesis exploring the experience of chronic low-back pain. *Clin J Pain.* 2013(29):907–916.
26. O'Sullivan P, Caneiro JP, O'Keeffe M, O'Sullivan K. Unravelling the Complexity of Low Back Pain. *J Orthop Sports Phys Ther.* 2016;46(11):932-937.
27. O'Sullivan PB, Caneiro JP, O'Keeffe M, et al. Cognitive Functional Therapy: An Integrated Behavioral Approach for the Targeted Management of Disabling Low Back Pain. *Phys Ther.* 2018;98(5):408-423.
28. Ojofeitimi S, Bronner S. Injuries in a modern dance company effect of comprehensive management on injury incidence and cost. *J Dance Med Sci.* 2011;15(3):116-122.
29. Hendry D, Straker L, Campbell A, Hopper L, Tunks R, O'Sullivan P. An exploration of pre-professional dancers' beliefs of the low back and dance-specific low back movements. *Med Probl Perf Art.* 2019;34(3):147-153.
30. Krasnow D, Kerr G, Mainwaring L. Psychology of dealing with the injured dancer. *Med Probl Perf Art.* 1994;9(1):7-9.
31. Mainwaring LM, Krasnow D, Kerr G. And the dance goes on: Psychological impact of injury. *JDMS.* 2001;5(4):105-115.
32. Ng SK, Cicuttini FM, Wang Y, Wluka AE, Fitzgibbon B, Urquhurt DM. Negative beliefs about low back pain are associated with persistent high intensity low back pain. *Psych Health Med.* 2017;22(7):790-799.
33. Jackson JK, Shepherd TR, Kell RT. The influence of periodized resistance training on recreationally active males with chronic nonspecific low back pain. *J Strength Cond Res.* 2011;25(1):242-251.
34. Richards T. Hip flexor extensibility and its correlation to hip hyperextension and lower back pain in dancers. *Undergraduate Theses and Professional Papers.* 2016;81.
35. Jacobs CL, Cassidy JD, Côté P, et al. Musculoskeletal injury in professional dancers: prevalence and associated factors: an international cross-sectional study. *Clin J Sport Med.* 2017;27(2):153-160.
36. Kenney SJ, Palacios-Derflingher L, Whittaker JL, Emery CA. The influence of injury definition on injury burden in preprofessional ballet and contemporary dancers. *J Ortho & Sports Phys Ther.* 2017;48(3):185-193.
37. Vassallo AJ, Pappas E, Stamatakis E, Hiller CE. Injury fear, stigma, and reporting in professional dancers. *Safety and Health at Work.* 2019;10:260-264.
38. Rohman E, Steubs JT, Tompkins M. Changes in involved and uninvolved limb function during rehabilitation after anterior cruciate ligament reconstruction: implications for Limb Symmetry Index measures. *Am J Sports Med.* 2015;43(6):1391-1398.
39. Kyritsis P, Bahr R, Landreau P, Miladi R, Witvrouw E. Likelihood of ACL graft rupture: not meeting six clinical discharge criteria before return to sport is associated with a four times greater risk of rupture. *Br J Sports Med.* 2016;50(15):946-951.
40. Bishop C, Lake J, Read P, Chavda S. Inter-Limb Asymmetries: Understanding how to Calculate Differences From Bilateral and Unilateral Tests. *Strength and Conditioning Journal.* 2018;40(4).
41. Bishop C, Turner A, Read P. Effects of inter-limb asymmetries on physical and sports performance: a systematic review. *J Sports Sci.* 2018;36(10):1135-1144.

42. Kimmerle M, Wilson M. Dance students' perceptions of lateral bias. 11th Annual Meeting of the International Association for Dance Medicine and Science 2001; Alcala, Spain.
43. Kimmerle M. Lateral bias, functional asymmetry, dance training and dance injuries. *J Dance Med Sci.* 2010;14(2):58-66.
44. Golomer E, Rosey F, Dizac H, Mertz C, Fagard J. The influence of classical dance training on preferred supporting leg and whole body turning bias. *Laterality.* 2009;14(2):165-177.
45. Baker A, Wilmerding V. Prevalence of Lateral Bias in the Teaching of Beginning and Advanced Ballet. *JDMS.* 2006;10(3-4):81-84.
46. Steinberg N, Tenenbaum S, Waddington G, et al. Unilateral and bilateral patellofemoral pain in young female dancers: Associated factors. *J Sports Sci.* 2020;38(7):719-730.
47. Liederbach M, Spivak J, Donald RJ. Scoliosis in Dancers: A Method of Assessment in Quick-Screen Settings. *JDMS.* 1997;1(3):107-112.
48. Yoon NY, Lee JH. Morphological Study of the Pelvis and Vertebral Column in University Dance Major Students. *Int J Morphol.* 2021;39(4):1235-1239.
49. Chowning L, Krzyszkowski J, Nunley B, et al. Biomechanical Comparison of Dominant and Non-Dominant Limbs During Leap-Landings in Contemporary Style Female Dancers. *J Dance Med Sci.* 2021;25(4):231-237.
50. Pavlovic M, Ogrinc N, Sarabon N. Body asymmetries as risk factors for musculoskeletal injuries in dancesport, hip-hop and ballet dancers? *Eur J Transl Myol.* 2022;32(4).
51. Swain CTV, Bradshaw EJ, Ekegren CL, et al. Multi-segment spine range of motion in dancers with and without recent low back pain. *Gait Posture.* 2019;70:53-58.
52. Mertz L, Docherty C. Self-Described Differences Between Legs in Ballet Dancers: Do They Relate to Postural Stability and Ground Reaction Force Measures? *J Dance Med Sci.* 2012;16(4):154-160.
53. Swain CTV, Whyte DG, Ekegren CL, et al. Multi-segment spine kinematics: Relationship with dance training and low back pain. *Gait Posture.* 2019;68:274-279.
54. Gupta A, Fernihough B, Bailey G, Bombeck P, Clarke A, Hopper D. An evaluation of differences in hip external rotation strength and range of motion between female dancers and non-dancers. *Br J Sports Med.* 2004;38(6):778-783.
55. Lin CW, Su FC, Wu HW, Lin CF. Effects of leg dominance on performance of ballet turns (pirouettes) by experienced and novice dancers. *J Sports Sci.* 2013;31(16):1781-1788.
56. Donohue MR, Ellis SM, Heinbaugh EM, Stephenson ML, Zhu Q, Dai B. Differences and correlations in knee and hip mechanics during single-leg landing, single-leg squat, double-leg landing, and double-leg squat tasks. *Res Sports Med.* 2015;23(4):394-411.
57. Prus D, Zaletel P. Body Asymmetries in Dancers of Different Dance Disciplines [Asimetrías Corporales en Bailarines de Diferentes Disciplinas de Baile]. *International Journal of Morphology.* 2022;40(1):270-276.
58. Krasnow D, Wilmerding MV, Stecyk S, Wyon M, Koutedakis Y. Biomechanical research in dance: a literature review. *Med Probl Perform Art.* 2011;26(1):3-23.
59. Feipel V, Daleen S, Dugailly P-M, Salvia P, Roose M. Kinematics of the lumbar spine during classic ballet postures. *Med Probl Perf Art.* 2004;111(4):174-180.
60. Kerr S, Green A, Olivier B, Dafkin C. Analysis of balance and body positioning in ballerinas with different levels of skill. *African Journal for Physical Activity and Health Sciences.* 2016;22(3):883-895.
61. Mira NO, Marulanda AFH, Pena ACG, Torres DC, Orrego JC. Study of Ballet Dancers During Cou-De-Pied Derriere with Demi-Plie to Pique Arabesque. *J Dance Med Sci.* 2019;23(4):150-158.
62. Hagins M, Swain CTV, Orishimo KF, Kremenic IJ, Liederbach M. Motion of the multi-segmented spine in elite dancers during passe and arabesque. *Gait Posture.* 2021;88:198-202.

63. Shivanna BH. *MUSCULOSKELETAL MODELLING OF BALLET*. Linköping, Sweden: Department of Management and Engineering, Linköping University; 2020.
64. Kawano Y, Lin CF, Kuno-Mizumura M. Both Upper and Lower Limb Movements Contribute to Aesthetics of the Pique Arabesque in Ballet. *J Dance Med Sci.* 2022;26(1):15-24.
65. Wilson M, Lim B-O, Kwon Y-H. A Three-Dimensional Kinematic Analysis of Grand Rond de Jambe en l'air Skilled Versus Novice Ballet Dancers. *JDMS.* 2004;8(4):108-115.
66. Bronner S, Ojofeitimi S. Pelvis and hip three-dimensional kinematics in grand battement movements. *J Dance Med Sci.* 2011;15(1):23-30.
67. Bronner S. Differences in segmental coordination and postural control in a multi-joint dance movement: developpe arabesque. *J Dance Med Sci.* 2012;16(1):26-35.
68. Charbonnier C, Kolo FC, Duthon VB, et al. Assessment of congruence and impingement of the hip joint in professional ballet dancers: a motion capture study. *Am J Sports Med.* 2011;39(3):557-566.
69. Orishimo KF, Kremenic IJ, Pappas E, Hagins M, Liederbach M. Comparison of landing biomechanics between male and female professional dancers. *Am J Sports Med.* 2009;37(11):2187-2193.
70. Monasterio R, Chatfield S, Jensen J, Barr S. *Postural adjustments for voluntary leg movements in dancers* [Thesis]. Eugene, OR, University of Oregon; 1994.
71. Mouchnino L, Aurenty R, Massion J, Pedotti A. Coordination between equilibrium and head-trunk orientation during leg movement: a new strategy build up by training. *J Neurophysiol.* 1992;67(6):1587-1598.
72. Ferland G, Fardener P, Lèbe-Néron RM. Analysis of the electromyographic profile of the rectus femoris and biceps femoris during the demi-plié in dancers [abstract]. *Med Sci Sports Exerc.* 1983;15:159.
73. Trepman E, Gellman RE, Micheli LJ, De Luca CJ. Electromyographic analysis of grand-plie in ballet and modern dancers. *Med Sci Sports Exerc.* 1998;30(12):1708-1720.
74. Trepman E, Gellman RE, Solomon R, Murthy KR, Micheli LJ, De Luca CJ. Electromyographic analysis of standing posture and demi-plie in ballet and modern dancers. *Med Sci Sports Exerc.* 1994;26(6):771-782.
75. Clippinger-Robertson K, Hutton R, Miller D, Nichols T. Mechanical and anatomical factors relating to the incidence and etiology of patellofemoral pain in dancers. In: Shell C, ed. *The Dancer as Athlete.* Vol 8. 1984 Olympic Scientific Congress Proceedings; 1986.
76. De Bartolomeo O, Sette M, Sloten J, Albisetti W. Electromyographic study on the biomechanics of the lower limb during the execution of technical fundamentals of dance: the releve [poster]. *J Biomechan.* 2007;40:S789.
77. Bronner S, Ojofeitimi S. Gender and limb differences in healthy elite dancers: passe kinematics. *J Mot Behav.* 2006;38(1):71-79.
78. Bosco Calvo J, Iacopini E, Pellico L. The spine and pelvis during grand battement: a 3-D video study [abstract]. the 14th Annual Meeting of the International Association for Dance Medicine and Science; 2004; San Francisco, CA.
79. Gorwa J, Dworak LB, Michnik R, Jurkojc J. Kinematic analysis of modern dance movement "stag jump" within the context of impact loads, injury to the locomotor system and its prevention. *Med Sci Monit.* 2014;20:1082-1089.
80. Murgia C. *Relationships among selected kinetic and kinematic parameters of three types of dance leaps* [Dissertation]. Eugene, OR, University of Oregon; 1995.
81. Jones Y. *Comparison of Ballet and Modern Dance in terms of Kinetics, Kinematics and Muscle Activation during Landing for College Dancers* [Thesis]. Scholar Works at UT Tyler: Department of Healthy and Kinesiology, University of Texas at Tyler; 2015.

82. Sato N. Improving reliability and validity in hip-hop dance assessment: Judging standards that elevate the sport and competition. *Front Psychol.* 2022;13:934158.
83. Sato N, Hopper LS. Judges' evaluation reliability changes between identifiable and anonymous performance of hip-hop dance movements. *PLoS One.* 2021;16(1):e0245861.
84. Sato N, Nunome H, Ikegami Y. Kinematic analysis of basic rhythmic movements of hip-hop dance: motion characteristics common to expert dancers. *J Appl Biomech.* 2015;31(1):1-7.
85. Sato N, Nunome H, Ikegami Y. Key motion characteristics of side-step movements in hip-hop dance and their effect on the evaluation by judges. *Sports Biomech.* 2016;15(2):116-127.
86. Sato N, Nunome H, Ikegami Y. Key features of hip hop dance motions affect evaluation by judges. *J Appl Biomech.* 2014;30(3):439-445.
87. Han K, Liu X, Ping S-k, Wang P. Bio-mechanical fuzzy analysis on the technical action of windmill coupling swipe in hip-hop movement. *Journal of Intelligent & Fuzzy Systems.* 2019;37:517-525.
88. Bronner S, Ojofeitimi S, Woo H. Extreme Kinematics in Selected Hip Hop Dance Sequences. *Med Probl Perform Art.* 2015;30(3):126-134.
89. Brown DD, Wijffels G, Meulenbroek RGJ. Individual Differences in Sequential Movement Coordination in Hip-Hop Dance: Capturing Joint Articulation in Practicing the Wave. *Front Psychol.* 2021;12:731901.
90. Van Tiggelen D, Wickes S, Stevens V, Roosen P, Witvrouw E. Effective prevention of sports injuries: a model integrating efficacy, efficiency, compliance and risk-taking behaviour. *Br J Sports Med.* 2008;42(8):648-652.
91. Finch C. A new framework for research leading to sports injury prevention. *J Sci Med Sport.* 2006;9(1-2):3-9; discussion 10.
92. Mescouto K, Olson RE, Hodges PW, Setchell J. A critical review of the biopsychosocial model of low back pain care: time for a new approach? *Disabil Rehabil.* 2022;44(13):3270-3284.
93. Henn ED, Smith T, Ambegaonkar JP, Wyon M. Low Back Pain and Injury in Ballet, Modern, and Hip-Hop Dancers: A Systematic Review. *Int J Sports Phys Ther.* 2020;15(5):671-687.
94. Henn ED, Smith T, Ambegaonkar JP, Wyon M. Perceived Severity and Management of Low Back Pain in Adult Dancers in the United States. *Journal of Dance Medicine and Science.* 2022;26(3):173-180.
95. Henn ED, Smith T, Ambegaonkar JP, Wyon M. Self-reported impact of low back pain on adult dancers in the United States. Paper presented at: 31st Annual Conference of the International Association for Dance Medicine and Science; 23 October 2021, 2021; Denver, Colorado, United States.
96. Modesti PA, Reboldi G, Cappuccio FP, et al. Newcastle-Ottawa Quality Assessment Scale (adapted for cross sectional studies). *PLoS One.* 2016.
97. Academy of Nutrition and Dietetics (Academy) Research Committee. Grade definitions and chart. In: Evidence Analysis Library; 2004.
98. de Aquino CF, Cardoso VA, Machado NC, Franklin JS, Augusto VG. Análise da relação entre dor lombar e desequilíbrio de força muscular em bailarinas. *Fisioter Mov.* 2010;23(3):399-408.
99. Batista CG, Martins EO. A prevalência de dor em bailarinas clássicas. *J Health Sci Inst.* 2010;28(1):47-49.
100. Arendt Y, Kerschbaumer F. Überlastungsschäden an Sprunggelenk und Fuß professioneller Ballett-TänzerInnen. *Z Orthop Ihre Grenzgeb.* 2003;141(S1).

101. Greer N, Mosser G, Logan G, Halaas GW. A practical approach to evidence grading. *Jt Comm J Qual Improv.* 2000;26(12):700-712.
102. Allen N, Nevill A, Brooks J, Koutedakis Y, Wyon M. Ballet injuries: injury incidence and severity over 1 year. *J Orthop Sports Phys Ther.* 2012;42(9):781-790.
103. Byhring S, Bo K. Musculoskeletal injuries in the Norwegian National Ballet: a prospective cohort study. *Scand J Med Sci Sports.* 2002;12(6):365-370.
104. Coplan JA. Ballet dancer's turnout and its relationship to self-reported injury. *J Orthop Sports Phys Ther.* 2002;32(11):579-584.
105. Costa MS, Ferreira AS, Orsini M, Silva EB, Felicio LR. Characteristics and prevalence of musculoskeletal injury in professional and non-professional ballet dancers. *Braz J Phys Ther.* 2016;20(2):166-175.
106. Drezewska M, Sliwinski Z. Lumbosacral pain in ballet school students. Pilot study. *Ortop Traumatol Rehabil.* 2013;15(2):149-158.
107. Gamboa JM, Roberts LA, Maring J, Fergus A. Injury patterns in elite preprofessional ballet dancers and the utility of screening programs to identify risk characteristics. *J Orthop Sports Phys Ther.* 2008;38(3):126-136.
108. Garrick JG, Requa RK. Ballet injuries. An analysis of epidemiology and financial outcome. *Am J Sports Med.* 1993;21(4):586-590.
109. Gildea JE, Hides JA, Hodges PW. Morphology of the abdominal muscles in ballet dancers with and without low back pain: a magnetic resonance imaging study. *J Sci Med Sport.* 2014;17(5):452-456.
110. Gildea JE, Van Den Hoorn W, Hides JA, Hodges PW. Trunk Dynamics Are Impaired in Ballet Dancers with Back Pain but Improve with Imagery. *Med Sci Sports Exerc.* 2015;47(8):1665-1671.
111. Leanderson C, Leanderson J, Wykman A, Strender LE, Johansson SE, Sundquist K. Musculoskeletal injuries in young ballet dancers. *Knee Surg Sports Traumatol Arthrosc.* 2011;19(9):1531-1535.
112. McMeeken J, Tully E, Nattrass C, Stillman B. The effect of spinal and pelvic posture and mobility on back pain in young dancers and non-dancers. *J Dance Med Sci.* 2002;6(3):79-86.
113. Nilsson C, Leanderson J, Wykman A, Strender LE. The injury panorama in a Swedish professional ballet company. *Knee Surg Sports Traumatol Arthrosc.* 2001;9(4):242-246.
114. Ramel E, Mortiz U, Jarnlo G-B. Recurrent musculoskeletal pain in professional ballet dancers in Sweden: a six-year follow-up. *J Dance Med Sci.* 1999;3(3):93-100.
115. Ramel EM, Moritz U, Jarnlo G-B. Validation of a pain questionnaire (SEFIP) for dancers with a specially created test battery. *Med Probl Perf Art.* 1999;14:196-203.
116. Ramkumar PN, Farber J, Arnouk J, Varner KE, McCulloch PC. Injuries in a Professional Ballet Dance Company: A 10-year Retrospective Study. *J Dance Med Sci.* 2016;20(1):30-37.
117. Sobrino FJ, de la Cuadra C, Guillen P. Overuse Injuries in Professional Ballet: Injury-Based Differences Among Ballet Disciplines. *Orthop J Sports Med.* 2015;3(6):eCollection: 2325967115590114.
118. Swain C, Bradshaw E, Whyte D, Ekegren C. Life history and point prevalence of low back pain in pre-professional and professional dancers. *Phys Ther Sport.* 2017;25:34-38.
119. Swain CTV, Bradshaw EJ, Whyte DG, Ekegren CL. The prevalence and impact of low back pain in pre-professional and professional dancers: A prospective study. *Phys Ther Sport.* 2018;30:8-13.
120. Zaletel P, Sekulic D, Zenic N, Esco MR, Sajber D, Kondric M. The association between body-built and injury occurrence in pre-professional ballet dancers - Separated analysis for the injured body-locations. *Int J Occup Med Environ Health.* 2017;30(1):151-159.

121. Baker J, Scott D, Watkins K, al. e. Self-reported and reported injury patterns in contemporary dance students. *Med Probl Perform Art.* 2010;25(1):10-15.
122. Echegoyen S, Acuna E, Rodriguez C. Injuries in students of three different dance techniques. *Med Probl Perform Art.* 2010;25(2):72-74.
123. Shah S, Weiss DS, Burchette RJ. Injuries in professional modern dancers: incidence, risk factors, and management. *J Dance Med Sci.* 2012;16(1):17-25.
124. Solomon RL, Micheli LJ. Technique as a Consideration in Modern Dance Injuries. *Phys Sports Med.* 1986;14(8):83-90.
125. van Merkensteijn GG, Quin E. Assessment of Compensated Turnout Characteristics and their Relationship to Injuries in University Level Modern Dancers. *J Dance Med Sci.* 2015;19(2):57-62.
126. Swain C, Ekegren C, Whyte DG, et al. Lifetime history and point prevalence of low back pain in pre-professional and professional dancers. *J Sci Med Sport.* 2017;20(e55).
127. Lawrence JP, Greene HS, Grauer JN. Back pain in athletes. *J Am Acad Orthop Surg.* 2006;14(13):726-735.
128. Wyon MA, Abt G, Redding E, Head A, Sharp NC. Oxygen uptake during modern dance class, rehearsal, and performance. *J Strength Cond Res.* 2004;18(3):646-649.
129. Emery CA. Risk factors for injury in child and adolescent sport: a systematic review of the literature. *Clin J Sport Med.* 2003;13(4):256-268.
130. Adirim TA, Cheng TL. Overview of injuries in the young athlete. *Sports Med.* 2003;33(1):75-81.
131. Micheli L, Wood R. Back pain in young athletes. Significant differences from adults in causes and patterns. *Arch Pediatr Adolesc Med.* 1995;149(1):15-18.
132. Cupisti A, D'Alessandro C, Evangelisti I, Piazza M, Galetta F, Morelli E. Low back pain in competitive rhythmic gymnasts. *J Sports Med Phys Fitness.* 2004;44(1):49-53.
133. Miletic D, Miletic A, Milavic B. Age-related progressive increase of lower back pain among male dance sport competitors. *J Back Musculoskelet Rehab.* 2015;28(3):551-560.
134. Miletic D, Miletic A, Lujan I, Kezic A, Erceg M. Health care related problems among female sport dancers. *Athl Ther Today.* 2015;20(1):57-62.
135. Miletić A, Kostic R, Miletic D. Pain prevalence among competitive international dancers. *Int J Athl Ther & Train.* 2011;16(1):13-16.
136. Kujala UM, Taimela S, Erkintalo M, Salminen JJ, Kaprio J. Low-back pain in adolescent athletes. *Med Sci Sports Exerc.* 1996;28(2):165-170.
137. Sallis RE, Jones K, Sunshine S, Smith G, Simon L. Comparing sports injuries in men and women. *Int J Sports Med.* 2001;22(6):420-423.
138. Kujala UM, Taimela S, Oksanen A, Salminen JJ. Lumbar mobility and low back pain during adolescence. A longitudinal three-year follow-up study in athletes and controls. *Am J Sports Med.* 1997;25(3):363-368.
139. Di Cagno A, Baldari C, Battaglia C, et al. Factors influencing performance of competitive and amateur rhythmic gymnastics--gender differences. *J Sci Med Sport.* 2009;12(3):411-416.
140. Miletic D. Motor status of competitive young sport dancers – gender differences. *Acta Kinesiol.* 2009;3(1):83-88.
141. McCabe TR, Wyon M, Ambegaonkar JP, Redding E. A bibliographic review of medicine and science research in dancesport. *Med Probl Perform Art.* 2013;28(2):70-79.
142. Gabbe B, Finch C, Bennell K, al. e. How valid is a self reported 12-month sports injury history? *Br J Sports Med.* 2003;37(6):545-547.
143. Low Back Pain. NCBI; 2012. https://www.ncbi.nlm.nih.gov/mesh.
144. *The jamovi project* [computer program]. Version 1.6. Sydney, Australia2019.

145. Hsieh H-F, Shannon S. Three approaches to qualitative content analysis. *Qualitative Health Research.* 2005;15(9):1277-1288.
146. Swain C, Redding E. Trunk muscle endurance and low back pain in female dance students. *J Dance Med Sci.* 2014;18(2):62-66.
147. Kruusamae H, Maasalu K, Wyon M, et al. Spinal posture in different DanceSport dance styles compared with track and field athletes. *Medicina (Kaunas).* 2015;51(5):307-311.
148. Oxland TR. Fundamental biomechanics of the spine--What we have learned in the past 25 years and future directions. *J Biomech.* 2016;49(6):817-832.
149. Requa RKG, James G. Do Professional Dancers Have Medical Insurance? Company-Provided Medical Insurance for Professional Dancers. *JDMS.* 2005;9(3-4):81-83.
150. Wasiak R, Kim J, Pransky G. Work disability and costs caused by recurrence of low back pain: longer and more costly than in first episodes. *Spine.* 2006;31:219-225.
151. Kozai A, Ambegaonkar JP. Health Literacy for Collegiate Dancers: Provision and Perceptions of Health-Related Education in University Dance Programs. *J Dance Med Sci.* 2020;24(3):118-125.
152. Mortimer M, Ahlberg G, Group M-NS. To seek or not to seek? Care-seeking behaviour among people with low-back pain. *Scand J Public Health* 2003;31:194–203.
153. Henn ED, Ambegaonkar JP, Smith T, Wyon M, Lanza S. Spinal Counts, Impact, and Partnering Movements in Ballet, Modern, and Hip Hop dance: A YouTube Video Analysis Study. *JDMS.* 2023(In press.).
154. Rampinini E, Coutts AJ, Castagna C, Sassi R, Impellizzeri FM. Variation in top level soccer match performance. *Int J Sports Med.* 2007;28(12):1018-1024.
155. Jennings D, Cormack S, Coutts AJ, Boyd L, Aughey RJ. The validity and reliability of GPS units for measuring distance in team sport specific running patterns. *Int J Sports Physiol Perform.* 2010;5(3):328-341.
156. Twitchett E, Angioi M, Koutedakis Y, Wyon M. Video analysis of classical ballet performance. *J Dance Med Sci.* 2009;13(4):124-128.
157. Wyon MA, Twitchett E, Angioi M, Clarke F, Metsios G, Koutedakis Y. Time motion and video analysis of classical ballet and contemporary dance performance. *Int J Sports Med.* 2011;32(11):851-855.
158. Baechle T, Earle E. *Essentials of Strength Training and Conditioning.* Champaign, IL: Human Kinetics; 2000.
159. Wyon M, Head A, Sharp C, Redding E. The cardiorespiratory responses to modern dance classes: differences between university, graduate, and professional classes. *Journal of Dance Medicine and Science.* 2002;6(2):41-45.
160. Twitchett E, Angioi M, Koutedakis Y, Wyon M. The demands of a working day among female professional ballet dancers. *J Dance Med Sci.* 2010;14(4):127-132.
161. Wyon M. Cardiorespiratory training for dancers. *JDMS.* 2005;9(1):7-12.
162. Johnson IK. Hip-hop Dance. In: Williams JA, ed. *The Cambridge Companion to Hip-Hop.* Cambridge: Cambridge University Press; 2015:22-31.
163. YouTube.com. Your data in YouTube. YouTube.com. https://myaccount.google.com/u/0/yourdata/youtube?hl=en. Accessed 29 October 2020.
164. DuckDuckGo.com. DuckDuckGo Privacy Essentials. DuckDuckGo. https://duckduckgo.com/?natb=v245-2__&cp=atbhc. Accessed 29 October 2020.
165. The Associated Press. Google buys YouTube for $1.65 billion. NBC Universal. https://www.nbcnews.com/id/wbna15196982. Published 9 October 2006. Accessed 29 October 2020.
166. *Danse Perdue with Joy von Spain and Masaki Satsu - "Miserere Mei" June 4, 2011* [Video dance recording]. YouTube.com: bennybrownell; 2011.

167. Quinlan E, Reinke T, Bogar W. Spinous process apophysitis: a cause of low back pain following repetitive hyperextension in an adolescent female dancer. *Journal of Dance Medicine and Science.* 2013;17(4):170-174.
168. d'Hemecourt P, Micheli L, Gerbino P. Spinal injuries in female athletes. *Sports Med Arthrosc.* 2002;10(1):91-97.
169. Gelabert R. Dancers' spinal syndromes. *J Orthop Sports Phys Ther.* 1986;7(4):180-191.
170. Alderson J, Hopper L, Elliott B, Ackland T. Risk factors for lower back injury in male dancers performing ballet lifts. *J Dance Med Sci.* 2009;13(3):83-89.
171. Adams MA, Dolan P. Time-dependent changes in the lumbar spine's resistance to bending. *Clin Biomech (Bristol, Avon).* 1996;11(4):194-200.
172. Adams MA. Biomechanics of back pain. *Acupunct Med.* 2004;22(4):178-188.
173. Shaw JW, Mattiussi AM, Brown DD, Springham M, Pedlar CR, Tallent J. The activity demands and physiological responses observed in professional ballet: A systematic review. *The Journal of Sport and Exercise Science.* 2021;5(4):249-269.
174. Rodrigues-Krause J, Krause M, Reischak-Oliveira A. Cardiorespiratory Considerations in Dance: From Classes to Performances. *J Dance Med Sci.* 2015;19(3):91-102.
175. Batson G. Revisiting overuse injuries in dance in view of motor learning and somatic models of distributed practice. *Journal of Dance Medicine and Science.* 2007;11(3):70-75.
176. Redding E, Wyon M. A comparative analysis of the physiological responses to training before and at the end of the performing period of two dance companies. Paper presented at: International Association for Dance Medicine and Science 2001; Madrid: IADMS.
177. Wyon MA, Redding E. Physiological monitoring of cardiorespiratory adaptations during rehearsal and performance of contemporary dance. *J Strength Cond Res.* 2005;19(3):611-614.
178. Krasnow D, Chatfield SJ. Dance Science and the Dance Technique Class. *Impulse.* 1996;4:162-172.
179. Wyon MA, Harris J, Adams F, Cloak R, Clarke FA, Bryant J. Cardiorespiratory Profile and Performance Demands of Elite Hip-Hop Dancers: Breaking and New Style. *Med Probl Perform Art.* 2018;33(3):198-204.
180. Mota GR, Marocolo M, Barbosa-Neto O, Ide BN. Street-dance: Physiological demands and effect of endurance training. *Journal of Physical Education and Sports Management.* 2011;5(2):53-57.
181. *The Royal Ballet morning class in full - World Ballet Day 2018* [Dance video recording]. YouTube.com: Royal Opera House; 2018.
182. *Tchaikovsky: Swan Lake - The Kirov Ballet* [Dance video recording]. YouTube.com: Warner Classics; 1991.
183. *S. Prokofiev - Ballet Romeo & Juliet* [Dance video recording]. YouTube.com: Volodimir Balyk; 1984.
184. Kozai AC, Twitchett E, Morgan S, Wyon MA. Workload Intensity and Rest Periods in Professional Ballet: Connotations for Injury. *Int J Sports Med.* 2020;41(6):373-379.
185. *Revelations* [Dance video recording]. YouTube.com: Karl Skellenger; Premiered 1960.
186. *S/HE* [Dance video recording]. YouTube.com: MN Dance Company; 2017.
187. *San Andrea (FR) vs. Ami (JP) | Final | Red Bull BC One B-Girl World Final 2018* [Dance video recording]. YouTube.com: Red Bull BC One; 2018.
188. Standaert CJ, Herring SA. Spondylolysis: a critical review. *Br J Sports Med.* 2000;34(6):415-422.
189. Kruse D, Lemmen B. Spine injuries in the sport of gymnastics. *Curr Sports Med Rep.* 2009;8(1):20-28.

190. Hutchinson M. Low back pain in elite rhythmic gymnasts. *Med Sci Sports Exer.* 1999;31(11):1686.
191. Kujala UM, Oksanen A, Taimela S, Salminen JJ. Training does not increase maximal lumbar extension in healthy adolescents. *Clin Biomech (Bristol, Avon).* 1997;12(3):181-184.
192. Hall SJ. Mechanical contribution to lumbar stress injuries in female gymnasts. *Med Sci Sports Exerc.* 1986;18(6):599-602.
193. Hartvigsen J, Hancock MJ, Kongsted A, et al. What low back pain is and why we need to pay attention. *The Lancet.* 2018;391(10137):2356-2367.
194. Moradi V, Memari A-H, ShayestehFar M, Kordi R. Low back pain in athletes is associated with general and sport specific risk factors: a comprehensive review of longitudinal studies. *Rehabilitation Research and Practice.* 2015;2015:1-10.
195. Graw BP, Wiesel SW. Low back pain in the aging athlete. *Sports Med Arthrosc Rev.* 2008;16(1):39-46.
196. Gabbett TJ, Ullah S. Relationship between running loads and soft-tissue injury in elite team sport athletes. *J Strength Cond Res.* 2012;26(4):953-960.
197. Whiteside D, Martini DN, Zernicke RF, Goulet GC. Ball Speed and Release Consistency Predict Pitching Success in Major League Baseball. *J Strength Cond Res.* 2016;30(7):1787-1795.
198. Crewe H, Campbell A, Elliott B, Alderson J. Lumbo-pelvic loading during fast bowling in adolescent cricketers: the influence of bowling speed and technique. *J Sports Sci.* 2013;31(10):1082-1090.
199. Webb M, Davis C, Westacott D, Webb R, Price J. Injuries in Elite Men's Lacrosse: An Observational Study During the 2010 World Championships. *Orthop J Sports Med.* 2014;2(7):2325967114543444.
200. Schoenfeld BJ. Squatting kinematics and kinetics and their application to exercise performance. *J Strength Cond Res.* 2010;24(12):3497-3506.
201. Chatfield SJ. Electromyographic response of dancers to isokinetic work and select dance movements. *Kinesiol Med Dance.* 1993/1994;16(1 (Fall/Win)):60-82.
202. Kuno-Mizumura M, Seta A, Mizumura S. Biomechanical characteristics of arm movements by skilled dancers in ‘Swan Lake.’. The 14th Annual Meeting of the International Association for Dance Medicine and Science; 2004; San Francisco, CA.
203. Leardini A, Biagi F, Merlo A, Belvedere C, Benedetti MG. Multi-segment trunk kinematics during locomotion and elementary exercises. *Clin Biomech (Bristol, Avon).* 2011;26(6):562-571.
204. Mitchell T, O'Sullivan PB, Burnett AF, Straker L, Smith A. Regional differences in lumbar spinal posture and the influence of low back pain. *BMC Musculoskelet Disord.* 2008;9(152).
205. Parkinson S, Campbell A, Dankaerts W, Burnett A, O'Sullivan P. Upper and lower lumbar segments move differently during sit-to-stand. *Man Ther.* 2013;18(5):390-394.
206. Christe G, Kade F, Jolles BM, Favre J. Chronic low back pain patients walk with locally altered spinal kinematics. *J Biomech.* 2017;60:211-218.
207. Crosbie J, Nascimento DP, Negrão Filho RdF, Ferreira P. Do people with recurrent back pain constrain spinal motion during seated horizontal and downward reaching? *Clin Biomech (Bristol, Avon).* 2013;28(8):866-872.
208. Schumacher P. BPM Calculator. https://anotherproducer.com/online-tools-for-musicians/bpm-calculator/. Accessed 23 January 2023.
209. Tchaikovsky PI. Sleeping Beauty Waltz. In. *London Symphony Orchestra play Tchaikovsky*: London Symphony Orchestra; 1987.
210. Tchaikovsky PI. Dance Of The Swans (from Swan Lake). In. *A Calendar of Classics*: K-TEL; 2007.

211. Tchaikovsky PI. Swan Lake, Op. 20: No. 5, The Black Swan Pas de Deux: V. Coda. In. *Swan Lake*: Victor Fedotov and the Mariinsky Theatre Symphony Orchestra; 2012.
212. Qualisys Motion Capture Systems. CAST Marker Full Body Set. In: Qualisys PAF package, ed2007.
213. Linton SJ, Boersma K. Early identification of patients at risk of developing a persistent back problem: the predictive validity of the Orebro Musculoskeletal Pain Questionnaire. *Clin J Pain.* 2003;19(2):80-86.
214. Miller RP, Kori SH, Todd DD. The Tampa Scale: a Measure of Kinesiophobia. *The Clinical Journal of Pain.* 1991;7(1):51.
215. Xsens Technologies B.V. *Xsens MVN User Manual: User Guide Xsens MVN, MVN Link, MVN Awinda.* 2018.
216. Zeng Z, Liu Y, Hu X, Tang M, Wang L. Validity and Reliability of Inertial Measurement Units on Lower Extremity Kinematics During Running: A Systematic Review and Meta-Analysis. *Sports Med Open.* 2022;8(1):86.
217. Gindre C, Lussiana T, Hebert-Losier K, Morin JB. Reliability and validity of the Myotest(R) for measuring running stride kinematics. *J Sports Sci.* 2016;34(7):664-670.
218. de Ruiter CJ, Wilmes E, Brouwers SAJ, Jagers EC, van Dieen JH. Concurrent validity of an easy-to-use inertial measurement unit-system to evaluate sagittal plane segment kinematics during overground sprinting at different speeds. *Sports Biomech.* 2022:1-14.
219. Wouda FJ, Giuberti M, Bellusci G, et al. On the Validity of Different Motion Capture Technologies for the Analysis of Running. 7th IEEE International Conference on Biomedical Robotics and Biomechatronics (Biorob); 2018; Enschede, Netherlands.
220. *MVN Analyse Pro software* [computer program]. Version 2021.0.1, build 6752, rev 1104212023.
221. Wang A-T, Huang C-C, Hsieh C-C, Hu C-C, Lu T-W. Electromyography analysis of grand battement in Chinese dance [translation]. 13th International Conference on Biomedical Engineering 2008; Singapore.
222. Ryman R, Ranney D. A preliminary investigation of two variations of the grand battement devant. *Dance Res J.* 1978/79;11(1/2):2-11.
223. Roussel N, De Kooning M, Schutt A, et al. Motor control and low back pain in dancers. *Int J Sports Med.* 2013;34(2):138-143.
224. Kautzmann BM, Kase JB, Coker CA. Prevalence of Movement Dysfunction in Female Collegiate Dancers. *J Dance Med Sci.* 2021;25(2):147-151.
225. Mattiussi A, Shaw JW, Brown DD, et al. Jumping in Ballet: A Systematic Review of Kinetic and Kinematic Parameters. *Med Probl Perform Art.* 2021;36(2):108-128.
226. Bronner S, Spriggs J. Jerk optimization as an indicator of skill in a complex dance movement. Paper presented at: APTA CSM 2002; Boston, MA.
227. Lin CW, Fang YT, Yang JF, Hsue BJ, Lin CF. Dancers with non-specific low back pain have less lumbar movement smoothness than healthy dancers. *Biomed Eng Online.* 2023;22(1):39.
228. *Pilobolus Dance Theater (Performance/Lecture)* [Dance video recording]. YouTube.com: Kennedy Center Education Digital Learning; 1998.
229. *Kansas City Contemporary Dance Fall Show 2017 Shifting Tides* [Dance video recording]. YouTube.com: Philip Koenig; 2017.
230. Robert-Lachaine X, Mecheri H, Larue C, Plamondon A. Validation of inertial measurement units with an optoelectronic system for whole-body motion analysis. *Med Biol Eng Comput.* 2017;55(4):609-619.
231. Teufl W, Miezal M, Taetz B, Frohlich M, Bleser G. Validity, Test-Retest Reliability and Long-Term Stability of Magnetometer Free Inertial Sensor Based 3D Joint Kinematics. *Sensors (Basel).* 2018;18(7):1980-2002.

232. Ofori EK, Wang S, Bhatt T. Validity of Inertial Sensors for Assessing Balance Kinematics and Mobility during Treadmill-Based Perturbation and Dance Training. *Sensors (Basel).* 2021;21(9).
233. van der Straaten R, Bruijnes A, Vanwanseele B, Jonkers I, De Baets L, Timmermans A. Reliability and Agreement of 3D Trunk and Lower Extremity Movement Analysis by Means of Inertial Sensor Technology for Unipodal and Bipodal Tasks. *Sensors (Basel).* 2019;19(1):141-155.
234. Larsen FG, Svenningsen FP, Andersen MS, de Zee M, Skals S. Estimation of Spinal Loading During Manual Materials Handling Using Inertial Motion Capture. *Ann Biomed Eng.* 2020;48(2):805-821.
235. Tafazzol A, Arjmand N, Shirazi-Adl A, Parnianpour M. Lumbopelvic rhythm during forward and backward sagittal trunk rotations: combined in vivo measurement with inertial tracking device and biomechanical modelling. *Clin Biomech (Bristol, Avon).* 2014;29(1):7-13.
236. Saber-Sheikh K, Bryant EC, Glazzard C, Hamel A, Lee RY. Feasibility of using inertial sensors to assess human movement. *Man Ther.* 2010;15(1):122-125.
237. Reininga IH, Stevens M, Wagenmakers R, et al. Compensatory trunk movements in patients with hip osteoarthritis: accuracy and reproducibility of a body-fixed sensor-based assessment. *Am J Phys Med Rehabil.* 2011;90(8):681-687.
238. Ha TH, Saber-Sheikh K, Moore AP, Jones MP. Measurement of lumbar spine range of movement and coupled motion using inertial sensors - a protocol validity study. *Man Ther.* 2013;18(1):87-91.
239. Faber GS, Chang CC, Kingma I, Dennerlein JT, van Dieen JH. Estimating 3D L5/S1 moments and ground reaction forces during trunk bending using a full-body ambulatory inertial motion capture system. *J Biomech.* 2016;49(6):904-912.
240. Gildea JE, Hides JA, Hodges PW. Size and symmetry of trunk muscles in ballet dancers with and without low back pain. *J Orthop Sports Phys Ther.* 2013;43(8):525-533.
241. Li F, Adrien N, He Y. Biomechanical Risks Associated with Foot and Ankle Injuries in Ballet Dancers: A Systematic Review. *Int J Environ Res Public Health.* 2022;19(8).
242. Biernacki JL, Stracciolini A, Fraser J, Micheli LJ, Sugimoto D. Risk Factors for Lower-Extremity Injuries in Female Ballet Dancers: A Systematic Review. *Clin J Sport Med.* 2021;31(2):e64-e79.

Appendices

Appendix 4.1 Dancer experience of low back pain survey

Dancer Experience of Low Back Pain Survey

Page 1: A questionnaire about dancers, and low back pain

Yes, I am at least 18 years old and I have read and agree to the informed consent.

1. The data in this questionnaire will be collected with the purpose of studying the prevalence of low back pain (LBP) in various dance populations, with the aim of helping future dancers. By submitting results to this survey, you are consenting to having your responses securely and anonymously stored, processed, and analysed for purposes related to scientific research. You may refuse to participate or withdraw from the study at any time. Any questions, withdrawals, or concerns can be directed to Erica Henn via email to e.d.henn@wlv.ac.uk. Please confirm you have read the informed consent above, that you are 18 years old or older, and that you are willing to participate in this survey. **Required*

Page 2: Tell us about yourself as a dancer:

2. How old are you? (Please answer in years and months, for example: 28 years and 5 months) * *Required*

3. How many years have you been dancing? (Please answer in years and months, for example: 8 years and 3 months) * *Required*

4. What country do you currently live and dance in for most of your time? * *Required*

5. What do you consider to be your primary dance genre, or closest to it? * *Required*

- Ballet / Classical dance
- Modern / Contemporary dance
- Hip-hop dance
- Other

5.a. If you selected Other, please specify:

6. How many years have you trained in this genre? (Please answer in years and months, for example: 4 years and 3 months) * *Required*

7. On average, how many hours of dance training per week (including class, rehearsal, and performance) do you typically participate in during a normal week? * *Required*

- 0-5 hours per week
- 6-10 hours per week
- 11-20 hours per week
- 21-30 hours per week
- 31-40 hours per week
- 41-50 hours per week
- More than 50 hours per week

8. How many hours of dance training (including class, rehearsal, and performance) did you participate in **last week** specifically? * *Required*

- 0-5 hours per week
- 6-10 hours per week
- 11-20 hours per week
- 21-30 hours per week
- 31-40 hours per week
- 41-50 hours per week
- More than 50 hours per week

9. On your busiest day of dance in the last **four weeks**, how many hours did you dance **in a single**

day?

- I did not dance for at least one hour in the last four weeks
- 1 - 3.5 hours
- 3 - 6.5 hours
- 7 - 8.5 hours
- More than 9 hours

10. How many rest **days** (days of no dance or other physical activity at all) did you average per week in the last **four weeks**?

- 0 days of rest, I am constantly performing physical activity every day of the week
- 1 day of rest
- 2 days of rest
- 3 days of rest
- 4 or more days of rest

11. How many **hours** of rest (time spent with no dance or other physical activity at all) do you average

- on a normal day (not including rest days or time spent sleeping)?
  No rest, I am constantly performing physical activity on a non-rest day
- 0.5 - 1.5 hours of rest
- 2 hours of rest
- 3 hours of rest
- 4 or more hours of rest

12. On a scale of 1 to 5, how stressed or anxious do you feel generally on an average day? * *Required*

- 1 No stress at all; my life is not affected by stress
- 2
- 3
- 4
- 5 The most stress possible; my stress greatly affects my life

Page 3: Tell us if you have any experience with low back pain:

13. Low back pain, as shown in the image below, is characterized as acute or chronic pain in the lumbar or sacral regions of the back. The dark gray shading indicates where low back pain is experienced. Have you experienced pain in this area before? * *Required*

- I do not have/have not had LBP
- Yes, I have had pain in the dark gray shaded area of this image

14. Where did your low back pain (LBP) originate? * *Required*

- My LBP comes from a non-dance source (caused by sport, non-dance work, etc.)
- My LBP comes from a dance source (dance class, dance performance, dance rehearsal, etc.)
- I am not sure where my LBP originated
- I do not have/have not had LBP

15. In the last **four weeks**, did you experience low back pain (LBP)? Did it limit your ability to complete normal day-to-day activities? Day-to-day activities are basic activities of every day life and self care, such as **dressing yourself, walking, sleeping, standing, eating**; in this case, everyday non-dance activities. * *Required*

- Yes, my low back pain DID limit my daily activities
- I had LBP, but it DID NOT limit my daily activities
- No, I did not have any LBP in the last four weeks

16. If you had low back pain (LBP) in the last four weeks, did this low back pain (LBP) limit your ability to dance fully? * *Required*

- Yes, my low back pain DID limit my ability to dance fully

- I had LBP, but it DID NOT limit my dancing
- No, I did not have any LBP in the last four weeks
- No, I did not dance in the last four weeks

17. Have you ever sought professional help for low back pain (LBP)? (Check all that apply) * *Required*

- No, I do not have/have not had low back pain
- No, I have not sought help, despite having had LBP
- Yes, medical doctor, including sport-specific doctors
- Yes, physiotherapist
- Yes, chiropractor
- Yes, acupuncture or other alternative method
- Other

17.a. If you selected Other, please specify:

18. How many times within the last **four weeks** have you sought professional help for low back pain (LBP)? * *Required*

- I have not sought help for LBP in the last four weeks
- 1-2 times
- 3-4 times
- 5-6 times
- 7 times or more

19. Have you ever been diagnosed with low back pain (LBP) from a medical professional? * *Required*

- Yes, within the last month
- Yes, within the last 6 months
- Yes, at some point in my life
- No, I have not been medically diagnosed with LBP

20. Have you been diagnosed with a general back INJURY from a medical professional? This would include fractured vertebrae, intervertebral disc injuries, blunt force trauma, or similar injury to **any part** of your back (between, but not including, your neck and your tailbone). * *Required*

- Yes, within the last month
- Yes, within the last 6 months
- Yes, at some point in my life
- No, I have not been medically diagnosed with a low back injury

Page 4: The impact of low back pain for those that have experienced it:

If you have **never** had low back pain, **please skip the next seven questions.**

21. Do you have chronic low back pain (LBP)? Chronic pain is defined as an "aching sensation that persists for more than a few months. It may or may not be associated with trauma or disease, and may persist after the initial injury has healed. Its localization, character, and timing are more vague than with acute pain. (MeSH Unique ID: D059350)"

- Yes, my low back pain is/was chronic
- No, my low back pain is/was acute (not chronic)

22. Do you feel that your low back pain is on your mind often, at least once per day?

- Yes
- No

23. Generally, do you feel that your low back pain regularly inhibit other non-dance aspects of your life?

- Yes
- No

24. Has your low back pain inhibited other non-dance aspects of your life within the last **four weeks** specifically? Please tell us about your experiences!
(Open ended)

25. How would you rate the average intensity of your low back pain?
0 1 2 3 4 5 6 7 8 9 10
No pain Intense, debilitating pain

26. Have you experienced any of the following due to low back pain?

- None of these
- Imaging (x-rays, MRI, CAT scan, ultrasound, etc.)
- Medical opioid treatments
- Surgery
- Injections into the painful area(s)
- Other

26.a. If you selected Other, please specify:

27. Are there any dance movements that increase your low back pain?
(Open ended)

Page 5: Final page

Thank you for participating in this questionnaire! We greatly appreciate the time and thought you have put into our study. Have a wonderful day!

Appendix 4.2a-c: Ethics Approval Letters from the University of Wolverhampton for Studies 1, 2, and 3

UNIVERSITY OF
WOLVERHAMPTON

Dr Alexandra Hopkins RN PhD MSc MBA RNT RCNT DANS
Dean of the Faculty of Education Health and Wellbeing

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United Kingdom

Telephone Codes
UK: 01902 Abroad: +44 1902

Switchboard: 321000

Internet: www.wlv.ac.uk

Date 16th April 2019

University of Wolverhampton
FEHW

Dear Erica

Re "A survey to determine the impact on ballet, modern, and hip-hop dancers due to low back pain and low back injury"

The Faculty Ethics Panel (Sports) has considered and reviewed your submission.

On review your Research Proposal was passed and the Panel believes that the ethical issues inherent in your study have been adequately considered and addressed. Therefore the Panel is giving you full ethical approval for your study (Code 1 – Approved –Unique Code: (16/19/EH1/UOW).

We would like to wish you every success with the project.

Yours sincerely

[redacted]

Head of Doctoral Studies
Chair – Faculty Ethics Committee

THE UNIVERSITY OF OPPORTUNITY

a)

UNIVERSITY OF WOLVERHAMPTON

Dr Alexandra Hopkins RN PhD MSc MBA RNT RCNT DANS
Dean of the Faculty of Education Health and Wellbeing

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21st June 2021

Erica Henn
University of Wolverhampton
FEHW

Dear Erica

Re: "Counts of dance movements identified through video analysis of YouTube ballet, modern, and hip-hop dance."

The Faculty Ethics Panel (Sports) has considered and reviewed your submission.

On review your Research Proposal was passed and the Panel believes that the ethical issues inherent in your study have been adequately considered and addressed. Therefore the Panel is giving you full ethical approval for your study (Code 1 – Approved –Unique code: (06/21/EH/UOW).

You are required to report any adverse effects within the research process to this Ethics Committee, and to resubmit for approval if a project requires amendment. Also at the end of the project could you inform the Committee that the project has ended and met its stated outcomes.

We would like to wish you every success with the project.

Yours sincerely

[redacted]

Head of Doctoral Studies
Chair – Faculty Ethics Committee

b) THE UNIVERSITY OF OPPORTUNITY

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7th March 2022

Erica Henn
University of Wolverhampton
FEHW

Dear Erica

Re: Motion capture study of ballet dancers performing an arabesque movement at varying speeds

The Faculty Ethics Panel (Sports) has consicered and reviewed your submission.

On review your Research Proposal was passed and the Panel believes that the ethical issues inherent in your study have been adequately considered and addressed. Therefore the Panel is giving you full ethical approval for your study (Code 1 – Approved –Unique code: (3/22/EH/UOW).

You are required to report any adverse effects within the research process to this Ethics Committee, and to resubmit for approval if a project requires amendment. Also at the end of the project could you inform the Committee that the project has ended and met its stated outcomes.

We would like to wish you every success with the project.
Yours sincerely

[redacted]

Head of Doctoral Studies
Chair – Faculty Ethics Committee

c)

Appendix 5.1: Video information for 75 YouTube dance videos used in a study of dance movement counts for ballet, modern, and hip-hop performances and ballet and modern dance classes.

Search Term	**Original Upload Date**	**Title**	**Uploaded By:**	**URL**
ballet dance class full	11-Aug-18	Intermediate Advanced Ballet Barre | Kathryn Morgan	Kathryn Morgan	https://www.youtube.com/watch?v=ZSIfgTOowYk
	9-Oct-18	The Royal Ballet morning class in full - World Ballet Day 2018	Royal Opera House	https://www.youtube.com/watch?v=FySuVhmb-OY
	22-Oct-19	Ballet Class | London Contemporary Dance School (full class live stream)	The Place	https://www.youtube.com/watch?v=kMwPoN7gw0E
	13-Dec-19	Complete Ballet Barre for beginners #1(Long version) Professional Ballet Class ITALIA CONTI VIRTUAL	Italia Conti Virtual	https://www.youtube.com/watch?v=e_veY_EdHys
	23-Mar-20	Ballet Barre 1 (Online Ballet Class) - Dutch National Ballet	Nationale Opera & Ballet	https://www.youtube.com/watch?v=FrISNpG0bZk
	9-Apr-20	Intermediate Ballet Class	Megan Fairchild	https://www.youtube.com/watch?v=iuapa4DB6AE
	20-Apr-20	60-min Ballet Class at Pacific Northwest Ballet	Pacific Northwest Ballet	https://www.youtube.com/watch?v=RErBAfGZ7zc
	14-May-20	60-min Ballet Class with Peter Boal at Pacific Northwest Ballet	Pacific Northwest Ballet	https://www.youtube.com/watch?v=KGN9O0NFyM0
	4-Jun-20	Zoom Group Ballet class. Full version.(Intermediate, Advanced) #ballet #dance @grandartballet	Grand Art Ballet Dance Studio	https://www.youtube.com/watch?v=hjBTf58Wto4
	2-Oct-20	AT HOME BALLET CLASS | Full Barre & Center | Rob Thaller Music	Dansique Fitness	https://www.youtube.com/watch?v=z45vQHbi9nc
ballet dance performance full	7-Mar-12	Tchaikovsky: Swan Lake - The Kirov Ballet	Warner Classics	https://www.youtube.com/watch?v=9rJoB7y6Ncs
	4-Jul-15	The Sleeping Beauty (ballet) - Tchaikovsky	Théâtre, concert, TV & humour	https://www.youtube.com/watch?v=g6eA4PjWhws
	27-Feb-17	S. Prokofiev - Ballet Romeo & Juliet	Volodimir Balyk	https://www.youtube.com/watch?v=-hM0B70F1YM
	6-Jun-17	The Nutcracker Ballet (FULL CONCERT)	1091 ON DEMAND	https://www.youtube.com/watch?v=kFZ8v5FfDd8
	15-Oct-18	Western Symphony Miami City Ballet	Violet	https://www.youtube.com/watch?v=AmT4v4rDwHc
modern dance class full	19-Jul-16	Intro to Modern Dance, Ellie Potts Barrett	Interactive Academy of Performing Arts	https://www.youtube.com/watch?v=RRnD8o-KCJE
	14-Sep-18	Contemporary Dance Class | London Contemporary Dance School (full free online class)	The Place	https://www.youtube.com/watch?v=k7xDuQvMyVQ
	16-Mar-20	Beginner Contemporary with Julie	Julie Carter Dance	https://www.youtube.com/watch?v=gG68LBBzgFQ
	24-Mar-20	Beginner Modern with Mark Morris Dance Group company member Dallas McMurray	Mark Morris Dance Group	https://www.youtube.com/watch?v=42nmC31pV7g

	29-Mar-20	A Complete Contemporary Dance Class #1- warm up, adage, allegro and a choreographed routine - ICV	Italia Conti Virtual	https://www.youtube.com/watch?v=-VK2hNMfetE
	31-Mar-20	Modern Dance Class #2 - Diana Ford Dance - Livestream - class is MIRRORED for your convenience!	Diana Ford Dance	https://www.youtube.com/watch?v=d_R47wSn3OI
	11-Apr-20	Contemporary class at home	Prima Stage School	https://www.youtube.com/watch?v=tI1ZsA9_iZo
	16-Apr-20	modern class	DanceCenter No1 International Ballet Academy	https://www.youtube.com/watch?v=nbN6aVQQEhk
	16-Apr-20	GRAHAM ON DEMAND: Advanced Class with Peggy Lyman	Martha Graham Dance Company	https://www.youtube.com/watch?v=mFovPTvJPLY
	24-Jul-20	Limon class Eric Parra.	José Limón Dance Foundation	https://www.youtube.com/watch?v=5bG2AB9jCS4
modern dance performance full	9-Jun-11	Danse Perdue with Joy von Spain and Masaki Satsu - "Miserere Mei" June 4, 2011	bennybrownell	https://www.youtube.com/watch?v=veZdwbBqYNQ
	23-Feb-13	Our Yellow River Modern Dance	xiang xu	https://www.youtube.com/watch?v=N1ihBx32lpY
	17-Dec-14	Contemporary Dance Performance «YesNoMaybe» / Buchok ART Family / BAF	BAF Dance	https://www.youtube.com/watch?v=37fHJAocm24
	14-Jul-16	Dance, Dance, Dance choreographed by Donald Byrd, performed by Spectrum Dance Theater	Seattle Theatre Group: STGtv	https://www.youtube.com/watch?v=OG4U_BJIzpI
	6-Dec-16	Alvin Ailey American Dance Theater: Revelations	Karl Skellenger	https://www.youtube.com/watch?v=RrPJ4kt3a64
	6-Dec-17	Kansas City Contemporary Dance Fall Show 2017 Shifting Tides	Philip Koenig	https://www.youtube.com/watch?v=-AEZg0NEQRk
	8-Aug-18	Pilobolus Dance Theater (Performance/Lecture)	Kennedy Center Education Digital Learning	https://www.youtube.com/watch?v=JhJii7RkZD4
	11-Nov-18	S/HE - contemporary dance performance - MN DANCE COMPANY	MN Dance Company	https://www.youtube.com/watch?v=qSIddQNyYVE
	24-Apr-19	Artistic Modern Dance Performance - july 2020	Sabhan Adam	https://www.youtube.com/watch?v=0CGIltoq3Ms
	18-May-20	Artificial Things | contemporary dance film by Stopgap Dance Company (inclusive dance)	Stopgap Dance Company	https://www.youtube.com/watch?v=VxP37djqmUg
hip-hop breakdancing	9-Jul-12	Massive Monkees vs Jinjo Crew | R16 BBOY Battle 2012 | YAK FILMS	YAKbattles	https://www.youtube.com/watch?v=-kT0HJhm5ck
	7-Oct-12	World Championship Hip Hop/Breakdance 2012 - Battle	Filmlyst	https://www.youtube.com/watch?v=QgGUrDV_8Kk
	14-Mar-13	AMAZING DANCE BATTLE! Boy vs Girl (54 million views)	God Bless Hip Hop	https://www.youtube.com/watch?v=NFzJyJXWkeU
	7-Mar-14	Breakdance Battle - Chelles Battle Pro 2014 Final	CANAL STREET Dance	https://www.youtube.com/watch?v=9tG-xwv0kw0

	29-Jan-16	New York City Hip Hop Breakdancing Street battle	Simone De Gasperis	https://www.youtube.com/watch?v=T1hydrnjWek
	22-Nov-17	OLD vs NEW | GROOVE SESSION 2017	ProDance TV	https://www.youtube.com/watch?v=V5L6x_p2z7w
	30-Sep-18	San Andrea (FR) vs. Ami (JP) | Final | Red Bull BC One B-Girl World Final 2018	Red Bull BC One	https://www.youtube.com/watch?v=GmoCdid5P2E
	26-Feb-19	Red Bull BC One All Stars vs. OBC Crew | Finals | Battle Pro 2019	Red Bull BC One	https://www.youtube.com/watch?v=Wce1hwpNx-A
	9-Nov-19	WATCH: Red Bull BC One World Final 2019	Red Bull BC One	https://www.youtube.com/watch?v=8RB6675aq98
	23-Feb-20	Jinjo Crew vs Celsius -45 | FINAL | 3 VS 3 | HIP OPSESSION 2020	ProDance TV	https://www.youtube.com/watch?v=m0Ec8CTpiLU
hip-hop dance battle	11-Jan-09	Hip Hop Locking Popping Dance Battle	GodMarius	https://www.youtube.com/watch?v=Weob1_d1TAY
	22-Aug-13	Kids Dance Battle | Monster Energy Arena | #WODBAY @dancersglobal	Dancersglobal	https://www.youtube.com/watch?v=0rOzeDr6d6g
	5-Feb-14	Dance battle: Majid vs Mamson - I Love This Dance 2012	CANAL STREET Dance	https://www.youtube.com/watch?v=IPXIqueuQNE
	20-Jul-16	DANCE BATTLE: Haleigh (LYE) vs Shemya (ATL)	Ladia Yates	https://www.youtube.com/watch?v=WGFS6FuZmzU
	23-Mar-17	Kids 7ToSmoke | Radikal Forze Jam 2017 | RPProds	RPProds	https://www.youtube.com/watch?v=5jGFlNXYqIs
	12-Apr-18	Kida vs Kidd ShowOut (Raw Battle)| #TBT ORIGINAL FOOTAGE OfficialTSquadTV | Tommy The Clown	OfficialTsquadTV	https://www.youtube.com/watch?v=ljC5TxDqa88
	26-Apr-18	Hip Hop Battle Finals | World of Dance Zaragoza 2017 | #WODZGZ17	Official World of Dance	https://www.youtube.com/watch?v=MIqL8J6W5qw
	30-Mar-19	A MUST WATCH HEAD TO HEAD STREET DANCE BATTLE! l Tommy the Clown l OfficialTsquadTV	OfficialTsquadTV	https://www.youtube.com/watch?v=GnKAGDYar2w
	28-Aug-19	Rochka vs Batalla JUDGE BATTLE Hiphop Forever - Summer Dance Forever 2019	Summer Dance Forever	https://www.youtube.com/watch?v=aTjzcPFLEYY
	15-Jan-20	RUSH BALL vs Les Twins WDC 2019 FINAL HIPHOP #WDC	WDC Japan	https://www.youtube.com/watch?v=QmxiqtsKtcQ
hip-hop dance cypher	3-Feb-14	Intermission Freestyle Cypher @ Coalescence 5th Annual Hip Hop Dance Showcase	DMV Dance Network	https://www.youtube.com/watch?v=0YXxG0ZnUfs
	11-Jun-15	CYPHER | FREESTYLE DANCING | REGGAE, HIP-HOP , AND MORE	DanceNation TV	https://www.youtube.com/watch?v=Vz6HfBm4Dqw
	10-Apr-16	Desiigner - Panda (Cypher)	DragonHouse	https://www.youtube.com/watch?v=M9Dhrxb-0Sw
	4-Mar-17	Bring Me Back To Life Remix #BaltimoreClub Dance Cypher!	The Baltimore Club Channel	https://www.youtube.com/watch?v=GbEiGM9wpqc
	13-Jun-18	Cypher Afro dance	Vins Crespo Chepe	https://www.youtube.com/watch?v=b63ZqAL0MfI
	6-Oct-18	Jersey Dance Cypher x Dj Smallz Trapped In The Closet (Jersey Club Remix)	Clouded Images	https://www.youtube.com/watch?v=2ue6MDrth84

9-Mar-19	1MILLION Cypher Freestyle	1MILLION Dance Studio	https://www.youtube.com/watch?v=_GKy5rea8wc
5-Jul-19	UNION SQUARE CYPHER | JUNE 2019	Artefakt TV	https://www.youtube.com/watch?v=vqACeiawarg
18-Feb-20	HIPHOP FREESTYLE CYPHER - SEMMY BLANK ft ALIF AIRCHO and LOMBOK STREET DANCERS	Semmy Blank	https://www.youtube.com/watch?v=zUyhR-Qnobw
20-Jul-20	THE BEST NYC DANCE CYPHER in 2020 | Duke Deuce - Kirk	Lord Hec	https://www.youtube.com/watch?v=xyIcS68qulA

Appendix 6.1: Graphical representations of motion capture data of the spine and gesture leg during ballet arabesque, modern dance attitude, and hip-hop dolphin dive movements at different speeds

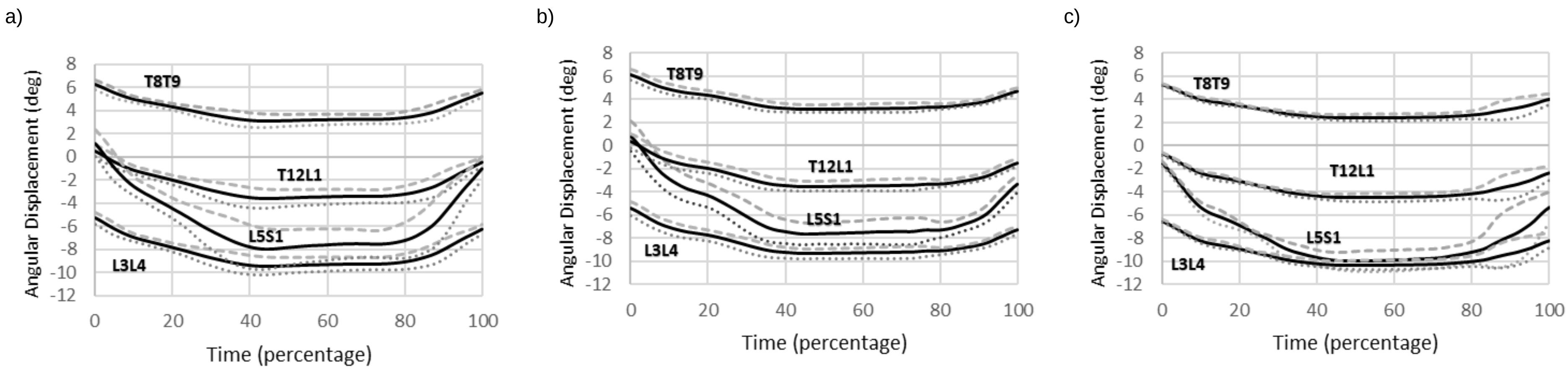

Figure 7.1a-c: Ballet arabesque sagittal motion of four spine joint angles (in degrees) mean and 95% confidence intervals of ***right-sided trials*** *at three speeds: a) fast, b) medium, and c) slow*

Positive values represent flexion of the spine, negative values represent extension of the spine.

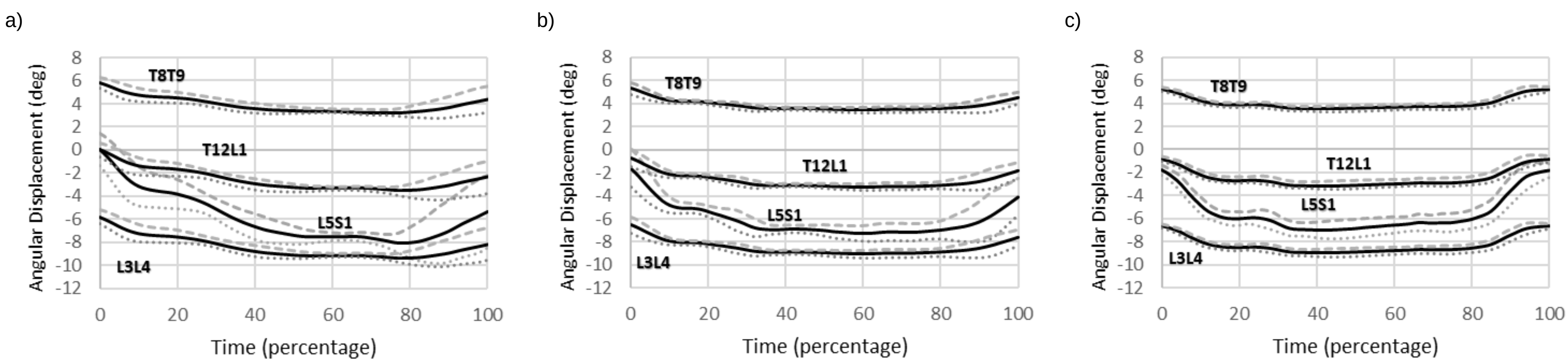

Figure 7.2a-c: Ballet arabesque sagittal motion of four spine joint angles (in degrees) mean and 95% confidence intervals of ***left-sided trials*** *at three speeds: a) fast, b) medium, and c) slow*

Positive values represent flexion of the spine, negative values represent extension of the spine.

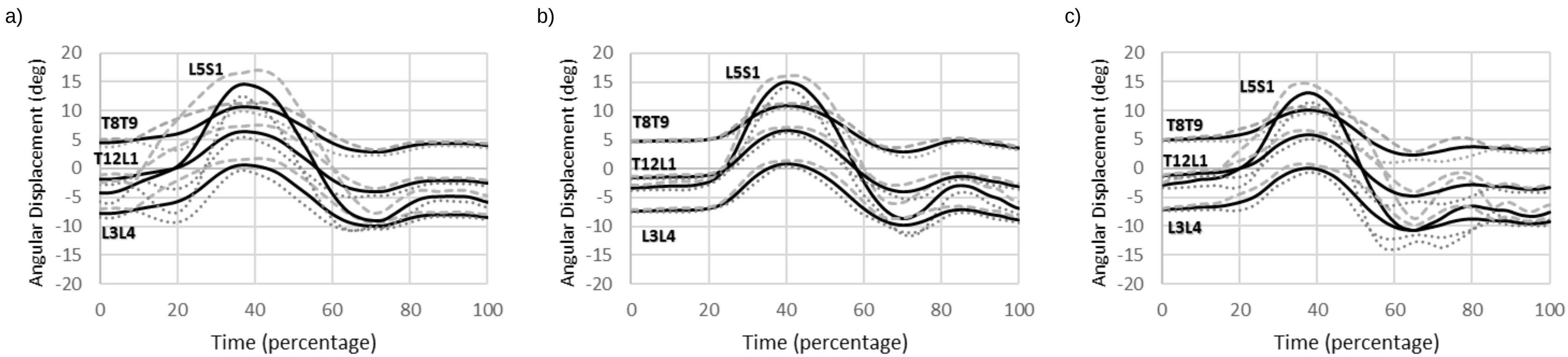

Figure 7.3a-c: Modern dance attitude with body roll sagittal motion of four spine joint angles (in degrees) mean and 95% confidence intervals of ***right-sided trials*** *at three speeds: a) fast, b) medium, and c) slow*

Positive values represent flexion of the spine, negative values represent extension of the spine.

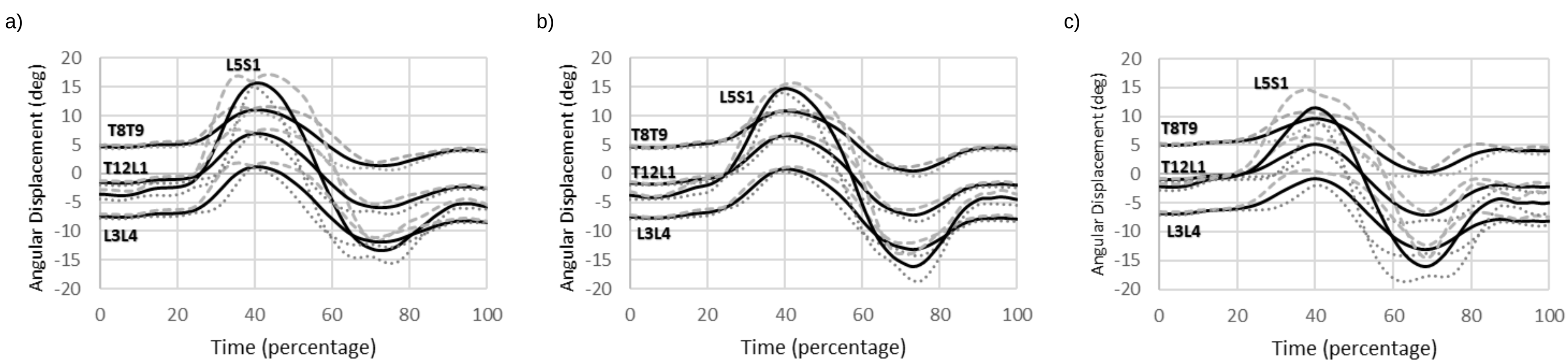

Figure 7.4a-c: Modern dance attitude with body roll sagittal motion of four spine joint angles (in degrees) mean and 95% confidence intervals of ***left-sided trials*** *at three speeds: a) fast, b) medium, and c) slow*

Positive values represent flexion of the spine, negative values represent extension of the spine.

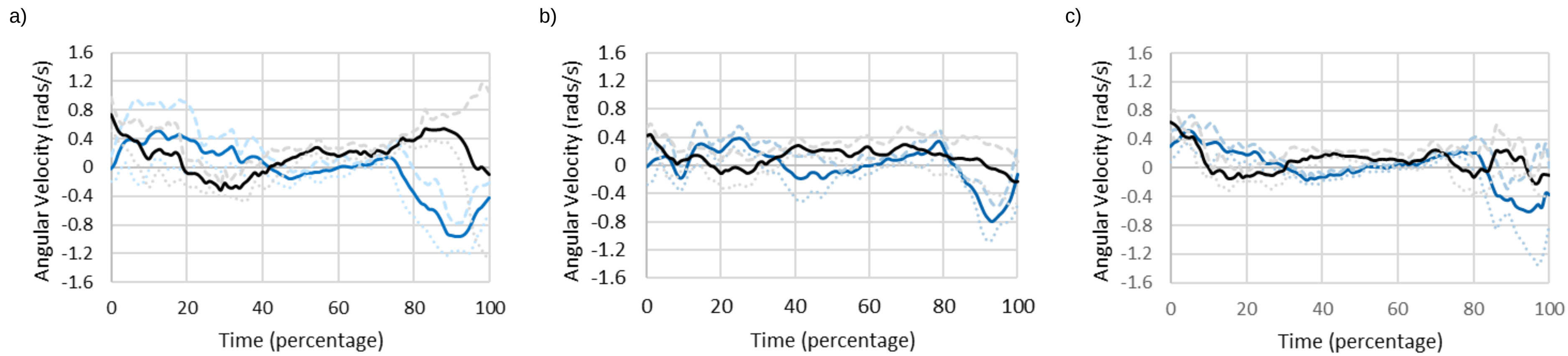

*Figure 7.5a-c: Ballet arabesque sagittal plane mean angular velocity of the spine and 95% confidence intervals for spinal segment **T8** for right- and left-sided trials at three speeds: a) fast, b) medium, and c) slow*

The blue line represents right-sided trial data (negative values represent flexion), the black line represents left-sided trial data (positive values represent flexion).

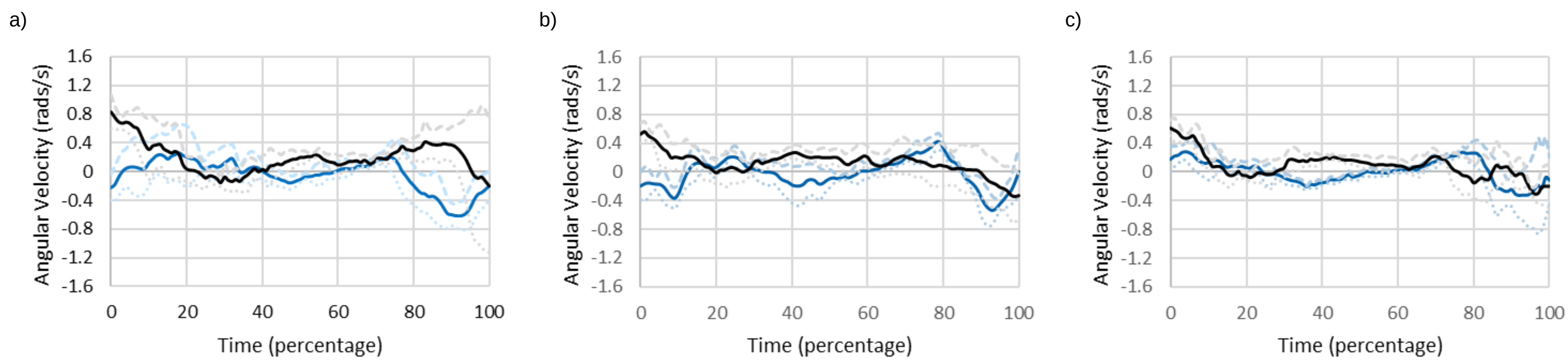

*Figure 7.6a-c: Ballet arabesque sagittal plane mean angular velocity of the spine and 95% confidence intervals for spinal segment **T12** for right- and left-sided trials at three speeds: a) fast, b) medium, and c) slow*

The blue line represents right-sided trial data (negative values represent flexion), the black line represents left-sided trial data (positive values represent flexion).

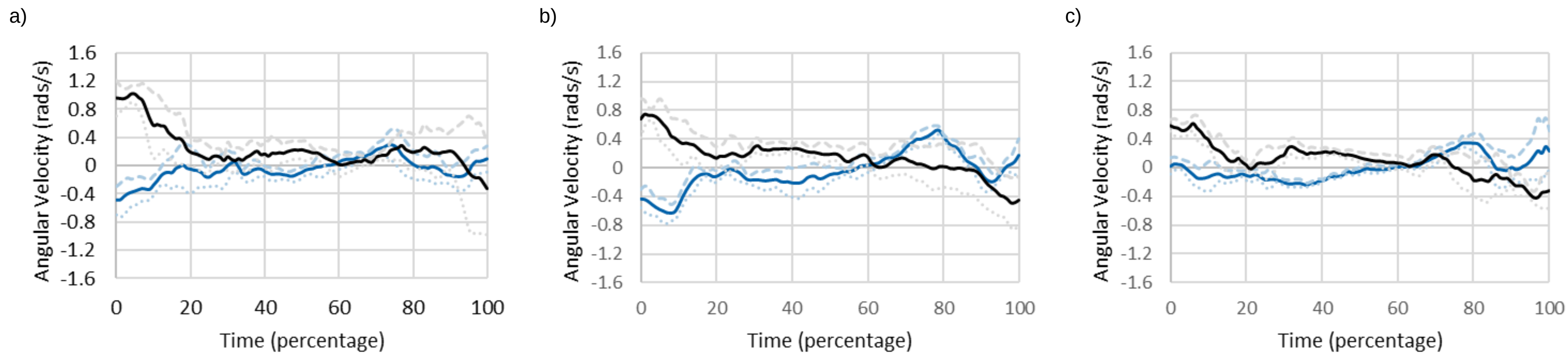

Figure 7.7a-c: Ballet arabesque sagittal plane mean angular velocity of the spine and 95% confidence intervals for spinal segment ***L3*** *for right- and left-sided trials at three speeds: a) fast, b) medium, and c) slow*

The blue line represents right-sided trial data (negative values represent flexion), the black line represents left-sided trial data (positive values represent flexion).

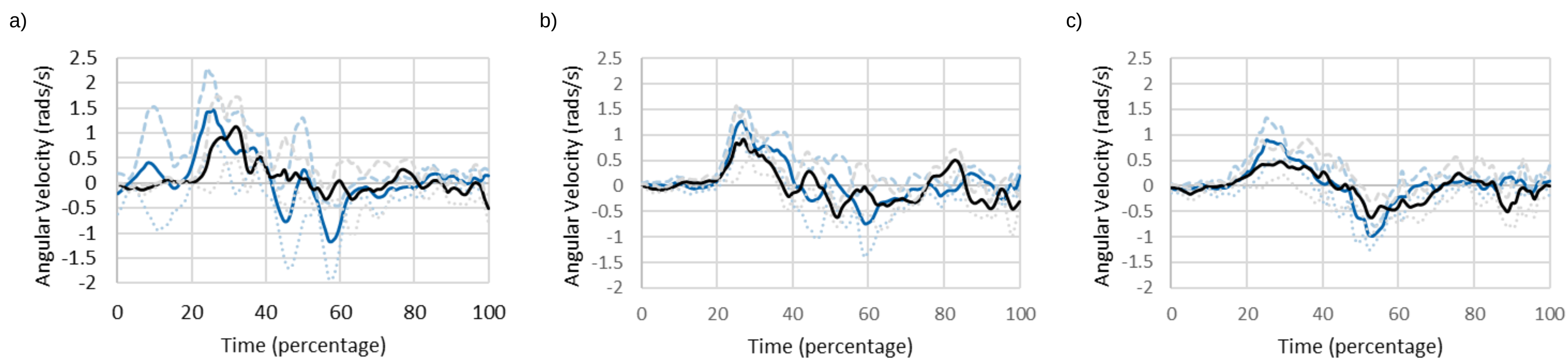

Figure 7.8a-c: Modern dance attitude with body roll sagittal plane mean angular velocity and 95% confidence intervals of the spine for spinal segment ***T8*** *for right- and left-sided trials at three speeds: a) fast, b) medium, and c) slow*

The blue line represents right-sided trial data, the black line represents left-sided trial data. Positive values represent flexion of the spine, negative values represent extension of the spine.

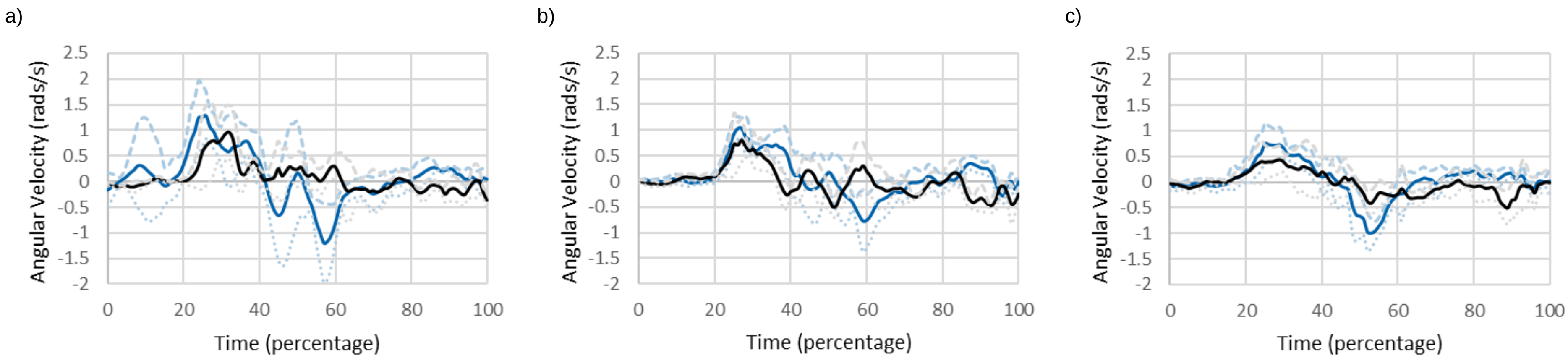

*Figure 7.9a-c: Modern dance attitude with body roll sagittal plane mean angular velocity and 95% confidence intervals of the spine for spinal segment **T12** for right- and left-sided trials at three speeds: a) fast, b) medium, and c) slow*

The blue line represents right-sided trial data, the black line represents left-sided trial data. Positive values represent flexion of the spine, negative values represent extension of the spine.

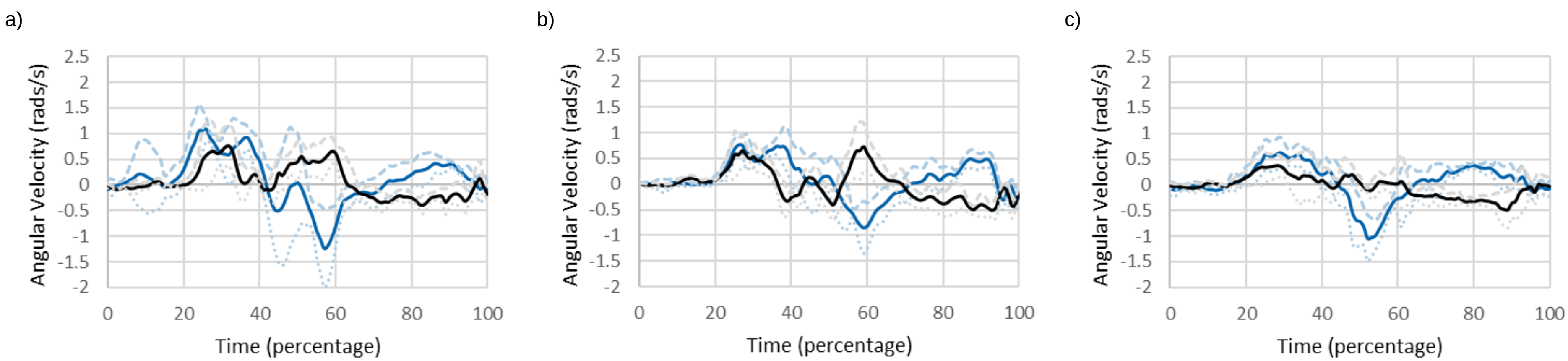

*Figure 7.10a-c: Modern dance attitude with body roll sagittal plane mean angular velocity and 95% confidence intervals of the spine for spinal segment **L3** for right- and left-sided trials at three speeds: a) fast, b) medium, and c) slow*

The blue line represents right-sided trial data, the black line represents left-sided trial data. Positive values represent flexion of the spine, negative values represent extension of the spine.

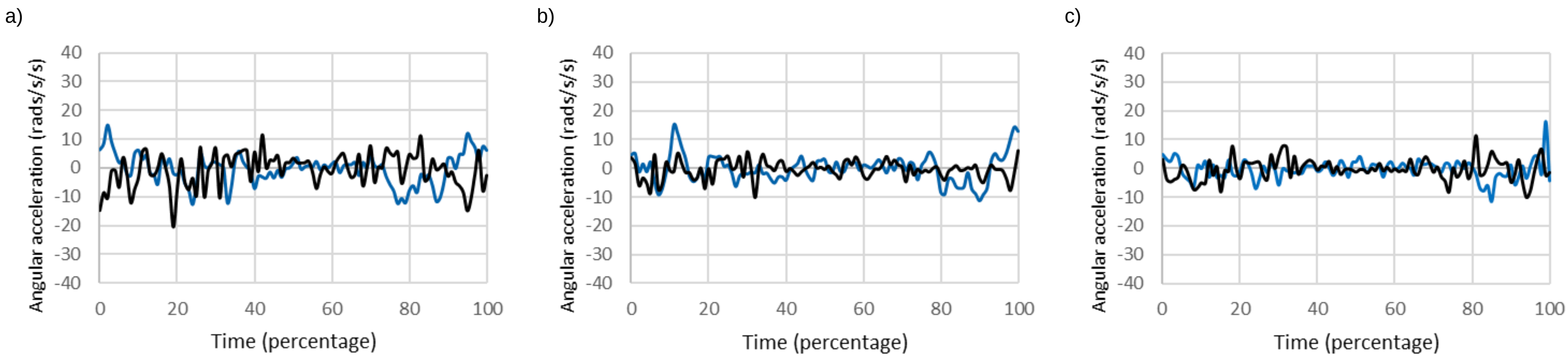

Figure 7.11a-c: Ballet arabesque sagittal plane mean angular acceleration of the spine for spinal segment ***T8*** *for right- and left-sided trials at three speeds: a) fast, b) medium, and c) slow*

Confidence intervals omitted for clarity. The blue line represents right-sided trial data (negative values represent flexion), the black line represents left-sided trial data (positive values represent flexion).

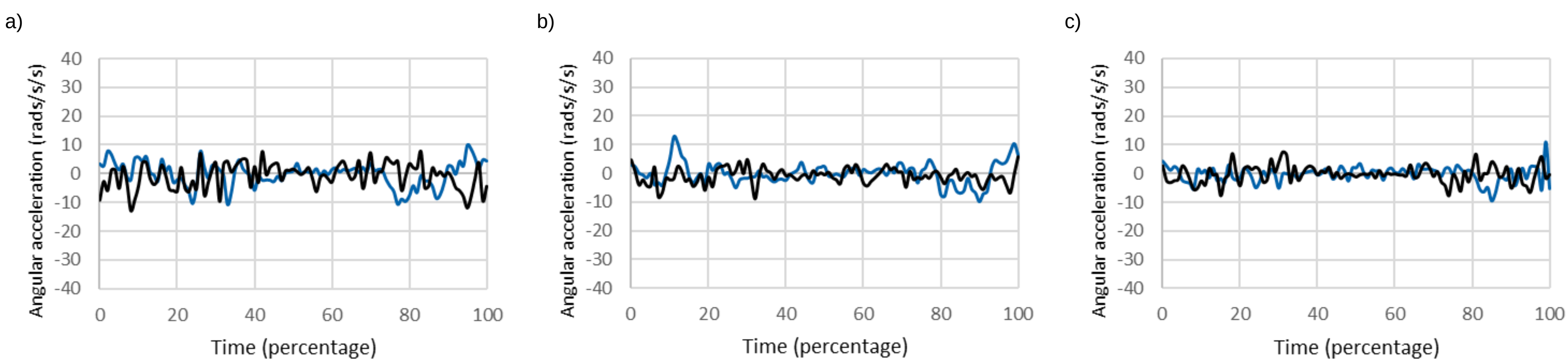

Figure 7.12a-c: Ballet arabesque sagittal plane mean angular acceleration of the spine for spinal segment ***T12*** *for right- and left-sided trials at three speeds: a) fast, b) medium, and c) slow*

Confidence intervals omitted for clarity. The blue line represents right-sided trial data (negative values represent flexion), the black line represents left-sided trial data (positive values represent flexion).

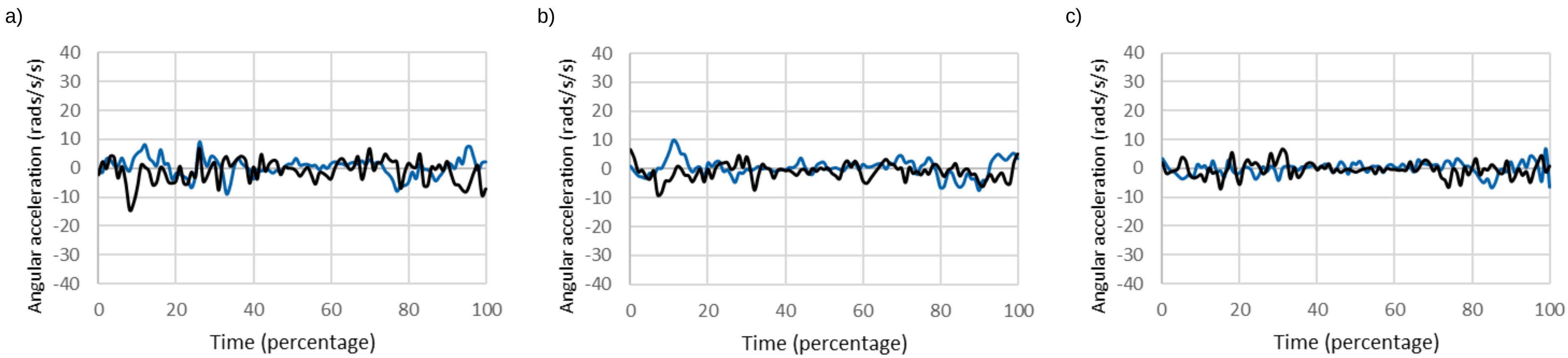

Figure 7.13a-c: Ballet arabesque sagittal plane mean angular acceleration of the spine for spinal segment ***L3*** *for right- and left-sided trials at three speeds: a) fast, b) medium, and c) slow*

Confidence intervals omitted for clarity. The blue line represents right-sided trial data (negative values represent flexion), the black line represents left-sided trial data (positive values represent flexion).

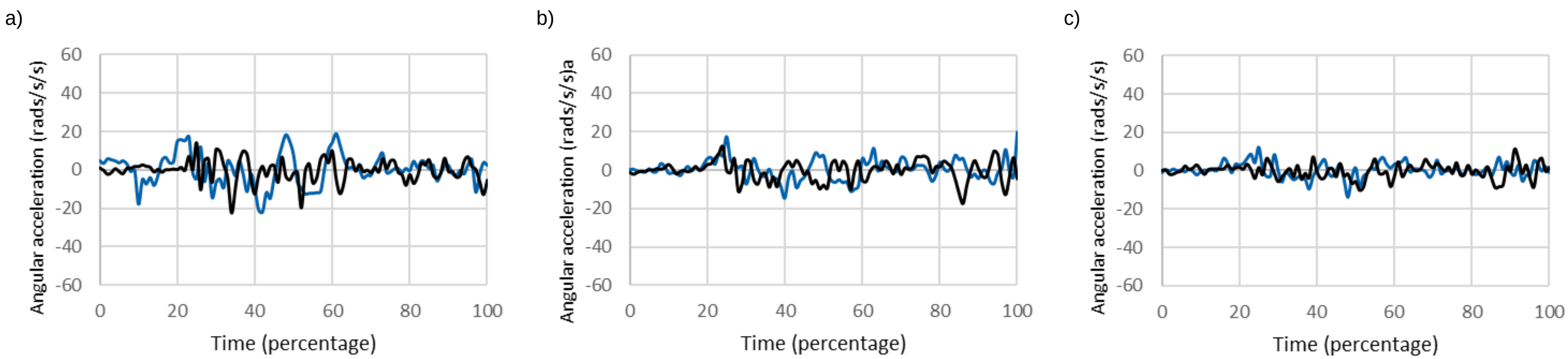

Figure 7.14a-c: Modern dance attitude with body roll sagittal plane mean angular acceleration of the spine for spinal segment ***T8*** *for right- and left-sided trials at three speeds: a) fast, b) medium, and c) slow*

The blue line represents right-sided trial data, the black line represents left-sided trial data. Positive values represent flexion of the spine, negative values represent extension of the spine. Confidence intervals omitted for clarity.

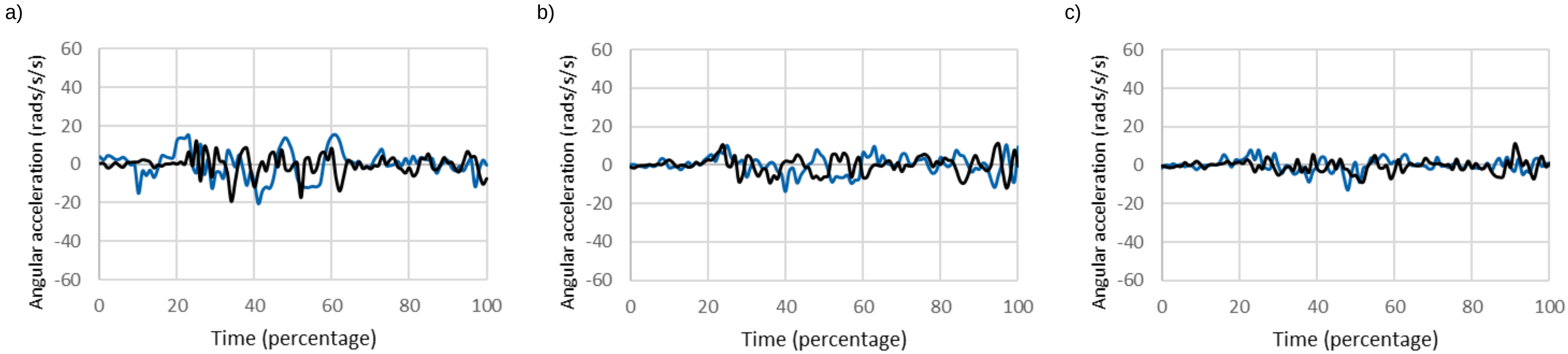

Figure 7.15a-c: Modern dance attitude with body roll sagittal plane mean angular acceleration of the spine for spinal segment ***T12*** *for right- and left-sided trials at three speeds: a) fast, b) medium, and c) slow*

The blue line represents right-sided trial data, the black line represents left-sided trial data. Positive values represent flexion of the spine, negative values represent extension of the spine. Confidence intervals omitted for clarity.

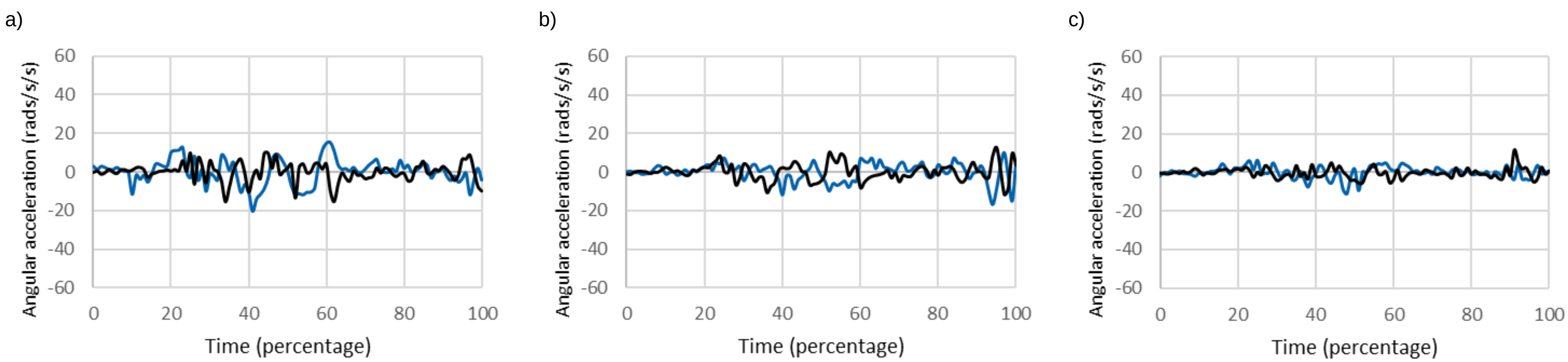

Figure 7.16a-c: Modern dance attitude with body roll sagittal plane mean angular acceleration of the spine for spinal segment ***L3*** *for right- and left-sided trials at three speeds: a) fast, b) medium, and c) slow*

The blue line represents right-sided trial data, the black line represents left-sided trial data. Positive values represent flexion of the spine, negative values represent extension of the spine. Confidence intervals omitted for clarity.

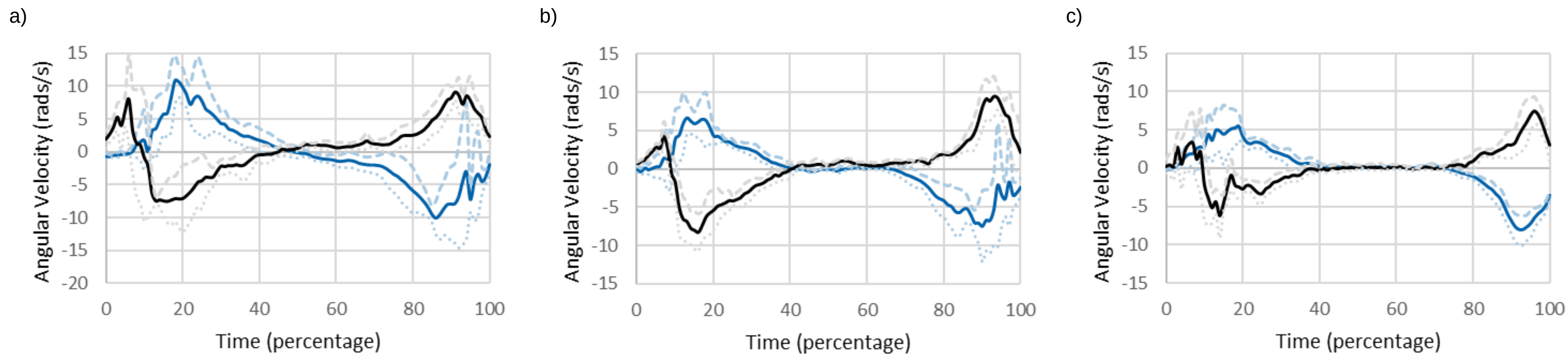

Figure 7.17a-c: Ballet arabesque sagittal plane mean angular velocity and 95% confidence intervals of the gesture foot for right- and left-sided trials at three speeds: a) fast, b) medium, and c) slow

The blue line represents Right Foot Y data (left-sided trials, positive values represent the superior aspect of the segment rotating anteriorly), the black line represents Left Foot Y data (right-sided trials, negative values represent the superior aspect of the segment rotating anteriorly).

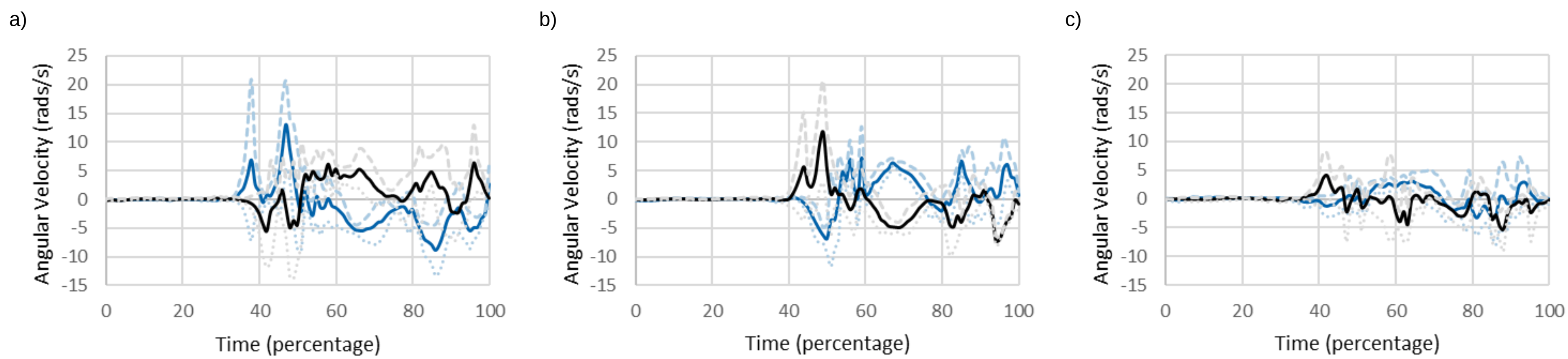

Figure 7.18a-c: Modern dance attitude with body roll sagittal plane mean angular velocity and 95% confidence intervals of the gesture foot for right- and left-sided trials at three speeds: a) fast, b) medium, and c) slow

The blue line represents Right Foot Y (right-sided trial, negative values represent the superior aspect of the segment rotating anteriorly) data, the black line represents Left Foot Y (left-sided trial, positive values represent the superior aspect of the segment rotating anteriorly) data.

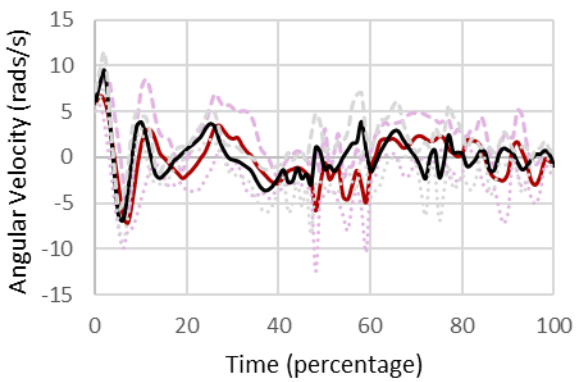

Figure 7.19: Hip-hop dolphin dive sagittal plane mean angular velocity and 95% confidence intervals of the gesture foot for right-sided trials at fast and slow speeds

The red line represents fast trial data, the black line represents slow trial data. Positive values represent the superior aspect of the segment rotating anteriorly, negative values represent the superior aspect of the segment rotating anteriorly.

a) b)

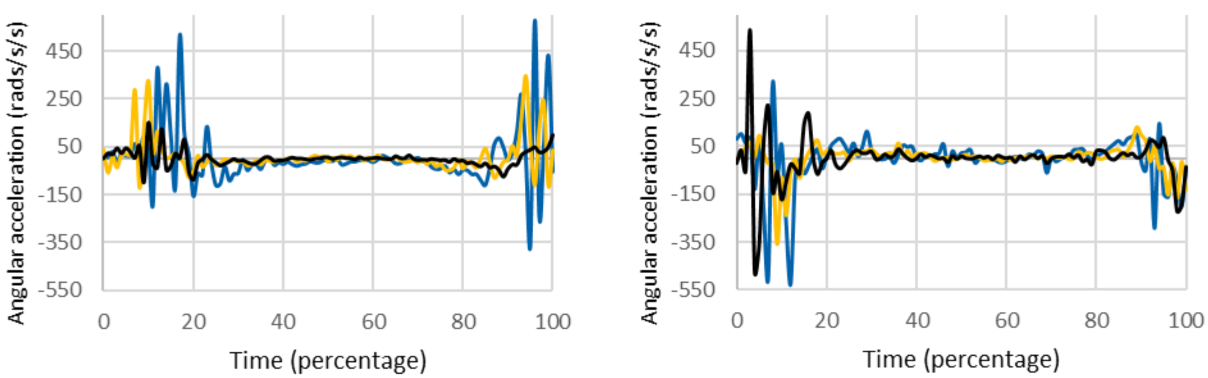

Figure 7.20a-b: Ballet arabesque sagittal plane mean angular acceleration of the gesture foot at fast, medium, and slow speeds for both sides: a) left-sided trials (Right Foot Y, positive values represent the superior aspect of the segment rotating anteriorly) and b) right-sided trials (Left Foot Y, negative values represent the superior aspect of the segment rotating anteriorly)

The blue line represents fast trial data, the yellow line represents medium trial data, and the black line represents slow trial data. Confidence intervals omitted for clarity.

a) b)

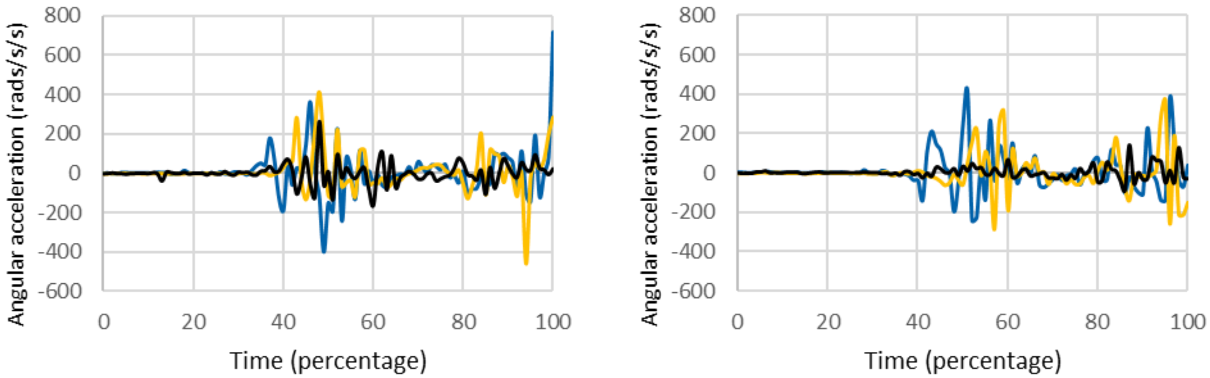

Figure 7.21a-b: Modern dance attitude with body roll sagittal plane mean angular acceleration of the gesture foot at fast, medium, and slow speeds for both sides: a) right-sided trials (Right Foot Y, negative values represent the superior aspect of the segment rotating anteriorly) and b) left-sided trials (Left Foot Y, positive values represent the superior aspect of the segment rotating anteriorly)

The blue line represents fast trial data, the yellow line represents medium trial data, and the black line represents slow trial data. Confidence intervals omitted for clarity.